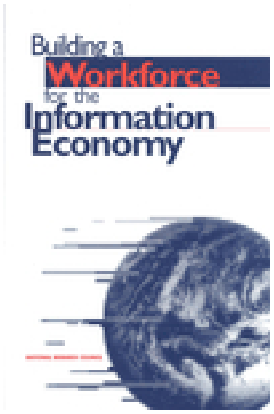

Building a Workforce for the Information Economy

Committee on Workforce Needs in Information Technology, Board on Testing and Assessment, Board on Science, Technology, and Economic Policy, Office of Scientific and Engineering Personnel, National Research Council

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Building a Workforce for the Information Economy

NATIONAL RESEARCH COUNCIL

Building a Workforce for the Information Economy

Committee on Workforce Needs in Information Technology

Computer Science and Telecommunications Board
Board on Testing and Assessment
Board on Science, Technology, and Economic Policy
Office of Scientific and Engineering Personnel

National Research Council

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NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

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Preface

BACKGROUND

In the spring of 1998, Congress conducted hearings on the needs of U.S. industry for high-technology workers. A primary impetus for these hearings was the insistence of information technology industry representatives that companies were unable to recruit sufficient domestic workers and needed to hire additional non-U.S. citizens. Several recent studies supported the industry position. Most notably, a 1997 Information Technology Association of America (ITAA) study estimated a shortage of 340,000 workers in the field of information technology.[1] In September of 1997 the Department of Commerce released a report concluding that there was a shortage of information technology workers.[2] This conclusion was based on projections from the Bureau of Labor Statistics that the United States would require more than 1 million additional information technology workers between 1994 and 2005, compared to the small number of U.S. bachelor's degrees in computer and information sciences awarded annually (24,553 in 1994).

In response to the perceived shortage of high-technology workers, bills were introduced in both the House and Senate (H.R. 3736, S. 1723) to

[1]Information Technology Association of America. 1998. *Help Wanted: 1998: A Call for Collaborative Action for the New Millennium*. Arlington, Va.: ITAA.

[2]Department of Commerce. 1997. *America's New Deficit: The Shortage of Information Technology Workers*. Washington, D.C., September.

increase the number of H-1B visas from the FY1998 level of 65,000 per year. After considerable debate, the resulting legislation (Public Law 105-277) increased the limit on H-1B visas temporarily (to 115,000 in FY1999 and FY2000, 107,500 in FY2001, and reverting to 65,000 in FY2002).

Meanwhile, some experts asserted that the methodology of the ITAA survey was flawed and exaggerated the need for information technology workers. An analysis done by the General Accounting Office (GAO) in March 1998 found methodological weaknesses in the Department of Commerce report, emphasizing that the relevant supply of talent is not limited to computer science graduates.[3] The GAO found that only 29 percent of information technology workers have degrees in computer science and that the majority of jobs in information technology are held by persons with degrees in math, science, social science, and business. More than 800,000 people graduate with math and science degrees (B.S., M.S., and Ph.D.) per year.

When Congress passed Public Law 105-277, it included a section (Section 417) that called for the National Science Foundation (NSF) to enter into a contract with the National Academy of Sciences to report on older workers in the information technology field. Section 418 of that law called on the NSF to report on high-technology labor market needs. Both studies were to be delivered to Congress by October 1, 2000.

Because of the overlap between these subjects, the National Science Foundation asked the National Academy of Sciences, and specifically, the National Research Council (NRC), to conduct a study of needs for a high-technology workforce over the next 10 years, focusing on information technology (IT) and providing broad though less detailed contrast with biotechnology as the other key dimension of high technology with respect to workforce issues.[4] In addition, the National Aeronautics and Space Administration, concerned about the future availability of technically skilled workers to support the nation's space objectives and industrial base, provided support for this study.

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[3]U.S. General Accounting Office, Health, Education, and Human Services Division. 1998. *Information Technology: Assessment of the Department of Commerce's Report on Workforce Demand and Supply*, GAO/HEHS 98 106R. Washington, D.C., March 20.

[4]The contract between the National Science Foundation and the NRC called for the project to "profile the demographic changes in the U.S. workforce of the future and identify measures to insure access by the IT industry to the full pool of potential talent. [The project] also will consider the extent of future reliance on foreign talent resident in the U.S. and abroad and policies affecting access to that talent via foreign investment and immigration, among others . . . . Comparisons will be attempted to the biotechnology workforce, addressing similar dimensions but with less detail. One important area of contrast between IT and biotechnology will be the educational preparation of the immigrant workforce (postdoctoral emphasis in biotechnology, doctorate and below in IT)."

Within the National Research Council, four units collaborated in conducting the project. The Computer Science and Telecommunications Board (CSTB) led the effort, joined by the Board on Testing and Assessment, the Board on Science, Technology, and Economic Policy, and the Office of Scientific and Engineering Personnel.

The study was structured to provide an integrated response to sections 417 and 418 (a) of PL 105-277 (see Box P.1); the former calls for an assessment of the status of older workers using the best available data, and the latter calls for an assessment of labor market needs for workers with high-technology skills over the next 10 years. The section 418 (a) (3) requirement for diverse inputs comports naturally with the NRC study process, which emphasizes a balanced study committee plus broad solicitation of inputs. In particular, the NRC sought to develop an integrated analytical perspective that would combine the perspectives of labor economists with those familiar with the issues at "ground level"—people performing or managing information technology work and people involved in the education and training of information technology workers.

By any standard, the story of IT and the economy is one of success. But against this background of success, concerns have emerged that the lack of an adequate, well-trained workforce may have negative effects on the U.S. economy. Furthermore, because the underlying information technologies change so rapidly, there is concern that the labor market does not work as efficiently in this arena as economic theory would predict—i.e., that rising wages will not relieve the tightness, at least not "in time." Finally, there are concerns that the benefits of employment in information technology or high technology are not being shared equitably.

AUDIENCE AND TIMING

The Committee on Workforce Needs in Information Technology (Appendix C) is well aware that during the time that it was collecting information and deliberating, the political process moved forward. Indeed, the committee anticipated the legislation that was enacted in October 2000 at about the time its report was first made available. This timing raised questions about when to release the report.

The committee notes that its charge did not focus on the H-1B visa issue; rather, the controversy surrounding this issue provided one element of the context surrounding its work. Although the H-1B visa cap is one of the most hotly contested issues in immigration policy today, it is only one of the issues facing the IT and high-technology (IT/HT) workforce. This report is not—and never has been—a report only or even primarily about H-1B visas.

BOX P.1
Legislative Charge to the National Research Council
Statutory Language: Public Law 105-277

SEC. 417.
REPORT ON OLDER WORKERS IN THE INFORMATION TECHNOLOGY FIELD.

(a) Study.—The Director of the National Science Foundation shall enter into a contract with the President of the National Academy of Sciences to conduct a study, using the best available data, assessing the status of older workers in the information technology field. The study shall consider the following:

(1) The existence and extent of age discrimination in the information technology workplace.

(2) The extent to which there is a difference, based on age, in—

(A) promotion and advancement;

(B) working hours;

(C) telecommuting;

(D) salary; and

(E) stock options, bonuses, and other benefits.

(3) The relationship between rates of advancement, promotion, and compensation to experience, skill level, education, and age.

(4) Differences in skill level on the basis of age.

(b) Report.—Not later than October 1, 2000, the Director of the National Science Foundation shall submit to the Committees on the Judiciary of the United States House of Representatives and the Senate a report containing the results of the study described in subsection (a).

SEC. 418.
STUDY AND REPORT ON HIGH TECHNOLOGY LABOR MARKET NEEDS.

(a) National Science Foundation Study and Report.—

(1) In general.—The Director of the National Science Foundation shall conduct a study to assess labor market needs for workers with high technology skills during the next 10 years. The study shall investigate and analyze the following:

(A) Future training and education needs of companies in the high technology and information technology sectors and future training and education needs of United States students to ensure that students' skills at various levels are matched to the needs in such sectors.

(B) An analysis of progress made by educators, employers, and government entities to improve the teaching and educational level of American students in the fields of math, science, computer science, and engineering since 1998.

(C) An analysis of the number of United States workers currently or projected to work overseas in professional, technical, and managerial capacities.

(D) The relative achievement rates of United States and foreign students in secondary schools in a variety of subjects, including math, science, computer science, English, and history.

continued

(E) The relative performance, by subject area, of United States and foreign students in postsecondary and graduate schools as compared to secondary schools.

(F) The needs of the high technology sector for foreign workers with specific skills and the potential benefits and costs to United States employers, workers, consumers, postsecondary educational institutions, and the United States economy, from the entry of skilled foreign professionals in the fields of science and engineering.

(G) The needs of the high technology sector to adapt products and services for export to particular local markets in foreign countries.

(H) An examination of the amount and trend of moving the production or performance of products and services now occurring in the United States abroad.

(2) Report.—Not later than October 1, 2000, the Director of the National Science Foundation shall submit to the Committees on the Judiciary of the United States House of Representatives and the Senate a report containing the results of the study described in paragraph (1).

(3) Involvement.—The study under paragraph (1) shall be conducted in a manner that ensures the participation of individuals representing a variety of points of view.

More importantly, the committee has tried in this report to provide a way of thinking about workforce issues in IT/HT that is largely independent of specific legislation. It seems safe to predict that the debate over the IT/HT workforce and immigration will not be definitively resolved by any one piece of legislation—such is the nature of controversial issues engaged by the political process. The committee thus tried to develop an intellectual framework and policy guidance for meeting the nation's needs for information technology workers over the next decade.

In the months since the report's initial release in October 2000, declines in stock valuation for IT and IT-enabled companies, together with well-publicized bankruptcies and layoffs, have affirmed the wisdom of the committee's longer-term horizon.

METHODOLOGY AND CAVEATS

A number of prior studies and analyses of workforce issues in IT constituted the committee's point of departure for its own work. In addition, the committee also heard from many stakeholders across a wide range of perspectives, commissioned a number of papers, sought and received white papers and other input electronically, and conducted several site visits to IT-sector firms. The report also draws insights from committee members most closely associated with IT.

One of the most troublesome aspects of the debate over workforce issues is the paucity of good data. Reliable, representative, timely "hard data" are by far the most preferred as the basis for reaching conclusions. But in practice, the available data are inadequate as a basis for drawing conclusions that are unambiguous.[5]

The committee did not limit itself to considering only those issues for which good-quality and timely data sets were available; to do so would have led to analytical paralysis. Rather, the committee used the best available data, and it relied on testimony and informed speculation when the data were unavailable or inadequate. Its findings, conclusions, and recommendations are based on a mix of data and committee judgment.

ACKNOWLEDGMENTS

Many people contributed to this complex study and comprehensive report. The committee took testimony from many individuals at its plenary sessions, including both scheduled briefers and IT workers who were promised anonymity. The committee is indebted to these people for sharing with it their ideas, concerns, time, and facilities. It also appreciates having received numerous formal and informal analyses and reports from a wide range of organizations and individuals with varying perspectives on the IT workforce. Subcommittees also held regional information-gathering sessions, and site visits were conducted in New York City; Austin, Texas; Bellevue, Washington; and Fairfax, Virginia. (Appendix D indicates the dates and locations of the plenary and regional meetings and lists the individuals who participated.)

For helping to organize the Austin events, the committee is indebted to Robert Glover, research scientist in the Ray Marshall Center for the Study of Human Resources at the University of Texas at Austin; Mary Jo Sanna, project director of Computer Science 2000 at the Capital Area Tech-Prep Consortium; Craig Eissler, from the Capital Area Training Foundation; and David Brant, associate vice president for research at the University of Texas at Austin. The committee also acknowledges management

[5]For example, data are often insufficiently timely. Data that are 2 years old—recent by most federal standards—are unlikely to reflect accurately today's state of affairs in the rapidly changing IT sector. Definitions of data categories (e.g., the definitions for items such as "computer scientist" or "systems analyst"), which are necessarily relatively stable over time, do not necessarily reflect the IT job titles of today because new types of jobs emerge quickly in the IT sector. In particular, data categories are generally too coarse and do not reflect important distinctions between IT jobs.

and staff at Trilogy Software, BMC Software, and Academic Software for agreeing to participate in focus group sessions with the Austin subcommittee and for speaking with the subcommittee on the challenges and opportunities of working in the high-tech industry.

In Seattle, the committee was assisted by Edward Lazowska, professor and chair of the Department of Computer Science and Engineering at the University of Washington and a member of CSTB. (Kathleen) Kay Williams, manager of computing skills management information services for the Boeing Company, and Gary Jackson, co-director of the International Association of Machinists/Boeing Company Joint Quality Through Training Program, facilitated focus group sessions with high-technology managers and workers at their respective companies.

In Fairfax, the committee met at George Mason University and appreciates the assistance of J. Thomas Hennessy, Jr., chief of staff to the president, and Darcy Cors, assistant to the president. Supporting the committee's site visits and focus group meetings were Sue Austin and Kerri Morehart of SRA International Inc., Mike Mendler of SAIC, Sudhaker Shenoy of IMC, (Lorraine) Pat Sherod of Litton PRC, and Rosanne Cuttitta of Celera Genomics.

A number of individuals responded to the committee's call for white papers, including Denise Gurer (3Com Inc.), Joyce Malyn-Smith (Education Development Center Inc.), Eric Roberts (Stanford University), David Lee (Suffolk University), and B. Lindsay Lowell and Susan Martin (Georgetown University). In addition, the committee commissioned a number of papers on its own initiative and received papers from Hal Salzman, Hal Salzman and Radha Roy Biswas (University of Massachusetts-Lowell), Charles Starliper, Kevin Murphy and Zinta Byrne (Colorado State University), and Robert Lerman (American University).

The National Science Foundation provided the committee with important data on IT workers and other scientific and engineering personnel. While the committee appreciates NSF assistance in this matter, the use of NSF data does not imply NSF endorsement of the research methods or conclusions contained in this report. In addition, the committee gratefully acknowledges Mark Regets, senior analyst for NSF, for the administrative and data-related assistance he provided on numerous occasions.

The committee also appreciates the hundreds of suggestions and constructive criticisms provided by the reviewers of an early draft of this report. That input helped the committee to sharpen its message and strengthen its presentation.

Within the NRC, the lead unit on the project was the Computer Science and Telecommunications Board. However, the committee received a high level of support from members and staff of the three other NRC units involved: the Board on Testing and Assessment, the Board on Science, Technology, and Economic Policy, and the Office of Scientific and Engineering Personnel.

NRC staff assisted and, at critical times, guided the committee in many ways. They provided essential insight into the NRC process and resources. They organized the regional site visits, arranged for briefings, and handled logistical matters for the committee with the utmost skill and patience. They provided research support to the committee, including a number of data analyses that were critical to the analytical content of the report. They facilitated numerous contacts with outside sources of expertise and content.

The issues addressed by the committee were wide-ranging. Any one issue or discussion could involve technical, political, social, ethical, educational, and human resource matters, among others. Similarly, the perspectives and biases of the committee were equally diverse, as were those of the intended audience. Herb Lin, senior scientist for CSTB and the study director for this project, turned discussions, individual ideas, and points of agreement and of initial disagreement into this important report. He crafted meeting agendas in such a way that the committee received the proper amount of diverse external input and had sufficient time to develop its conclusions and recommendations. This study could not have been carried out nor this report written without Herb. The committee is deeply indebted to him.

Finally, the assistance of Bill Spencer (Sematech), William Eddy (Carnegie Mellon University), Stephen J. Lukasik (SAIC), and John Kreick in the launch of this project is appreciated.

Acknowledgment of Reviewers

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

Tom Bailey, Columbia University,
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Scott Bradner, Harvard University,
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Stephen Yale-Loehr, True, Walsh & Miller and Cornell University.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Stephen J. Lukasik, appointed by the Commission on Physical Sciences, Mathematics, and Applications, and Samuel H. Preston, appointed by the Report Review Committee, who were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

Contents

Appendixes

For every complex problem, there is a solution that is neat, simple, and wrong.

—H.L. Mencken

Executive Summary

The products of advanced technology and, in particular, information technology (IT) permeate our lives. These products extend from the personal computer in homes and offices to smart chips that make cars more fuel-efficient. In medicine, the research leading to the recent success in mapping the human genome, based in large part on advanced use of information technology, has already led to fundamental advances in understanding the mechanisms of many diseases and, in the foreseeable future, will result in the design of interventions to improve health that can be more highly customized to the needs of individual patients. We live in the midst of a time when IT is—on a worldwide basis—transforming how businesses interact with their customers and with one another and even how people interact with each other for business, social, educational, governmental, and recreational reasons. Many familiar with IT trends, pointing to the substantial and sometimes surprising impact of the Internet in just a few years, suggest that we have only begun to see the societal transformations enabled by IT.

The need for information technology workers depends on the demand for information technology throughout the economy, both in the United States and worldwide, and IT markets and talent can be found all over the world. Information technology is becoming increasingly ubiquitous, and with that trend has come a burgeoning demand for IT workers, both to enable the use of existing information technologies and to develop such technologies for the future. There is a growing body of evidence that IT is playing a significant role in improving national productivity, and that any constraints on IT production and support—such as those that might arise from excessive tightness in the IT workforce—may have a pervasive impact on the growth of the economy.

The creation, acquisition, and management of information have emerged as the central focus of the new economy, a development contemporaneous with the shift in the mid- to late-20th century from a manufacturing to a services emphasis in both the United States and other developed nations. The primacy of information drives a continuing and growing need for information technology that supports the use of this information, and the scale, scope, and speed of the diffusion of information technology throughout the global economy—in developing and developed nations—are important drivers of economic change. This speed rewards adaptability and responsiveness for individual IT-sector firms. Rapid IT diffusion and business transitions also reduce the effectiveness of the market in reconciling labor supply and demand and the effectiveness of many putative policy solutions. Even when demand is growing, it takes time for technologically sophisticated workers to become adept at new skills. It also takes time for the promise and importance of the new information technology to motivate students and other workers to move into IT fields.

As the economy comes to depend on IT, the availability of IT workers has become a question of national importance. But perceptions of the IT labor market depend in large part on who perceives it. Employers often report that they cannot find qualified workers to fill their vacancies, especially when they are trying to hire systems designers, systems engineers, computer scientists, systems analysts, and programmers to design and build IT systems and applications. Many employers assert the existence of an IT labor "shortage" and additionally argue that if they are unable to hire qualified foreign workers to fill open positions, they will be at a competitive disadvantage in a global IT industry. At the same time, some job seekers find it difficult to obtain jobs in information technology, despite having credentials that they think should qualify them for employment. Some who are older (over 40) observe that the majority of IT workers are younger, and some assert the existence of widespread and rampant age discrimination in the IT industry. Some who are U.S. citizens observe that many IT workers are foreigners, and suspect that they are being displaced from good jobs by foreigners residing in the United States, particularly those who are in the United States under a special class of nonimmigrant visas known as H-1B visas. And it is apparent to all that relatively few women and non-Asian minorities are employed in IT jobs, compared with jobs in other sectors of the economy.

Policymakers are caught in the middle. While they recognize the important role that information technology has played in driving economic growth, they hear the concerns of both employers asserting critical shortages of labor and IT workers who are not sharing fully in the benefits of the strong economy. The economic benefits of IT are compelling, and numerous government actions have celebrated and sought to nurture IT-related economic activity. But the rising expressions of concern about such side effects as possible age discrimination and other inequality of opportunity for U.S. IT workers are troubling for policymakers. What is needed is an objective analysis of today's circumstances and the likely conditions for tomorrow.

When Congress raised the H-1B visa quota on temporary immigrants in 1998 in response to industry's demand for skilled workers, it called for two studies. The first study, assigned to the National Science Foundation, was to investigate domestic high-technology workforce needs and sources of supply over the next 10 years. The second study, assigned to the National Academy of Sciences, was to investigate the status of older workers in the information technology field. Because these issues are so closely related, the National Science Foundation asked the National Academy of Sciences to address both subjects through the National Research Council process, which centers on the deliberations of a committee of diverse experts. That committee—the Committee on Workforce Needs in Information Technology—focused on IT workers, that subset of high-technology workers that has been at the core of H-1B and other policy controversies, with a complementary (though less detailed) consideration of biotechnology workers for contrast.

Given the divergent perceptions of the high-technology labor market, it was clear to the committee from the outset that an examination of future workforce needs in high technology had to be embedded in a larger context that went beyond the immediate political debate. What defines a labor shortage, and what evidence is needed to assert its existence? How is the IT labor market likely to evolve in the future? What are the current sources of workers, and how are these sources changing? What role do foreign workers play in the IT labor market? To what extent can education and training help to reduce employer difficulties in hiring? What is needed to tap previously untapped pools of potentially productive workers?

The committee sought answers to questions such as these by gathering statistical data, inviting experts to discuss the issues, holding public information-gathering sessions that were open to all in centers of high-technology employment, soliciting comments on a Web site, reviewing a wide range of published analyses and reports, and commissioning analytical papers. Its research underscored how little was truly known—as opposed to believed or hypothesized—about the IT workforce and how fragmented and inadequate is the knowledge base regarding the many component issues. Its deliberations were a microcosm of the larger policy debate, embracing both stakeholders and analysts. The committee's report is designed to present in one place a wide range of information useful for understanding IT workforce issues while explaining the shortcomings of that information and the range of inferences that can and cannot be made from it.

THE NATURE OF IT WORK

For purposes of this report, IT workers are those persons engaged primarily in the conception, design, development, adaptation, implementation, deployment, training, support, documentation, and management of information technology systems, components, or applications.

As in many other domains, expertise in IT depends both on formal knowledge that is generally acquired in the context of formal education and on situated knowledge that is specific to a work or problem situation. In addition, it is useful to differentiate between two gross categories to understand the full range of IT work. What the committee calls Category 1 work involves the development, creation, specification, design, and testing of an IT good or service, or the development of system-wide applications or services. Category 1 work also includes IT research. What the committee calls Category 2 work primarily involves the application, adaptation, configuration, support, or implementation of IT products or services designed or developed by others. Some types of work, such as implementation of a concept, have some characteristics of Category 1 work and others of Category 2 work.

Most IT jobs require a mix of Category 1 and Category 2 work, though the mix depends on the responsibilities of the specific job in question. Because most jobs require such a mix, the boundary between Category 1 and Category 2 workers is fluid. However, these distinctions are important for making sense of, and responding to, issues in the supply of and demand for IT workers. (In this report, the term "IT worker" without qualification refers to both Category 1 and Category 2 workers.)

Like other workers, IT workers care about their financial compensation, which can be a mix of salary, bonuses, and stock options and/or equity stakes. But for many, the opportunity to work on challenging projects with new and interesting technology is a great motivator, and many surveys report that employees commonly rank compensation lower on their priority lists than technical challenges and the opportunity to learn new technical skills.

THE PROBLEM

The committee believes that today's IT labor market is tight and likely to remain so for the immediate future, barring dramatic change. The fundamental driver of this tightness is growth in the use of IT throughout a strong economy, a tightness that is significantly exacerbated by the currently low unemployment rate in the overall labor market.

The committee has chosen the term "tightness" rather than "shortage" for several reasons. First, there is no universally accepted definition of "shortage." Second, the use of the term "shortage" can imply a binary condition—either there is or is not a shortage. But the term "tightness" can encompass "shortage" as its limiting case—the condition in which employers find it impossible to find qualified workers no matter what they pay or how long they wait—and still account for the continuum nature of the phenomenon. Third, the committee feels that "tightness" is a broader and more encompassing term that does better justice to the complexity of the issue.

Tightness in the overall labor market helps to account for the consistent employer reports of difficulty in hiring IT workers. However, perceptions of tightness reported by individual employers are driven by job openings and vacancies (i.e., variables that are perceived at firm level), which are recognized by labor market analysts as unreliable indicators of tightness or shortage in the overall market per se. This point is significant because vacancy rates depend as much on job turnover as on company growth in employment. High job turnover is common during periods of sector-wide growth, but employers have a number of methods available to reduce turnover.

Tightness in the overall IT labor market is not uniformly distributed across all positions, all geographic regions, or all levels. The uneven experience is due, in part, to the fact that IT work is highly diverse—not only can IT work be divided into the two different categories defined by the committee, but it can also, of course, be more finely differentiated into job requirements of varying stringency. And workers trained for one type of IT work may not be able to move easily to another type of work. Uneven experience in the IT labor market across the nation is also due to the different mix of industries and employers in a given region. Thus, labor market experience in Silicon Valley, home to many IT-producing businesses, has national impact, but it is not comparable to labor market experiences in Austin, Seattle, Boston, New York City, or other places examined by the committee.

A significant increase in the supply of Category 1 workers is likely to take at least several years (i.e., the time needed for large numbers of these individuals to earn degrees as well as time for workers to ground their formal learning in real-world experience and context), while training efforts for Category 2 workers can—in principle—bear fruit in a matter of months. This differential arises because Category 1 work tends to require more years of formal exposure to IT-related disciplines than does Category 2 work. Reflecting tightness and to attract and retain workers, real wages have grown in Category 1 IT occupations overall at a rate of about 3.8 to 4.5 percent annually from 1996 to 1999, according to data from the Current Population Survey (CPS), though this figure masks much more substantial growth in certain subspecialties and lower growth in others, and also does not include the impact of stock options and equity stakes on total compensation. By comparison, all other professional specialty occupations as a whole experienced an average annual increase in income during this period of 3.2 percent. The wage trajectory for the Category 2 workforce is unknown because of its highly heterogeneous composition and a lack of consensus on which occupations should be included.

THE SIZE AND STRUCTURE OF THE IT WORKFORCE

The IT workforce in the United States draws workers from many sources, including recipients of degrees in IT-related fields such as computer science or computer engineering and nonmajors who take a number of IT courses. Other sources include those who study IT after they have completed their formal education (in a non-IT-related field) and foreign workers who have generally been educated in whole or in part abroad.

The size of the IT workforce is difficult to estimate. However, the committee estimates that the overall size of the IT workforce is at least 5.0 million, with approximately 2.5 million Category 1 workers and a number of Category 2 workers that is at least as large. Because IT has permeated the economy, society, and workplace in myriad ways, the bounds on the Category 2 workforce are unclear. Consequently, estimating the number of Category 2 workers is difficult and, ultimately, depends on a definition on which there is little consensus (or data). (For comparison, the total U.S. labor force is approximately 140 million.)

The IT workforce has grown rapidly in the last 8 years, with the Category 1 workforce having increased by 60 to 75 percent. Nearly two-thirds of Category 1 workers are employed in firms with 500 or more employees, and nearly three-fourths of them are employed outside the "computer services" segment of the IT sector. These noncomputer services employers include those in manufacturing, finance and related industries, retail and wholesale trade, and government. This distribution belies the stereotypical image of IT workers in small start-up "dot-com" firms or even in large computer or software firms.

Demographically, the Category 1 workforce is predominantly male, white, and younger than the workforce in general, as well as U.S.-born. Trends indicate that the Category 1 IT workforce is becoming increasingly diverse in terms of race, ethnicity, and country of birth and less so in terms of gender; it is also aging. And the Category 1 workforce is highly educated, with most Category 1 workers having at least a bachelor's degree (though frequently not in an IT-related discipline); Category 2 workers often have a bachelor's degree or less. Furthermore, IT occupations are expected to experience a growth rate that is significantly higher than those of other occupations for the next decade, assuming that downturns of economic significance do not materialize.

AGE AND EMPLOYMENT IN THE IT WORKFORCE

Despite rapid and continuing growth in IT employment, concerns have been raised that older workers are less likely to be hired and retained than younger workers who appear to have the same skills. Some who have gone on record on this issue, and others responding to the committee's call for input, allege that widespread age discrimination is an important cause of the asserted IT worker shortage.

The committee found limited data useful in assessing age discrimination questions, but its assessment yields some important observations. Given the demand for IT workers today and the number of jobs expected to be added to the IT workforce yearly, elimination of all potential age discrimination in the IT workforce would not likely have a significant impact on tightness in the IT workforce in the long term, although it could have a small, but important, one-time effect.

The available data relevant to age and employment of older Category 1 IT workers indicate that the IT workforce is younger than that in other occupations with workers of comparable educational attainment, and that older IT workers (those 40 years and older) are more likely to lose their jobs than younger IT workers. However, these data also indicate that older IT workers are just as likely to find new jobs as are younger IT workers, and the length of time it takes for them to find new jobs is similar to that for younger IT workers. Finally, these data indicate (though not at a level that is statistically significant) that when displaced older workers find new jobs, their base salary is lower than that of their previous jobs, whereas displaced younger workers in a comparable position find higher base salaries.

However, the data available to the committee do not allow the causality of differences to be determined. The data available are insufficient to establish either the presence or the absence of age discrimination, and did not allow the committee to determine whether these differences are the result of illegal age discrimination, legal conduct by employers that may be perceived as discriminatory, personal choices made by individual employees, or the ramifications of a rapidly changing industry. As a result, the committee could not determine whether illegal age discrimination exists to a greater or lesser extent among employers of Category 1 IT workers as compared to employers of other professional occupations.

With all that said, the committee believes that the nation cannot afford to underutilize valuable labor resources, especially during times of labor market tightness, and the differential experiences of older IT workers indicate some likelihood that this qualified segment of the workforce is not being fully utilized.

FOREIGN WORKERS AND THE IT WORKFORCE

The use of foreign workers (defined to be those working in the United States on either temporary or permanent resident visas) in the U.S. IT workforce inspires concern and passion, reflecting earlier debates over the appropriate role of foreigners in the labor force and their impact on the U.S. economy. Today, the politics of this debate have been shaped by arguments over the appropriate number of H-1B visa holders that the United States will admit each year.

According to data collected from the CPS, foreign-born individuals (a term that encompasses foreign workers as well as naturalized citizens) constitute about 17 percent of the Category 1 IT workforce and about 10 percent of the total U.S. population. The committee estimates that H-1B workers constitute about 10 percent of the Category 1 IT workforce, though this figure most likely represents an upper bound. From the perspective of employers, the critical feature of the H-1B program is that it enables them to hire qualified foreign workers in a matter of months, in contrast to the years required to attract and train additional U.S. students or to obtain green cards for prospective permanent residents.

The committee believes that foreign Category 1 and Category 2 IT workers—including the H-1B visa holders working in IT—can make positive contributions in a number of ways to the U.S. IT sector, IT-intensive firms, and the economy as a whole. For example, while H-1B visa holders are far from the dominant influence on the IT workforce, their relative number is large enough that without these workers there would likely be a slowdown in the rate of growth in the IT sector. At the same time, economic theory implies that an increase in the supply of IT workers, including temporary nonimmigrant workers, will cause the corresponding IT wage rates to be lower than they otherwise would have been. Theory alone does not imply any particular numerical magnitude of this effect. It is the committee's judgment that the current size of the H-1B workforce relative to the overall Category 1 IT workforce is large enough to exert a nonnegligible moderating force that keeps wages from rising as fast as might be expected in a tight labor market.

The committee recognizes very well the political salience of the H-1B issue, but it has found no analytical basis on which to set the "proper" level of H-1B visas. Thus, decisions to reduce or increase the cap on H-1B visas are fundamentally political. The committee also believes that the use of foreign workers will continue to be necessary for the immediate future, and that foreign workers will continue to make important contributions as described above, but policy governing the use of foreign workers must consider not only the benefits of admitting foreign IT workers but also potential negative effects on the domestic workforce, and take steps to ameliorate those negative effects.

ENGAGING THE EXISTING IT WORKFORCE

To produce more without additional hiring, a firm may ask its workers to work overtime. Some amount of overtime work is common in the IT industry and in IT-intensive firms. But the common stereotype portrayed in the popular press of IT workers who work as much as 80 hours per week is not supported by any of the quantitative data available to the committee. The data also do not support the notion that longer workdays are more typical in smaller firms. Nevertheless, anecdotal evidence suggests that the large-scale averages indicating a minimal amount of overtime may mask a wide variation in work hours characteristic of different IT employers.

It is also possible for employers to relax the requirements needed by a successful job applicant. While it is understandable that an employer would search for the perfect candidate, insistence on a long list of qualifications inevitably makes it harder to find a qualified worker, and in the time they are waiting to find the perfect applicant, they may be able to hire an almost-perfect applicant and provide training. There are limits to this process, of course, but in fact some employers are indeed adopting the hire-and-train strategy with some success.

Assessment is central to engaging the pool of job applicants. On the whole, IT employers have been generally successful in screening out unqualified applicants, a claim that can be reasonably inferred from the IT sector's broad success and growth throughout the economy. On the other hand, given existing tightness in the IT workforce, IT employers may be able to do a better job in finding additional qualified and productive applicants from underrepresented groups that are now overlooked to some degree.

Because of the heterogeneity of IT-sector firms, it is difficult to make broad generalizations about assessment practices across the IT sector. Nevertheless, it appears that many IT firms do not make use of structured assessment methods (i.e., procedures that are used to evaluate a job applicant that are administered in a standardized and uniform manner, scored in a consistent manner, and validated against indicators of job success). Many such methods have a solid empirical basis, a long and consistent record of validity, and cost-effectiveness, and also have been shown to expand the selection process to include larger numbers of persons from traditionally underrepresented groups such as women and minorities.

At the same time, the success of structured assessment depends largely on a formal job analysis that specifies the duties, responsibilities, and requirements of a job. But, because many aspects of IT work change as rapidly as the technologies change (i.e., very rapidly), it may be difficult to apply traditional methods of job analysis to many IT jobs, especially those in Category 1. Some structured assessment methods have the further advantage that an employer who uses them can protect itself against legal challenges that more often arise when applicants and employees are being evaluated against a set of employment standards less formal than those implied by structured assessment.

There is some controversy in the IT community regarding the amount of productivity gain that can be expected in the coming decade from tools and management approaches. Nevertheless, while individual productivity has been and can in the future be increased through the use of tools and/or the use of different organizational or managerial strategies, such tools and strategies are not likely to play a decisive role in reducing the current tightness in the IT labor market in the coming decade.

FORMAL EDUCATION

Education and training increase the supply of qualified workers by attracting and preparing new entrants to the IT workforce, enabling individuals already working in IT to acquire skills qualifying them for higher-skilled and better-paying jobs, and helping current highly skilled IT workers keep their skills up to date.

Current high school mathematics education in the United States is inadequate to meeting the challenge of increasing the supply of IT workers. By developing reasoning and problem-solving skills needed in IT work and by providing the prerequisites for entry into many 4-year IT programs, improving secondary mathematics education can increase the number of students who are interested in and prepared for IT work or postsecondary study in IT-related fields.

At the postsecondary level, the quality of formal education at 4-year colleges in IT-related fields is such that graduates in these fields are in great demand by IT employers. Exposure to formal computer science education provides an in-depth understanding of the fundamentals of the subject, the skills to work successfully on large IT projects, and a greater ability to adapt to new technologies. Although the number of graduates in IT-related fields is increasing annually, there is concern that lack of resources (e.g., faculty, laboratory space) will limit further expansion. IT minors and other forms of partial IT concentration provide an additional way to increase the IT labor pool.

Community colleges also play an important role in extending and enriching the IT workforce. They provide 2-year associate's degree programs in IT, feed students into the IT programs at 4-year colleges, and provide lifelong IT skills development for students of all ages and educational backgrounds. Although 2-year and 4-year institutions face similar barriers to expansion (lack of qualified faculty, lack of computing facilities), community colleges are generally able to respond more quickly to changes in local labor markets and to increase the capacity of their IT courses more rapidly.

Postbaccalaureate education in computer science competes for talent with an IT sector that offers the promise of greater—and more immediate—financial rewards. Because it depletes the talent engaged in the research enterprise, this trend does not bode well for the long-term health of the IT field.

Finally, education aimed at certification is a large and rapidly growing source of skills for IT workers, particularly those who perform mostly Category 2 work. Certification is supported by the IT industry largely as a way to provide support for products that it offers.

TRAINING

Training refers to activity aimed at improving a current IT worker's job performance or preparing an individual for IT work. For new hires, training often includes orientation to the culture of the company. In other cases, training is oriented toward the acquisition of new skills, whether technical or nontechnical. The term "training" generally includes formal training as well as more informal training, such as learning by doing.

It is generally accepted that all users of computer systems, and especially IT workers, must continually learn and update their skills to keep pace with rapidly changing technology. However, the training that most, especially smaller, employers make available to their employees tends to be small compared to the need.

In both the shorter and longer terms, ongoing training could relieve tightness in the IT labor market both by reducing turnover and by increasing the supply of qualified labor. The pace of technological change in IT increases the costs and benefits of training for both employers and workers. Employers gain by having an alternative to hiring new workers, and thus, appropriately structured training, involving the integration of work experience with "formal" learning, can help to relieve tightness in the IT labor market. On the other hand, workers who receive training may be more likely to leave, and economic and competitive pressures discourage employers from providing support for ongoing training. From the worker's standpoint, rapid technological change increases the intellectual burdens to stay current, but staying current also makes him or her more employable. The committee believes that IT workers are likely to receive an adequate level of ongoing training only if the responsibilities are shared between worker and employer. Workers must be willing to spend some of their own time on training efforts, and employers must be willing to explicitly support worker training.

INTEGRATION OF WORK EXPERIENCE, TRAINING, AND EDUCATION

The committee heard considerable testimony that employers prefer a combination of formal education and training with work experience that is relevant to the jobs for which applicants are being hired. Cognitive theory and workplace experience both suggest that application is usually necessary for formally acquired knowledge to become useful "on the job." Such experience implies very strongly that internships and work-based education and training opportunities have many advantages over other approaches to education and training that do not integrate work experience as an essential component.

A POINT OF COMPARISON: IT AND BIOTECHNOLOGY

Information technology and biotechnology are both "high-tech" industries. A comparison of the environment and workforces of the two industries provides a broader appreciation of IT workforce issues.

The biotechnology industry is similar to the IT industry in a number of key dimensions. Both depend on research and development, are entrepreneurially driven, and place a very high premium on speed—IT in its concern over "time to market" and biotechnology in its concern to be "first to invent" and "first to patent." There are also key differences. Compared to IT product development, product development in biotechnology is generally more risky, more costly (a characteristic cost of development and trials is $50 million), and generally more time-consuming because of clinical testing required following product development (several years). (Today, only about 1 in 10 drug products entering the clinical phase succeeds commercially. Thus, a successful commercial biotechnology drug today reflects development and trial costs of $500 million—of which $450 million is accounted for by products that were unsuccessful.) The capital investment needed for biotechnology (especially in the initial stages) is generally much higher than that for much of the IT industry (chip fabrication aside). Furthermore, the biotechnology industry is highly regulated, for example, through the Food and Drug Administration and the U.S. Department of Agriculture.

While both industries are driven by the creation of innovative products and processes, the complexity of modern biotechnology generally requires on average a more highly educated and trained workforce than does IT. At many R&D-based biotechnology companies, the majority of the workforce has college degrees in the life sciences; often more than half the workforce has advanced degrees, and several years of postdoctoral laboratory-based training as well.

Despite a widely acknowledged oversupply of individuals with Ph.D.s in the life sciences, biotechnology employers share with IT employers similar difficulties in hiring people with appropriate expertise (e.g., analytical chemistry, instrumentation, organic synthesis, clinical biostatistics, bioinformatics, production quality, regulatory affairs). These difficulties have arisen because universities have not yet been able to respond to the changing skills requirements as the biotechnology industry becomes more manufacturing-oriented and biotechnology becomes a highly data-intensive enterprise.

Bioinformatics presents particular employment challenges. Biotechnology is a data-rich field, and it will become more so as increasing amounts of genomic information become available. Other areas that will increase the need for managing large amounts of information include rational drug design and the conduct of genotype-profiled clinical trials, both of which shorten development times and target drug delivery more precisely. Increasing numbers of bioinformatics specialists—with an understanding of both biotechnology and computer science—are needed to analyze and understand the growing volumes of data that are becoming available.

COPING WITH A TIGHT LABOR MARKET

In the face of labor market tightness, firms in the near term must pursue some combination of the strategies available to employers in all sectors. These include recruiting newly available domestic or foreign workers, paying higher wages, making do with fewer workers than they would like, and retooling or making better use of the workers they have. In the longer term, steps need to be taken to increase the supply of IT workers. Those steps include attracting more students to study and teach IT, increasing the efficiency of employee screening and recruiting, and supporting the training and retraining of those already in the labor force.

Responses to tightness in the IT labor market are already evident—

enrollments are up in computer science degree programs, and employers are taking many of the steps described below to increase supply. But under conditions of sustained growth in demand, supply will lag demand, and today, the ability of market forces alone to bring supply and demand into close balance is an open question. Tight labor market conditions can be alleviated through policies or actions that reduce employer demand for workers and/or that increase the supply of qualified workers. In the absence of such policies and actions, work is produced differently, postponed, abandoned, or altered in character.

PRINCIPLES FOR ACTION

The committee believes that there is no single solution to relieving the tightness in the IT labor market, and multiple approaches involving public and private stakeholders as well as individual workers will be necessary. Effective approaches to addressing tightness must be responsive on the time scale of significant change in information technology, and employers must be able to hire workers on a business time scale (i.e., weeks or months rather than years). Policy actions taken to relieve tightness in the IT labor market must be reversible or capable of being moderated if and when such tightness no longer obtains.

Policy decisions would be easier and less controversial if there were data that permitted analysts to quantify benefits, costs, and the degree of labor market tightness. Unfortunately, the relatively recent emergence of IT as a major element in the economy and the speed with which it has become critical to the global economy have far outpaced the rate at which data collection systems evolve. Many numbers are developed, published, and debated, but even the best among them are deficient for a variety of reasons. The committee has limited its recommendations to those that can be supported by evidence and be adjusted if economic conditions change.

RECOMMENDATIONS

Coping with a tight labor market requires the best efforts of all stakeholders: employers, employees, educational institutions, and government at all levels. Yet any action taken to alleviate labor market tightness will take time to show results. Further, actions that provide relief in the short run may diminish the urgency of longer-term measures. The steps recommended below are not novel—and most are already being taken by some stakeholders in some places. The committee believes it is important to gather them in one place to illustrate the multiplicity and interdependence of steps needed to ensure the continued health of the IT workforce.

Employers should expand their repertoire of human resources practices by:

• *Using validated structured assessment techniques in recruiting and promotion.* These can help by identifying able candidates who might be missed when more informal techniques are used and by expanding the selection process to include people from traditionally underrepresented groups such as women and minorities. They also have a higher likelihood of eliminating unconscious bias on the part of those responsible for making employment-related decisions.

• *Developing strategies to increase the numbers of women and minorities involved in IT work.* Providing programs that allow members of underrepresented groups to enter the IT field through alternative paths would help to encourage women and minorities who were discouraged from considering or were unable to pursue IT early in their careers.

• *Identifying and implementing steps to improve the quality of life for current and future workers.* Employers have a wide range of nonmonetary approaches to improving job attractiveness, including alternative work arrangements (e.g., telecommuting), policies that support work-family integration, opportunities for on-the-job learning of new technologies, and high-quality project management. Increasing job attractiveness can significantly help with the recruitment and retention of top-quality employees.

• *Promoting training opportunities for current workers in order to enhance skills and increase loyalty.* While human capital theory predicts that an employee who receives training may well move on to another job, thereby depriving the employer of the benefits of a more highly skilled employee, recent empirical research indicates that in some cases training both helps the employer and increases employee loyalty. Training existing employees may be a better option than recruitment. Collaborating with other employers to provide training helps expand the local workforce, benefiting all employers in a region.

Educational institutions are critical to IT workforce development in the longer term. They should:

• *Improve secondary school mathematics education* so that high school graduates are better prepared for studying technical fields and for IT-related fields in particular. Improvements should emphasize problem solving and conceptual thinking, encompass both individual and group work, and demonstrate that the skills learned can address real-life problems.

• *Give greater emphasis to promoting IT fluency in K-12 and in higher* *education.* The ability to use IT tools for learning and at work is a skill that every citizen should have.

- *Better align educational programs in IT with the demands of the IT workplace.* Classroom learning and workplace experience are both necessary in the education of an IT worker. IT students should participate in co-op and internship programs in industry. Conversely, IT problems facing industry should be studied in the classroom.
- *Expand available faculty in IT-related fields.* The number of computer science majors has increased in recent years, but further increases are limited by constraints on the number of faculty available. To overcome this problem, computer science departments should seek more faculty, make greater use of adjunct faculty drawn from industry, upgrade the skills of existing faculty, and allow faculty in other departments to assume some of the teaching load.
- *Encourage IT course taking by those not majoring in an IT-related discipline.* The growing ubiquity of IT means that familiarity with IT techniques and issues will be required of most students when they enter the workforce. Significant exposure to the formal content of computer science curricula will increase the pool of students prepared for a career in IT.
- *Develop and implement ways to increase the attractiveness of IT-related majors to women and underrepresented minorities.* These groups are underrepresented in IT, as well as in other areas of science. Increasing their numbers would significantly expand the pool of potential IT workers.

Individual workers have a responsibility for maintaining the currency of their technical skills in the face of rapidly changing technologies. They should:

- *Negotiate release time* for training and professional development where possible; employer financial support for training, professional development, and additional formal education; and placement into jobs that will develop and enhance skills with current technologies.
- *Seek internships* with potential employers when using formal education to learn new skills.
- *Take advantage of training opportunities* offered by their employers.
- *Participate in professional societies* that publish technical journals and sponsor technical conferences and tutorials.
- *Take advantage of self-study programs,* community college courses, vendor certification programs, and other resources for updating their skills.

Government policymakers should take steps to shape the labor market environment by:

1. *Supporting training and research and improving data collection.* Specifically, government should:

• *Provide incentives for employers to increase training.* Under conditions of sustained growth, market forces alone are unlikely to balance the supply of and demand for IT labor. This argues for some form of government incentives for employers to increase training. For example, a mix of public and private funding could support regional training consortia in which member companies define the training program, and 2- and 4-year colleges provide some of the pedagogical resources. Sharing the costs and benefits of training might be especially helpful for smaller IT firms that lack expertise and resources for training.

• *Collect more timely, disaggregated data on different dimensions of the IT workforce and flows into and out of it.* The committee has found existing data to be lacking in detail and too out-of-date for many purposes. To make empirically based policy and business decisions, disaggregated data are needed on the size of the IT labor force, including information on all forms of compensation and data describing the career paths of IT workers. These data must be made available more quickly, in more detail, and for larger samples than data the government typically collects through surveys such as the Current Population Survey and the Occupational Employment Statistics program. Better data on immigration are also needed to analyze the role of foreign workers in the IT sector.

• *Support research directed toward reducing tightness in the IT labor market* by addressing areas such as organizing work for improved productivity, developing structured assessment tools specialized for IT jobs, improving software engineering (focusing on flexibility, security, reliability, manageability, quality of service, modifiability, scalability, and reuse), and achieving a better integration of the above areas. More generally, support of high-risk, high-payoff research would help to retain and attract top researchers in and to academia.

2. *Ensuring that foreign workers are as free as domestic workers to change jobs, and streamlining the green-card process,* i.e., the process through which a foreign worker can obtain permanent residency in the United States. Much of the controversy over the H-1B program is rooted in the belief that the use of H-1B workers places U.S. workers at a disadvantage, because the H-1B workers' lack of mobility and their status as "temporary" in the labor force enable employers to exploit them in ways that are not possible when more mobile workers, such as U.S. citizens and green-

card holders, are involved. To reduce these presumed disadvantages for U.S. workers, the committee believes that the government should take action in two ways:

• H-1B visas should be made more "portable" so that a foreign temporary nonimmigrant worker can more easily change jobs in the United States.

• The green-card process should be reformed and significantly streamlined, thus reducing the time needed to obtain green cards.

Furthermore, the government should consider the effect of having increased the numbers of H-1B visas without having significantly streamlined the labor certification process or reevaluating the numerical limits on permanent residents available in the current employment-based immigration program (i.e., the number of permanent visas available to foreign workers based on their job skills and country of origin). The committee believes that it would be a mistake to adopt "stopgap" measures for this group of workers and miss the opportunity for a considered debate on the nation's policies regarding employment-based immigrants in the light of increased globalization of the U.S. economy.

3. *Reconsidering the government's own employment policies as a major employer of IT workers.* The federal government has severe recruitment problems—an imminent major retirement bulge of IT workers, limited remuneration packages as compared to those for private sector employers, and restricted opportunities to use foreign labor. The federal Chief Information Officers (CIO) Council's Education and Training Committee has been active in seeking solutions to these IT workforce problems. The committee supports the recommendations in the council's 1999 report, *Meeting the Federal IT Workforce Challenge,* for the federal government to:

• *Be more flexible in remuneration and recruiting methods,* by eliminating fully the restrictions on the remuneration of retired federal employees and by emphasizing the federal government's special advantages as an employer, including the defined hours, the family-friendly work environment, the stability of employment, and the health care and pension benefits.

• *Make more resources available for training its IT workers* and raise its investment in IT training to match the best levels in the private sector.

• *Use contractors more effectively* by removing unnecessary skill requirements for contract workers, and giving more flexibility for billing for the training of contract staff.

• *Establish a mechanism, such as the Federal Cyber Corps, through which* *the government can pay for undergraduate and/or graduate IT education in return for government service.*

Taken together, these recommendations, if followed, should increase both the numbers and the effectiveness of the IT workforce and, in so doing, improve the competitiveness of the U.S. economy, both now and in the future.

Part I

1

The IT Sector: Context and Character

1.1 THE TRAJECTORY OF INFORMATION TECHNOLOGY

Few foresaw the rate of progress in information technology (IT) and the IT-producing industries over the last few decades—a brief period in which computing went from infancy to ubiquity. Digital technologies have become plentiful, inexpensive, and powerful. Through successive waves, computing advanced from stand-alone systems to batch processing, from batch processing to time-sharing, from time-sharing to personal computers, and now from personal computers to information appliances connected to the Internet. Each of these transitions enabled computing to reach an ever-widening circle of users. Microprocessors are now in machines everywhere, from supercomputers to servers, to very powerful desktop and portable computers, to consumer devices and specialized equipment of all kinds. They are embedded in automobiles, aircraft, and telephones, controlling such functions as antilock brakes, automated landing systems, and cellular call processing.

While small or everyday systems capture the popular imagination, large systems power many sophisticated applications. When characterizing IT systems, large can refer to the kind of problem to be solved, and so-called high-performance systems handle complex applications with large numbers of computations or store huge amounts of information. Large can also refer to the number of connections among devices and smaller systems, and thanks to the Internet, computer-based networking is increasingly large-scale, integrating products and applications from different vendors and organizations. The prospect of a connected planet has become compelling, driving public and private IT investment around the globe.

Advances to date are only the beginning, because their impact cumulates and compounds. As a result, the IT industries and everything they touch are in the process of profound and ongoing change. IT has gone from a niche sector, touching relatively few people (compared to the telephone, automobile, and broadcast industries), to one that feeds every aspect of business and society. No longer just a set of tools aimed at business and technical users, IT has started to reach larger and larger numbers of people, promising to bring all kinds of information and applications into homes and social interactions as well as businesses, governments, universities, and other institutions. It is changing how institutions operate and deal with constituents from employees to customers, and it is changing how people deal with each other, whether at work or at home. These phenomena provide an important foundation for understanding the issues surrounding the IT workforce.

1.2 AS GOES IT, SO GOES THE IT WORKFORCE

The IT workforce is both a result and an enabler of IT, the family of technologies associated with computing, communications, and related information handling. The history of IT[1] is brief enough that many are familiar with IT-related occupations that grew and then declined, notably computer operators and data-entry workers—occupations made obsolete by advances in the ease and extent of use of computers sketched above. These, however, are occupations relating to IT use—a large and diverse set of occupations becoming pervasive in the labor force but outside the scope of this report. Here is addressed "IT work," which (as explained in Chapter 2) makes possible the growing variety of IT uses. IT work begins with the production of the essential components of IT and extends into the art of combining those components into more elaborate systems and applications—the steps that help people to realize the potential of the technologies.

Put simply, there are three categories of IT components,[2] which may be used independently or, increasingly, in combinations realized as a

[1]For an overview of that history, which is concentrated in the second half of the 20th century, see Computer Science and Telecommunications Board, National Research Council. 1999. *Funding a Revolution: Government Support for Computing Research*. Washington, D.C.: National Academy Press.

[2]This report uses the term "components" broadly to cover the three categories described, rather than narrowly, as is sometimes the case, to refer only to hardware.

burgeoning variety of applications—office productivity enhancements, electronic commerce, entertainment, enterprise management, travel reservation systems, supply-chain management, distance learning, telemedicine, data mining and knowledge management, military command and control, electronic government, and so on.[3]

- First, IT includes hardware, from the semiconductor components ("chips") that provide basic processing, memory, and other functions to the larger devices (such as computers of various sizes, the routers that move Internet traffic, or personal digital assistants) that house such components. The vaunted rapid rate of change in IT is most evident in hardware, where numerous components and larger devices have become commodities or mass-market products, as predicted by Moore's law, which projects a doubling of chip capacity about every 18 months.[4] Hardware production, per se, is manufacturing and as such involves a wide range of occupations and benefits from the kinds of productivity improvements that can be realized in manufacturing.[5] It begins with design and development, which are highly skilled professional and technical activities. IT hardware increasingly involves complementary software development—there is software used in the design of complex hardware, and there is software encoded directly in certain components, adding to their sophistication and capability. IT hardware has become an ingredient of a widening array of (non-IT) products, where it is said to be "embedded." Many of these products are highly specialized (e.g., automobiles, industrial machinery, kitchen appliances).
- Second, IT includes the software that makes the hardware do useful things. Because so much IT hardware (notably "computers," per se, but also their components) is general-purpose, because so many new kinds of devices incorporate IT hardware, and because, as a result of the first two factors, innovation in generating new applications through software is abounding, software has increasing importance within IT. The past 50 years have seen growing diversity in software, which has been

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[3]Applications are routinely described in a variety of trade and business publications (e.g., *Computerworld, InformationWeek, PC Magazine, Harvard Business Review, Forbes*) and increasingly touted in the mass media as well.

[4]"Moore's law" characterizes how the number of transistors on a chip—a metric of a chip's capability—has been growing for the past couple of decades by a factor of two every 18 months, a rate expected to continue for at least another decade. See the Intel Web site at <http://www.intel.com/intel/museum/25anniv/hof/moore.htm>.

[5]Manufacturing productivity—output per unit of labor—has been increasing with growth in the use of specialized equipment or automation, and manufacturing productivity can also grow with changes in how production processes are organized and how resources are used.

associated with a widening circle of people who can produce software. Software is far from homogeneous: it ranges from the highly specialized software that composes the tools used by people writing (other) software applications or that drives high-reliability applications such as avionics or integrated management systems to software for a video game, which may or may not be sophisticated, and software for office applications, which may also vary in sophistication. Software can be bought "off the shelf" as a mass-market product, commissioned for custom development as a service product, or bought as a specialty product that may be further customized and adapted—or it may be written directly by the people who want it. Users who develop their own software may be either skilled in doing so or do-it-yourself dabblers.

- Third, IT includes communications networks, which may be small or large in scale, private or public in access and use, and supportive of not only data communication but also communication of voice, images, video, and their combinations—which, thanks to digitization and packet switching, are realized as a kind of data communication. Networks involve equipment (hardware), software, and services. Typically, network hardware producers also produce specialized software (or motivate independent software production aimed at their products). Networking businesses are service firms that own and/or operate hardware and software for customer applications, which range from communications, per se, to ancillary access to information resources and support for specialized communications needs. Customers for network systems have tended to be organizations, but a new market in household networks is growing; customers for network services have always included organizations, households, and individuals.

IT experts envision a steady flow of innovation that will continue to change what we see as common applications of IT, making it hard to describe the technologies in enduring terms. Although prediction can be perilous, an obvious trend is the rise of networked information systems, which is fundamental to the 1990s and now 2000s explosion in uses of IT and the spread of those uses to more and more individuals, households, and different kinds of organizations.[6]

Commercialization of the Internet catalyzed this trend, which builds on decades of experiments and experience with data networks. Network capacity is growing through both optical (fiber-cabled) and wireless tech-

[6]As context to innovation, new circumstances—notably the splitting up of the old Bell System in telephony in 1984, the commercialization of the Internet backbone in 1995, and the Telecommunications Act of 1996—combined with falling cost and increased ease of use to stimulate demand and supply for networking and other IT.

nology, supporting more and faster communications plus mobility; the dream is to be able to communicate anything, anytime, anywhere.

A related trend is "digital convergence," a term often used to characterize how IT can support many kinds of media and activity. Digital convergence lies behind the use of cable modems for Internet access, distribution of music and videos over the Internet, Web access from cellular telephones, and so on—people with access to suitable technology are already becoming as comfortable with exchanging still and moving pictures and sound as with exchanging text and data over networks. New applications take advantage not only of increasing communications bandwidth but also of steady improvements in processing and memory or storage; the shape of an application depends on how all of these factors are traded off, depending on their relative cost. New applications are also likely to be smart (i.e., involving machine-to-machine interactions). The use of software agents to gather and compare information on the Web is but an indicator of what may be possible.

Falling relative costs, increasing capabilities, and constant experimentation argue for more and more IT products and IT use. That expectation is reinforced by prospects for improved ease of use, for example through input technologies such as speech recognition and touch-sensing or gesture that will open IT to people and circumstances that do not tolerate today's typical keyboard and mouse. Another will be progressive embedding of computing and communications capability, signaled by today's proliferation of consumer options (phones, information appliances, alternative Web-access devices, set-top boxes and other TV-attached devices, network-attached embedded devices in conventional household appliances, and so on) and the expectation of a wider variety of sensor technologies for monitoring everything from household-member health to facilities security. Related to these is the spread of wireless communications technology, already at high levels in many countries and evolving to support more data (including Internet and Web) applications,[7] and growth in in-home computer networks linking multiple devices to each other and the Internet.

Finally, although large systems remain important in many contexts (notably the support of far-flung organizations, or the interactions of groups of organizations and individuals), the hallmark of contemporary IT is that it is on a personal scale—from small, personal, and increasingly

[7]See, for example, Broadview International LLC. 1999. *The Wireless Web: The Coming Communications Revolution*. New York: Broadview International LLC. For an overview of mobile and wireless technologies, see Computer Science and Telecommunications Board, National Research Council. 1997. *The Evolution of Untethered Communications*. Washington, D.C.: National Academy Press.

portable devices to software that a user can modify to meet individual preferences and needs and services that a provider can tailor to different customers. Just as ordinary individuals, rather than telephone operators, set up most telephone calls, conduct many of their own banking needs through automated teller machines or PCs, and pay for the gasoline they pump through computerized systems connected to a data network, people can expect to set up more and more activities and many aspects of the IT that they use directly. Empowering end users adds to the complexity of the systems they use—and adds to the challenge faced by the IT workers that produce and support them.

Against this backdrop, IT workers are those individuals who create and provide IT capacity—the people who develop and enable the use of the IT hardware, software, networks, systems, and services. Their work may fashion the components described above or integrate them into more complex systems and applications, work often done under the rubric of systems integration or consulting. A more detailed discussion of IT workers and IT work is contained in Chapter 2.

This report concentrates on those IT workers associated with software rather than hardware, because they pose the greatest labor market challenges within the larger population of IT workers. They are found in the production of all three of the categories of IT products, they dominate employment in systems integration and consulting (a $150 billion business in 2000[8]), and they may be employed in industries of any classification in the economy. They perform work associated with service production, even if they are employed in a firm or industry focused on goods production.

1.3 WHY HAS INFORMATION TECHNOLOGY CAPTURED SO MUCH ATTENTION?

IT captures attention because it is so dynamic and versatile, because so many people use it, and because its importance to the economy has grown. The economic impact of IT is broad: it begins with the group of industries that produce it and extends to the rest of the economy. The result is growing public and public policy attention.

[8]See Palma, Michael J. 1999. "Forecast Analysis: 1999 Preliminary Worldwide IT Services Market Forecast." Dataquest Consulting and System Integration North America Program, June 14. Dataquest defines a larger set of professional services (including education and training, operational services, help desk management, transaction processing, and more) that totals closer to $340 billion.

1.3.1 Flourishing of the IT Sector

The production and delivery of IT goods and services have become the substance of a major economic sector, what this report terms "the IT sector." It includes industries that are significant contributors to the nation's economic performance, both directly and through their sales to other industries that use their output; that contribution was particularly striking in the second half of the 1990s (even as compared to the earlier 1990s). For example, the Department of Commerce estimates that the IT producing industries (a broad set of hardware, software, and communications goods and services industries) contributed on average almost one-third of total real economic growth between 1995 and 1999 because of industry growth and falling prices, despite producing under 10 percent of total economic output.[9] In that period, output of communications services grew at an annual average of 7 percent, computer and communications hardware at an annual average of 9 percent, and prepackaged software and computer services at an annual average of 17 percent (nominal dollars).[10] Given the negligible revenue of start-ups in their early phases, these statistics underscore the economic importance today of established IT firms.

The general perception of rapid rates of growth contributes to a sense of urgency that characterizes IT-sector industries. In these markets, being first to market is a common objective, and even where it is not, executives talk about competitive pressures and the need to generate and produce new products (wholly new or new versions) quickly.[11] This impatience clearly influences perceptions about the labor market, as is discussed in Chapter 2, because product innovation (and marketing success) depends on talent (people), and because these businesses depend on software, whose development is labor-intensive. At the same time, the driver of IT sector growth is demand for IT in other sectors—and a result of that demand is growth in IT worker employment in those sectors, which together constitute the majority of the economy.

[9]See U.S. Department of Commerce, Economics and Statistics Administration. 2000. *Digital Economy 2000*. Washington, D.C., June. Also, note that market researchers who follow the IT sector consistently forecast significant growth in these industries, but the methodology of these projections is hard to validate. Federal sources document their assumptions and methodology in detail.

[10]This is measured using the concept of "gross product originating," the industry contribution to the gross domestic product of the nation net of its purchases of intermediate products from other industries.

[11]Perhaps the epitome of these sentiments is in the oft-cited quasi-autobiographical book by the chairman of the board of Intel Corporation, Andy Grove, called *Only the Paranoid Survive* (New York: Bantam Doubleday Dell, 1996).

The IT sector looks to the world for its resources, beginning with people. It has defined its markets internationally since its early years. Firms owned and headquartered in the United States recognized overseas market potential early on; such IT pioneers as IBM (née International Business Machines) not only began to export early in their histories but also established overseas facilities and employment beginning in the late-middle of the 20th century as part of building a global presence. Chapter 5 describes various reasons why IT companies might locate operations overseas. Although the 1980s were marked by concerns about international competition in IT hardware, associated largely with shifts of some commodity hardware production (specifically dynamic random-access memory chips) to Asia, U.S. IT firms have always been world market leaders, especially in software, services, and hardware design and development.[12]

Part of the strategy of U.S.-owned firms for growing and sustaining market share worldwide has been to locate operations in different countries as well as the United States, where "operations" range from marketing and sales to product design and development and R&D, the latter kinds of activity often conducted in collaboration with U.S.-based activities. Multinational operations imply multinational labor forces. These circumstances complicate the concept of a U.S. firm, and even though specific sets of operations may be labeled geographically (e.g., IBM Europe), simple observation shows a global orientation in the ways that executives talk about their businesses. Intel, for example, spells out its annual revenues by global region (North America, Asia-Pacific, Europe, and Japan).[13] Moreover, cross-border trade among parent and affiliate units is a significant component of IT trade.[14] The fact that there are many countries with lower penetration of IT than the United States only adds to the appeal of those markets to IT industries, as the steady attempt by numerous IT firms to develop presence and ventures in the People's Republic of China demonstrates.

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[12]See Computer Science and Telecommunications Board, National Research Council. 1990. *Keeping the U.S. Computer Industry Competitive: Defining the Agenda*. Washington, D.C.: National Academy Press. Also, Computer Science and Telecommunications Board. 1992. *Keeping the U.S. Computer Industry Competitive: Systems Integration*. Washington, D.C.: National Academy Press.

[13]See Intel's annual report. The 1999 version is available online at <http://www.intel.com/intel/annual99/index2.htm>.

[14]Foreign operations play a significant enough role that, given how economic statistics are calculated, they contribute to aggregate trade deficits in IT. In some markets, such as prepackaged software, there are trade surpluses. See Department of Commerce, 2000, *Digital Economy*, Chapter 6.

At least as important for considering the growth of the IT workforce is that the composition of the IT sector has changed over time and will continue to change. In the middle of the 20th century, for example, telecommunications was less overtly linked to computing and was treated as a sector in its own right (as it still is, for some purposes), while the computer and software industries (and related service industries) were smaller, albeit interrelated. The growth in independent (i.e., separate from hardware-producing firms) software producers was an important part of the late-20th-century growth in the software industry. Independent software products, in turn, fed demand for more hardware, although the identity and market share of hardware producers changed significantly over the past 50 years—firms have exited, entered, and adapted IT production. Growth has been concentrated in specific kinds of IT products because of what some analysts call network effects.[15] A result is the rise of dominant players for various IT products (although dominance may be long- or short-lived), which may lead other players to focus on compatible or complementary products.

By the late 1990s, growth in individual IT-producing industries and digital convergence blurred old industry boundaries. Recent years have witnessed alliances, mergers, and acquisitions among firms that produce different kinds of content and those that run network-based services for delivering that content to customers—changes in industrial organization that further cloud the picture of who does what work, where. At the same time, new companies have emerged with service offerings leveraging the Internet as a delivery channel—the so-called dot-coms. The dot-coms seem to dominate mass-media discussions of IT, but they are not necessarily in IT industries (for example, they are often in retail trade of various kinds and increasingly in wholesale trade—these are the business-to-consumer and business-to-business electronic commerce ventures); they are sometimes bought out by IT companies; and as mid-2000 news reports suggest, they are experiments that may well fail. The typical dot-com is small, and so is its employment capacity; it is common to read about dot-coms employing 5 to 20 people as well as those that grow closer to 100. By contrast, larger IT firms, including dominant and other players, hire comparatively large numbers of people (measured in the hundreds or thousands—for example, Intel's total employment, only some of which is IT workers, exceeds 70,000 people) and display more elaborate occupational mixes. Chapter 2 comments on the distribution of IT work by firm size.

[15]With network effects there is a relationship between what individuals choose to use and a tendency to gravitate toward standard choices, which reduce learning costs and facilitate interoperability. See, for example, Katz, Michael L., and Carl Shapiro. 1994. "Systems Competition and Network Effects," *Journal of Economic Perspectives* 8(2): 93-115.

Another broad IT sector trend with uncertain prospects is growth in outsourcing, the supply of IT services to other kinds of companies and nonprofits. Outsourcing takes place when an IT-using organization arranges for another firm to operate or manage IT resources, such as networking, Web hosting, large-database hosting, and so on. With outsourcing, employment shifts from the organization that uses the IT to the organization that operates and/or manages the IT for it. Outsourcing may be undertaken by specialists or as an offering of firms classified in different kinds of IT industries (for example, the service firm EDS and the hardware-focused firm IBM are both major outsourcers). The late-1990s growth in outsourcing represents a swing back to a kind of centralization of IT support that had been common in the 1960s and 1970s but began to decline with the rise of PCs and distributed systems in the 1980s;[16] it illustrates that both centralized and decentralized approaches can coexist and complicates forecasting the shape of future applications.

1.3.2 Rise of the High-Technology Sector

The rise of the IT sector has been an impetus to the rise of an even larger, high-technology sector of which IT is a part. Definitions of high technology are not consistent, and today the term is often used narrowly as a synonym for the IT sector. Typically, high technology is defined more broadly to include industries with high levels of research and development (R&D, most of which tends to be development or applied research).[17] Four prominent examples of high-technology industries include computers and office machinery, electronics and communications equipment, pharmaceuticals, and aerospace, all industries with high rates of growth. Because of high R&D spending, high-technology industries tend to have comparatively high levels of employment for science and engineering and technical personnel and, more generally, an association with demand for high-level skills.[18] Public and public-policy interest in the economics of high technology emerged in the 1980s, when its cachet, potential for high-skill employment, and other potential economic benefits such as innovation led to its being targeted for local and regional economic devel-

[16]During the late 1980s, third-party data processing and time-sharing service businesses declined as companies developed internal processing capabilities and became less dependent on centralized mainframe computing systems.

[17]See Rausch, Lawrence M. 1998. "High-Tech Industries Drive Global Economic Activities," NSF 98-319, Issue Brief. Washington, D.C.: National Science Foundation, July 20. Available online at <http://www.nsf.gov/sbe/srs/issuebrf/sib98319.htm>.

[18]See Luker, William, Jr., and Donald Lyons. 1997. "Employment Shifts in High-Technology Industries, 1988-96," *Monthly Labor Review* 120(6): 12-25.

opment activity and for monitoring by such organizations as the National Science Foundation and the Organization for Economic Cooperation and Development.

Biotechnology, which is more science- and scientist-based, may provide the greatest contrast to IT within the high-technology arena, and accordingly Appendix A outlines contrasts between IT and biotechnology. Biotechnology involves the commercial use of living organisms or biological techniques developed through basic research. Products include drugs (such as antibiotics, insulin, and interferon), diagnostics, insecticides, genetically modified plants, and techniques for waste recycling. Such products cut across many fields, including health care, agriculture, industry, and environmental biotechnology. Box 1.1 provides a short list of seminal events for biotechnology.

Though biotechnology has a history of thousands of years, the modern biotechnology industry is smaller than the IT industry. Value is created through the development of information (e.g., information about gene structure and function) and products (e.g., gene-defined drugs, genetically

BOX 1.1
A Short History of Events Central to the Development of Biotechnology

- 1953: James Watson and Francis Crick published their paper describing the double helix structure of DNA, marking the beginning of the modern era of genetics.
- 1970: University of California at San Francisco scientist Herbert Boyer identified restriction nucleases, opening the way for gene cloning.
- 1973: Stanley Cohen and Herbert Boyer perfected genetic engineering techniques to isolate DNA and reproduce the new DNA in bacteria.
- 1975: Walter Gilbert and Allan Maxam of Harvard University, and Fred Sanger of Cambridge University, separately developed two different techniques for sequencing DNA.
- 1976: Robert Swanson, a venture capitalist in Silicon Valley, and Herbert Boyer teamed up to form Genentech, Inc., with the goal of cloning human insulin.
- 1982: Human insulin became the first recombinant DNA drug approved by the Food and Drug Administration. Genentech had previously licensed the human insulin technology to Eli Lilly.
- 1985: Genentech became the first biotechnology company to launch its own biopharmaceutical product—a growth hormone for children.
- 1995: The first complete genome sequence was identified (for *Hemophilus influenzae*).
- 2000: A "rough draft" of the human genome was announced.

based tools for diagnosis, gene-modified plants for agricultural use, and proteins manufactured as drugs).

The biotechnology industry is similar to the IT industry in a number of key dimensions. Both are leaders in scientific innovation. Both enjoy a close relationship among their industrial, academic, and government components. Advances in each industry are driven by R&D (e.g., cloning in biotechnology, object-oriented programming in IT), though the biotechnology industry spends a greater proportion of its revenues on R&D than does the IT industry. Both are entrepreneurially driven, with great importance attached to the availability of venture capital at the front end of the process and the hope for substantial market capitalization after a firm's initial public offering. And both industries place a very high premium on speed—IT in its concern over "time to market" and biotechnology in its concern to be "first to invent" and "first to patent," as well as with time to market.

There are also key differences. Compared to IT product development, product development in biotechnology is more risky, more costly, and generally more time-consuming. Unlike the IT industry, the biotechnology industry is highly regulated, for example, through the Food and Drug Administration for drugs, foods, cosmetics, diagnostics, medical devices, and animal and human food additives, and through the U.S. Department of Agriculture for animal vaccines, plant pesticides and derivatives, and transgenic plants and animals.

While biotechnology spans the development of products with very short life cycles (e.g., genomics information that currently is passed from business to business, rather than business to consumer) and products with long life cycles (e.g., gene therapy), product times-to-market can be much longer (several years), and bringing a product to market successfully can cost up to $50 million. But, since the success rate of bringing products to market has averaged about 10 percent or so, every successful product on the market can represent an investment of around $500 million. The capital investment needed to pursue biotechnology (especially in the initial stages) is much higher than for much of the IT industry (chip fabrication aside). Finally, biotechnology has a much longer history of protecting its innovative efforts by creating barriers to entry (proprietary relationships, especially with the pharmaceutical industry, and patents) than does the IT industry (although the IT industry is rapidly adopting patents to protect its innovations as well).

There are other key industrial organization differences: for example, the nascent biotechnology industry has strong connections to the much larger pharmaceutical industry. The pharmaceutical industry plays a role similar to that of the venture capitalists in the IT industry—it provides capital in return for access to new drug technologies. (This is not to say that venture capital funds do not play a role in the biotechnology industry—just that the biotechnology industry does not rely solely on such funds.) Increasingly, biotechnology is becoming an enabling technology for both pharmaceutical and agricultural companies large and small.

1.3.3 Enabler of Broad Economic Change

The economic impacts of IT, like its uses, are pervasive. As one indicator, the Department of Commerce reports that current-dollar industry spending on IT hardware and software was 46 percent of all equipment spending in 1999, totaling $407 billion.[19] Although media attention to the impact of the Internet can focus on dot-coms and the IT sector, the greater impact of IT may be in its transforming effects on more traditional businesses, which continue to produce the majority of national economic output. Not only has IT been a factor in the growth of various industries and in the economy as a whole, but it has contributed as well to changes in the nature and mix of activities undertaken by firms, through that process altering the nature and organization of industries.[20]

Information can be found, created, processed, communicated, and used in so many ways that it is hard to limit what is possible, although what will show up in the economy, and when, will depend on what people are willing to buy and use. The 1980s and early 1990s saw much trial and error with IT among individuals and organizations. The late 1990s, which seem to shape today's perceptions, built on that experience base, while in 2000 uncertainties, constraining some of the dot-com enthusiasm, underscore that demand for IT and the products it enables remains at least as important as innovation in how IT may be used.

Today, the impact of IT is summarized in the phrase "the new economy." This is the latest version of a metamorphosis previously characterized as the knowledge economy and before that as the information economy. Whatever the character of the economy should be called, it builds on decades of change that were first evident in the mid-1900s, when computers were scarce. At that time, the seeds of a shift from manufacturing to services were evident, a shift that accelerated with the

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[19]Department of Commerce, 2000, *Digital Economy 2000.*

[20]See Oliner, Stephen D., and Daniel E. Sichel. 2000. "The Resurgence of Growth in the 1990s: Is Information Technology the Answer?" Washington, D.C.: Federal Reserve Board, February. Available online at <http://www.federalreserve.gov>. See also Computer Science and Telecommunications Board, National Research Council. 1993. *Information Technology in the Service Society: A Twenty-First Century Lever.* Washington, D.C.: National Academy Press.

gradual growth and diffusion in use of computers and communications technologies. Computers facilitated growth in services because they not only fueled IT-based services (e.g., telecommunications, systems integration) but also combined with communications to fuel growth in service-type activities based on information collection, processing, and use within goods-producing industries.[21] Innovations in IT and its applications revolve around better or more effective use of more and more information. This characterization applies as much to the contributions of IT to automotive and aerospace manufacturing or agriculture as to new "edutainment" businesses, proliferating online information and trading services, and other efforts often aggregated as electronic commerce.[22]

E-commerce and other manifestations of the new economy can be seen in many mainstream firms and industries, both in interactions with consumers and, increasingly, other businesses. E-commerce is achieved through infrastructure providers (the companies that provide the Internet services and related systems and/or their underlying facilities), integrators (which combine physical infrastructure with operating and applications capabilities), and a variety of applications providers, which may be free-standing or part of an existing business; who does what to make a given e-commerce application possible cannot always be predicted. The applications may include so-called portals, which aggregate access to different kinds of information and activity; auctions and exchanges; content publishing; supply-chain management and distribution; wholesale and

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[21]See Computer Science and Telecommunications Board, 1993, *Information Technology in the Service Society*. As that report discussed, growth in IT use was associated with growth in service activity, but service industry productivity lagged, in part because of the difficulties of learning how best to use the technologies and in part because of the time needed to work through concurrent shifts in industrial organization. See also Wolfe, Edward N. 1996. *The Growth of Information Workers in the U.S. Economy, 1955-1990: The Role of Technological Change, Computerization, and Structural Change.* New York: C.V. Starr Center, New York University.

[22]E-commerce impacts are often described in sweeping terms. For example, one market research report asserts that "eBusiness is remaking the business world by:

- Redefining virtually every business process and function.
- Changing conventional concepts and rules about strategic alliances, outsourcing, competition, industry specialization, and customer relationships.
- Creating a wealth of information about customers, enabling businesses to anticipate and satisfy individual needs (one-to-one marketing).
- Blurring the lines between industries (convergence).
- Challenging every business to reinvent itself and move to a "clicks and bricks" model.

See Ross, Eric M., and Adam C. Liebhoff. 1999. *eBusiness Innovators: Navigating the Digital Economy.* New York: CIBC World Markets, Equity Research, December, p. 4.

retail sales; and a variety of other online services.[23] Some business analysts have begun to argue that e-commerce is a step on the way to more comprehensive application of IT: "e-business"[24] (sometimes written eBusiness). As the list of included players and activities for e-commerce (or e-business) grows, it is clear that IT work is only part of the work being generated.

E-commerce may add to existing products and product-distribution channels—and therefore employment—or replace them, but it is a mistake to see e-commerce as the exclusive province of new businesses. Instead, it is part of the transformation of the economy as a whole that is associated with contemporary IT. This can be seen in the efforts of such mainstream companies as GE to incorporate the Web into all of its businesses, as well as the struggles of the publishers of the Encyclopedia Britannica to respond to the abundance of information available online. And because that transformation is so pervasive, it is harder to understand, measure, and describe than if it were limited in scope. For example, e-commerce raises questions about the extent of disintermediation and the number of viable specific trading exchanges that can actually be sustained in different industries;[25] the more diffuse concept of e-business raises questions about the broad impact of greater and deeper interconnection among businesses (and other organizations). Answers will affect the shape and size of many industries and firms—and therefore their employment prospects. These answers are very hard to predict at a time when, for example, online retail was estimated to be about 1 percent of retail sales in 1999[26]—IT industry executives and business analysts argue that we are on the threshold of a change that cannot yet be measured.

Broad-scale economic shifts imply broad-scale social change. Some of that change is evident in the workforce at large. The proliferation of IT as a tool in a wide range of jobs implies a concern about relevant skills—and about the ability of people whose skills are subject to lower levels of demand to adopt new skills involving the use of IT—that is beyond the

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[23]See, for example, William Blair & Company. 1999. *Business-to-Business Internet Research*. Chicago: William Blair & Company LLC. Also, Redmond, Roger W., and Linda M. Courtney. 2000. *Enterprise Applications Converge with the Web*. Minneapolis: Goldsmith-Agio-Helms, June.

[24]See, for example, Truog, David, et al. 2000. *eBusiness Networks*. Cambridge, Mass.: Forrester Research, April.

[25]See, for example, Banc of America Securities. 2000. *B2B E-Commerce: Technology Industry Overview*. San Francisco: Banc of America Securities LLC, January 3.

[26]See Redmond, Roger W., and Linda M. Courtney. 2000. *E-Commerce in the New Millennium*. Minneapolis: Goldsmith-Agio-Helms, May, p. 8. These analysts go on to say that online retail will be dwarfed by e-business (including business-to-business interactions).

scope of this report but has been covered in others.[27] Some of it is evident in the incorporation of IT into noneconomic activity—social interactions (most obvious today in such applications as e-mail or online chat), entertainment (e.g., online games, online music and video, Web sites for various hobbies), and civic or political exchange (e.g., list-serv distribution of newsletters and focused Web sites). The spread of broadband access to the Internet from homes will increase the capability for systems to be always on, which is expected to increase the amount of use and change the kind of use to include more automated activities (i.e., those that meet individuals' needs without their having to engage directly with a device to make something happen). The potential for social change is less well understood (or studied) than the potential for economic change,[28] but it may itself generate new economic activity, as today's experimentation with Web businesses to support noneconomic activity suggests. Indeed, a major change beginning in the late 1990s from previous decades is the emergence of technology transfer from personal contexts to business applications rather than the other way around.[29]

1.3.4 IT as a Policy Driver

The emergence of IT as a major input into the economy contributes to the rise of numerous public policy concerns about IT. Some of these concerns have deep roots, such as national security, into which IT plays in many ways (for example, it is an enabler of new military strategy and tactics[30]) and regional economic development (for example, numerous regions seek to emulate or complement Silicon Valley). Many more popu-

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[27]See, for example, McConnell, Sheila, et al. 1996. "The Role of Computers in Reshaping the Work Force," *Monthly Labor Review* 119(8):3-56. Of course, even before broad use of computers, concern about job impacts from automation surged in the 1960s, leading to a congressional commission; in the early 1980s job displacement from computerized manufacturing automation triggered similar concerns. In both cases, economic growth led to employment growth that offset displacement numerically, although displaced individuals did not necessarily shift easily to new jobs.

[28]CSTB has recommended a program of research to address the broad range of economic and social impacts of IT, anticipating the new interest of computer science research programs in addressing such impacts. See Computer Science and Telecommunications Board. 1998. *Fostering Research on the Economic and Social Impacts of Information Technology*. Washington, D.C.: National Academy Press.

[29]See Computer Science and Telecommunications Board. 1995. *Keeping the U.S. Computer and Communications Industry Competitive: Convergence of Computing, Communications, and Entertainment*. Washington, D.C.: National Academy Press.

[30]See, for example, Computer Science and Telecommunications Board, National Research Council. 1999. *Realizing the Potential of C4I*. Washington, D.C.: National Academy Press.

lar IT policy concerns, such as online privacy, are comparatively new, reflecting the relative recency of an IT mass market, the growing impact of IT use on people's lives, and the combination of experimentation and inexperience that characterizes many Internet-based ventures. Some of these concerns are associated with the prospects of regulation, often associated with consumer protection and avoidance of fraud or safety hazards. Some are associated with new conflicts associated with property rights as transactions and resources shift from the physical to the virtual; the policy wrangling associated with intellectual property on the Internet is emblematic.[31] Some reflect differences in population groups that use IT, notably inequalities in access to the Internet that have been popularized as a "digital divide." And some reflect the growing importance of IT to the work of the government at various levels: "e-government" and "digital government" are terms that describe how IT is transforming both intra- and intergovernment interactions and the interactions of individuals with the government.

Many issues are compounded by their international flavor: the global nature of the IT sector (and many IT uses) implies trade policy, antitrust policy, and other areas where U.S. policy interests may need some reconciliation with those of other countries. In the last few years, for example, the European Union has influenced U.S. approaches to online privacy, and U.S. officials have negotiated with officials in many countries on harmonization of laws and procedures for handling computer crime. Although discussion of employment highlights immigration policy, that is just one of the international issues addressed by policymakers that may influence demand and supply for information technology workers.

Because of broadening policymaking attention to IT there is a growing body of policymakers scrutinizing how IT is used and in some cases how it is made, either or both of which can have an influence on the future shape of IT industries and the supply and demand for IT goods and services. There are occasional attempts to integrate governmental attention to IT policy concerns—for example, a variety of intragovernmental working groups and congressional hearings have addressed e-commerce and the digital economy beginning in the late 1990s—but many IT-related policy concerns are being pursued more or less separately by more and more governmental organizations. This situation is another part of the backdrop for policymaking relating to the IT workforce: different kinds of policy action can affect the costs of producing and/or using IT, the

[31]See, for example, Computer Science and Telecommunications Board, National Research Council. 2000. *The Digital Dilemma: Intellectual Property in the Information Age*. Washington, D.C.: National Academy Press.

nature of features that are provided, and so on, influencing the market for IT and therefore the demand for IT workers. Effects will be experienced in short and long terms, depending on the nature of the policy intervention.

The full policy context, of course, extends beyond those policies aimed more or less directly at IT to include those aimed at the economy at large. Recent attention to the observations made by Federal Reserve Chairman Alan Greenspan, for example, links his comments about the impact of IT on the performance of the economy to the potential for macroeconomic policy (such as changes in interest rates) to affect the overall climate for investment, which would affect demand for IT and IT workers as well as other quantities.[32] Although this report focuses on IT and IT workers, it is written with the recognition that IT interacts with other factors in the economy and that IT workers are counted in the context of a large, multi-occupational labor force.

1.4 WHY ASSESS IT WORKFORCE ISSUES NOW?

The IT sector is a major player in U.S. labor markets, beyond what simple counts suggest. For example, the Department of Commerce reports that employment growth in IT-producing industries outpaces average employment growth.[33] From 1989 to 1997, employment in IT-producing industries grew 2.4 percent annually compared with the 1.7 percent annual rate of growth for all private industries. Between 1996 and 1997, IT-producing industries experienced a 1-year increase of 7.7 percent in employment (to 4.8 million) compared with average employment growth of about 3 percent. Most of this growth has occurred in the IT software and services subsector of this category, in which employment grew at an average annual rate of 8.3 percent.

The "computer services" segment of the IT sector (including the packaged software industry, applications and systems consulting, information retrieval services, and other related activities) accounts for about 27 percent of those that the Current Population Survey (see below) identifies as computer scientists, systems analysts, and computer programmers. But as important as the IT sector is for employment, IT-intensive industries are the numerically dominant users of IT talent. Apart from the IT sector, other large users of similar IT talent include manufacturing (18 percent of those employed as computer scientists, systems analysts, computer engi-

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[32]See, generally, <http://www.federalreserve.gov/boarddocs/speeches/2000/>.

[33]Henry, David, Patricia Buckley, Gurmukh Gill, Sandra Cooke, Jess Dumagan, and Dennis Pastore. 1999. *The Emerging Digital Economy II*. Washington, D.C.: U.S. Department of Commerce, June. Available online at <http://www.ecommerce.gov/ede>.

neers, and programmers), finance and related industries (11 percent), retail and wholesale trade (7 percent), and government (9 percent).[34]

Though a shortage of technical professionals has been reported in a number of fields over the last 20 years, concerns about tightness or shortage in the IT labor market appear to have emerged in the late 1990s. ("Tightness" in the labor market refers to a condition in which it is difficult for employers to find qualified workers, and is discussed in greater detail in Chapter 3.) Given that personal computers began to appear on desktops in the early 1980s, and the price/performance ratio of information technologies has been dropping steadily over this time, why would information technology labor market concerns have emerged in the late 1990s?

Many developments came together in the mid-1990s, in the context of a strong economy, to generate strong growth in demand for IT and IT innovation in the mid- to late-1990s. Of special note is the transformation of the Internet from a network supporting research and education to a medium of enormous commercial and business significance. The potential of the Internet to support commercial and business ventures is largely unknown and unexplored, but the potential appears to be vast. For this reason, it is not surprising to see a high demand for IT workers who can exploit the Internet effectively. Furthermore, the Internet seems to have catalyzed a more general interest in information technology to change how businesses can seek competitive advantage. The easing of a tight labor market is needed to prevent the loss of opportunities for IT and IT-intensive firms in the United States in a globally competitive economy.

Today's picture is different from that of the last National Research Council examination of the IT workforce—a modest examination that flagged qualitative concerns that persist, such as the evolution of the occupational mix, but concluded, in 1993, that at that time supply and demand for IT workers seemed more or less in balance.[35] The outlook as this report is written is different, not merely because more, and more kinds, of IT are in use, but because of the corresponding economic impacts, evident as industrial growth and transformation, increasing personal use of IT, and a broad perception that IT provides critical infrastructure on which the economy depends. The committee is mindful of the tension between the economic momentum of the period in which it worked and

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[34]Bureau of Labor Statistics, Industry/Occupation Matrix, baseline data for 1996, as seen on the United Engineering Foundation Web site at <http://www.uefoundation.org/report1.html>.

[35]Computer Science and Telecommunications Board. National Research Council. 1993. *Computing Professionals: Changing Needs for the 1990s.* Washington, D.C.: National Academy Press.

the recognition that no boom-time is indefinite; it drew on various inputs and its own expertise to craft a report that assumes, on balance, continued growth and vitality associated with IT production and use.

There are higher stakes in effective IT production and use, and there is broader distribution of those stakes among government, various industries, organizations, and the general public, than were evident in the early or mid-1990s. The proliferation of government meetings and inquiries on e-commerce, online privacy and security, the digital divide, IT-related trade and employment, proposed IT industry mergers, and other IT policy arenas is symptomatic. So, too, is the rise in lobbying and advocacy by a wide range of groups concerned about the role of IT in the economy and who benefits from it. Industry-based groups have become more numerous; more IT companies have established Washington, D.C., offices; more IT-related issue-advocacy groups have sprung up; and traditional consumer advocacy and labor groups have embraced IT policy concerns along with their other concerns.[36] Thus, IT is becoming more politicized. This factor shows up in issues that underscore a change in the image of IT: originally cast as a performance and productivity tool, it is now being scrutinized as a factor in quality of life, economic opportunity, and even the democratic process itself.

The politicization of IT implies that more statements are being made about more topics by professional advocates. It is in the nature of advocacy that messages are often simplified in the interests of effective and efficient communication. That reality has been in evidence in the debates over H-1B visas, discussed in Chapter 5, which motivated the request for this report. This report is designed as an antidote to advocacy statements: it characterizes the complexity of the issues, presents numerous and sometimes conflicting sources of information and perspectives, and describes where information is adequate for making certain judgments and where it is not. It is intended to be a primer on a large, complex, and interrelated set of issues, responding to a charge from Congress (described in the preface). It presents tools for thinking about this set of issues, recognizing that answers to specific questions may arise from politics as much as from analysis.

1.5 ORGANIZATION OF THIS REPORT

Part I of this report is devoted to examining the entire issue space. In this part, Chapter 1 describes in broad terms the IT sector: technological drivers, changes in the business environment, structural factors at work

[36]Of course, newer efforts are often labeled as relating to the Internet, the effective mascot for the larger corpus of IT.

in the IT sector, the IT sector's increasing globalization, and future trends in IT. Chapter 2 characterizes the IT workforce: the nature of IT work, who counts as an "IT worker," what the intellectual and knowledge requirements for IT work are, how big the IT workforce is, and the IT work environment. Chapter 3 frames workforce problems in IT in context, looking at reports of difficulty in hiring and the corresponding inference of a worker shortage. It then describes the committee's view of the problem, and comments on segmentation in demand for IT workers. Finally, it makes projections to the future.

Part II addresses various dimensions of relieving difficulties in hiring and related issues. Chapter 4 deals with age-related concerns as an aspect of today's tightness in the IT workforce. Chapter 5 focuses on concerns regarding the use of foreign workers in the U.S. IT workforce, a concern that reprises older and earlier debates over the appropriate role of foreigners in the labor force and their impact on the U.S. economy. Chapter 6 addresses a variety of approaches that individual companies can take to make more effective use of workers and job applicants that they already have. Chapter 7 addresses ways of expanding the number of people willing and capable of doing IT work. Focused mostly on education and training, such expansion is mainly a long-term approach to the problem of tightness in the IT workforce.

Part III consists of a single chapter—Chapter 8—that is a synthesis of the entire report. Chapter 8 also provides principles for action and recommendations for the various stakeholders.

2

Understanding the IT Workforce

2.1 WHO IS AN IT WORKER?

As noted in Chapter 1, "information technology" is a broad term encompassing computer and communications technology. For purposes of this report, the committee is concerned about IT workers based on what they do. Specifically, IT workers are those persons engaged primarily in the conception, design, development, adaptation, implementation, deployment, training, support, documentation, and management of information technology systems, components, or applications. In addition to "computer occupations" described by the (mostly software) job categories of the Bureau of Labor Statistics (i.e., computer programmers, computer scientists, and systems analysts), this definition includes:

- Persons who design, install, upgrade, or maintain and support IT hardware, including computers, switches, routers, and chips with a digital aspect to their operation;
- Persons who design, author, adapt, test, implement, maintain, or support software or databases;
- Persons who install, configure, support, maintain, or utilize "back office" systems and applications for use by those who interact directly with these systems for business purposes;
- Persons who design, develop, document or train on, or implement computer-based business solutions for clients;

- Persons undertaking software-based enterprise resource planning or just-in-time inventory control and systems integration;
- Persons who write software code for embedded systems such as hand-held, palm-top devices or equipment controllers;
- Persons who develop design tools, simulation, and IT-intensive systems for the delivery of electronic content;
- Persons who are responsible for testing, documentation, or configuration management; and
- Persons who directly manage IT workers.

Box 2.1 lists some sample titles of IT workers. Excluded are persons who work primarily with "front office" or end-user applications that are necessary to job functions not included in the above definition. For example, most office workers use word processors and spreadsheets, but they would not be considered IT workers in this definition.[1] Help-desk personnel and technicians who install the PCs, networks, and software applications would be included.

The committee has a number of reasons for choosing a definition based on what people do.

- To the extent that IT is a pervasive enabling technology that requires expertise to implement or to apply to specific business problems, IT workers are necessarily found in all sectors of the economy, not just the industries

[1]The reason for such an exclusion is that "users" of IT—even heavy users—use IT for purposes that are secondary to their jobs. In other words, users of IT generally use IT in support of other job functions that are not related to IT per se. The business manager of an office may use spreadsheets in an extremely sophisticated manner, and the intellectual skills used may be those that characterize highly skilled programmers, but the primary purpose of his or her use of spreadsheets is to manage budgets in support of an office. By contrast, a Web page designer is included, even though his or her work relies in a similar way upon the use of Web authoring tools, because the primary purpose of the job is the management of IT-enabled electronic content. Also, workers such as the business manager described above are not generally the focus of concern that led to the commissioning of this report. Nevertheless, it must be acknowledged that distinguishing between the class of workers instantiated by business managers (excluded from the definition of "IT workers") and the class instantiated by Web page designers (included in the definition of "IT worker") is somewhat arbitrary.

An additional complication arises when dealing with IT hardware. A semiconductor firm manufactures chips and integrated circuits for others to integrate into finished IT hardware systems. But a semiconductor manufacturing plant requires chemical engineers and process control engineers and materials scientists to design and maintain the production line. Such individuals are as critical to the semiconductor industry as are the designers of integrated circuits and microprocessors, but they are not what one might usually imagine when considering the term "IT worker." The committee had no access to data relevant to such ambiguities, and thus such individuals are omitted from the analysis.

BOX 2.1
Sample Titles of IT Workers

Analyst
Animator
Applications analyst
Applications developer
Circuit design engineer
Communications engineer
Computer-aided design specialist
Computer hardware engineer
Computer operations manager
Computer programmer
Computer science teacher, postsecondary
Computer security specialist
Computer software engineer
Computer systems analyst
Data analyst
Data warehouser
Database administrator
Database manager
Design engineer
Document specialist
Help desk technician
Integrated circuit design engineer
Media specialist
Microprocessor design engineer
Network administrator
Network engineer
Network technician
PC support specialist
Program manager
Programmer/analyst
Project manager
Software developer
Software engineer
Software quality assurance specialist
System architect
Systems administrator
Systems analyst
Systems engineer
Systems integrator
Technical writer
Telecommunications systems engineer
Telecommunications technician
Two-dimensional/three-dimensional artist
Web manager and Web administrator
Web page developer

responsible for creating and developing IT. Thus, a definition based solely on industry of employment is inappropriate.

- To the extent that IT work does not require a formal background in information technology or computer science (and this extent is considerable), IT workers have a wide variety of educational backgrounds. Thus, a definition based solely on educational pedigree is inappropriate.
- To the extent that job titles do not reflect what IT workers actually do from day to day, job titles are inadequate. Indeed, IT work in the IT sector and in IT-intensive firms is much more varied for a given job title than in some other sectors such as construction or manufacturing. Thus, a definition based solely on job titles may not fully capture all IT workers of interest to the committee.

Unfortunately, however, there do not exist data that identify workers based on what they do, although data do identify workers' industry, education, and/or job title. For this reason, and because job titles are developed as an attempt to capture what workers do, IT workers are in this report identified primarily based on their job title or occupation. Nevertheless, the committee recognizes that job titles often mask wide variation in what actually happens on the job for many workers.

2.2 THE NATURE OF IT WORK

The nature and scope of IT work are highly diverse. All IT work draws to some extent on core or foundational knowledge, acquired either formally through classroom training or circumstantially through contextual application. Future development of IT workers at every level requires mastery of this core knowledge, often referred to as "IT literacy" or "IT fluency." For example, IT workers must generally have some facility with applications programs such as word processors, e-mail, Web browsers, and spreadsheets. They must also understand the basic purpose or application of algorithms, digital representation of information, and the basic technical aspects, features, and limitations of information technology systems.

Most IT jobs require a mix of conceptual ability, knowledge of theoretical IT constructs and frameworks, and applied technical skills. The mix depends on the extent to which the job requires creativity and the invention of original work as compared to application of previously developed skills in typical situations.

2.2.1 Category 1 Work

It is helpful to distinguish between two different types of IT work.

Category 1 work involves the development, creation, specification, design, and testing of an IT artifact, or the development of system-wide applications or services; it also involves IT research. Such work involves conceiving of and sketching out the basic nature of a computer system artifact, or conducting research and development leading to new approaches to hardware and software. Category 1 work relies heavily on conceptual ability and theoretical knowledge, and also involves high creativity, self-discipline, and logical thinking, and often the ability to translate business and organizational needs to hardware and software systems specifications. Some job titles associated with primarily Category 1 work include computer scientist, entrepreneur, product designer, research engineer, systems analyst, computer science researcher, requirements analyst, system architect, system designer, programmer, software engineer, tester, computer engineer, microprocessor designer, and chip designer.

Category 1 work results in the creation of a new product, service, or application, or even a new technology. But creation of new products, services, and applications has aspects of both conceptualization and implementation. For conceptualization, cognitive skills of evaluation, judgment, and synthesis are crucial. The conceptualization of an IT product or service is dependent on human insight and understanding, and the constraints within which a conceptualizer must work are limited only by imagination and the understanding of the problem to be solved.

Category 1 work is often too complex to be performed by one person. Also, the path from determining a requirement to developing a product or service is not entirely sequential, and the events are not independent. An apparently small change in a functionality requirement, for instance, may result in big performance penalties. Providing more convenience features for users might create inadvertent security issues. Therefore, the ability of Category 1 people to work in teams, develop appropriate specifications, communicate effectively, visualize and anticipate, develop creative and original solutions to unique problems, and produce to specification in a timely manner in a rapidly changing technical environment is paramount. Category 1 work is therefore sometimes likened to playing music in ensemble. Not only must each person be extremely competent in his or her own right, but each must also understand the work of the other members of the team, and all must "play together."

Finally, Category 1 work usually requires an individual to be able to manage complexity well. Today's IT systems are very complex artifacts, involving large amounts of highly sophisticated code, and the ability to maintain a good mental model of the relevant parts of a system—and how they interact with each other—is highly valued.

2.2.2 Category 2 Work

By contrast, Category 2 work primarily involves the application, adaptation, configuration, support, or implementation of IT products or services designed or developed by others. In general, Category 2 work also requires the ability to support technical systems and to communicate with both equipment vendors and system users. Category 2 work relies heavily on technical skills related to specific platforms or applications software, and the ability to do Category 2 work depends on high levels of technical knowledge especially in areas of configuration, maintenance, installation, functionality, and system capabilities or constraints. Category 2 work entails an understanding of how applications are used, what conflicts might arise from coexistent applications, and how to work around system-imposed limitations and the capabilities of users. Category 2 work may entail the ability to use the end-user programming capabilities provided by the IT artifacts in question. And Category 2 work requires a knowledge of the business context in which the work is done. Some job titles associated with primarily Category 2 work include system consultant, documentation writer, customer support specialist, help desk specialist, hardware maintenance specialist, network installer, and network administrator.[2]

Category 2 work often demands well-developed problem-solving and troubleshooting capabilities. Individuals doing Category 2 work are the first (and often the only) resource when users have problems with applications or hardware. They are expected to size up the problem quickly, make correct judgments about the set of most likely solutions, and help test these solutions systematically until the problem is remedied. Hypothesis development and testing, good interpersonal skills, and excellent communication skills are a must for this work, and a well-developed understanding of and experience with typical problems and likely problem fixes enhances the value and productivity of Category 2 workers.

2.2.3 The Interaction Between Category 1 and Category 2 Work

Both IT-sector and IT-intensive firms require employees who do both kinds of work, although the mix may differ. For example, software-producing companies would be expected to employ individuals doing a great deal of Category 1 work—senior-level programmers, applications

[2]In addition to the technical support they provide, these individuals are often the point of contact for management on IT issues because they have day-to-day exposure to an organization's information technology infrastructure. Thus, they may find themselves part of the decision process, helping to determine whether, when, and how new applications are to be deployed. As a result, they can be important conduits for organizational learning.

developers, software designers, and testers, all of which are critical to their core mission. However, they might outsource maintenance of their computers or administration of their corporate Web site to a third-party service provider, who would employ many individuals doing Category 2 work.

Both Category 1 and Category 2 work are themselves highly differentiated. In Category 1, for example, development of software tools (e.g., programming language environments) that will be used by others to develop their own applications is different from the development of those applications themselves. Category 2 work also covers a wide range of work, and so, for example, troubleshooting a new network installation with hubs, routers, and servers requires significantly more technical knowledge and problem-solving ability than does stepping a user through a flowchart to figure out why a PC modem won't dial. As a general rule, two individuals with the same job title may well require different skill sets and background knowledge.

Implementation is an aspect of IT work that straddles the border between Category 1 work and Category 2 work. As described above, Category 1 work involves the specification of performance requirements that reflect an understanding of what an IT artifact is supposed to do. Implementation, which can be regarded as work that simply creates an IT artifact designed by another party, thus is arguably Category 2 work.

Implementation is also medium-dependent. For example, implementation of an IT artifact may need to be done in a specific programming language or for a particular database management system. Thus, implementation-related skills change as rapidly as the implementation medium changes, i.e., as fast as the underlying information technology evolves. And it is the case that exceptional technical knowledge is often needed for implementation. The development of new or faster operating system kernels, for instance, must occur with detailed knowledge of the architecture of the microprocessor on which the system will run. New processor design must occur in the context of the applications for the device. New applications must be developed with very detailed knowledge of user requirements, platform capabilities, and functionality issues. Systems integration work requires the ability to form clear pictures of how different components could fit together, the ability to anticipate what the interface issues might be, and knowledge of what the possible benefits or penalties of different options might be.

To the extent that the underlying information technologies are "backwards-compatible," learning of new skills is not especially necessary to implement the same product conceptualizations in the same way. But learning of new skills is always needed to take advantage of new features or capabilities enabled by improvements in IT. For example, the speed of microprocessors has increased by an order of magnitude over the past several years. Faster microprocessors enable new applications and functionality (e.g., speech recognition). Developers who wish to take advantage of newly available speech recognition capabilities enabled by faster microprocessors must clearly learn new skills. And, as the disparity between processor speed and secondary memory speed has increased, the consideration of techniques to lessen memory access and to manage and exploit memory hierarchies has become much more important and has made many software system design problems much more difficult. Because the skills needed for implementation can change with the technology, implementation can seem like Category 2 work.

At the same time, the implementation of an IT product or service can require creativity and innovation. A variety of ways of implementing a given concept are possible, and these possible implementations differ considerably with respect to various dimensions of quality (Box 2.2), leaving a wide variation in the range of solutions that individual implementers will develop. In general, a very productive implementer is probably able, in the same amount of time as a less productive worker, to develop an implementation that is more robust, has more functionality, is easier to change and evolve, and overall embodies more of the "ilities" (e.g., flexibility, reliability, security).

Furthermore, requirements specification and implementation do not necessarily proceed sequentially. Indeed, for the most part they do not proceed sequentially, but are rather highly intertwined. Nor are they independent of each other; sometimes, a small change in performance requirements can have a large impact on the ease or difficulty of implementation. And finally, because there are in general many different ways to implement a given specification, implementation can also involve considerable technical judgment and creativity. In this way, it is more like Category 1 work.

2.2.4 Category 1 and Category 2 Workers

Any given IT worker is likely to do work that involves a mix of Category 1 and Category 2 work. A good example is individuals who can be characterized as modifiers or extenders (e.g., maintenance programmers, programmers, software engineers, computer engineers, database administrators), who modify or add on to existing information technology artifacts. In the software domain, they write code based on design created by others, and they modify or tailor software to meet specific user needs. Note also that Category 1 and Category 2 work both entail a need for skills in problem solving, time management, and interpersonal relationships.

BOX 2.2
Productivity Variations in Software Developers

In the software domain, there appears to be considerable variation in the productivity of software developers. The landmark study in this area, published in 1968,[1] showed variations of more than 20 to 1 in the time required of programmers to solve particular programming problems. In addition, the fastest programmers developed programs that had fewer errors and were more efficient in both running time and utilization of memory than those of their counterparts. Thus, the fastest programmers were arguably more effective than would be indicated by their problem-solving speed alone. The results of other, more recent studies[2] are consistent with the results of the Sackman study.

Some detailed insight is provided in a study by Lutz,[3] who found that the median program written by the top half of a group of graduate student programmers was 30 times as efficient as the median program written by the bottom half of the group (as measured by run time and memory use; the programming problem involved the conversion of telephone numbers into word strings). Further:

- The time used by the various programmers to code the programs varied by a factor of 20.
- The quality of a program was far more dependent on who coded the program than on the language in which it was implemented.

Findings such as these—quite consistent over a wide range of studies—suggest that employers of IT workers have considerable incentives to find the most productive personnel.

Measuring the quality of software produced can be problematic. One key reason is that such measures can generally account only for how a given set of requirements has been implemented in software—and not for whether those requirements capture any kind of functionality that is useful or helpful to users. Related is the fact that systems that have been tightly optimized for performance are often very difficult to change. Conversely, systems designed in a flexible manner almost always exhibit suboptimal performance. A second reason is that some measures of program quality may not be particularly valuable in the marketplace. For example, run time or resource usage may be less significant when the hardware on which programs run can provide rapidly growing increases in speed and resources such as memory. At the same time, software producers who wish to develop products that will run on a large installed base of hardware cannot exploit such growing resources fully, simply because many of their target platforms will not be new.

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[1]Sackman, H., W.J. Erikson, and E.E. Grant. 1968. "Exploratory Experimental Studies Comparing On-line and Off-line Programming Performance," *Communications of the ACM* 11(1):3-11.

[2]Bryan, G. Edward, 1997, "Not All Programmers Are Created Equal," in Richard Thayer, *Software Engineering Project Management* (second edition), IEEE Computer Society; Curtis, William, 1981, "Substantiating Programmer Variability," *Proceedings of the IEEE,* July; DeMarco, Tom, and Timothy Lister, 1985, "Programmer Performance and the Effects of the Workplace," pp. 268-272 in *Proceedings of the 8th International Conference on Software Engineering*, IEEE Computer Society Press, August.

[3]Prechelt, Lutz. 1999. "Comparing Java vs. C/C++ Efficiency Differences to Interpersonal Differences," *Communications of the ACM* 42(10).

The fact that most IT workers engage in a mix of Category 1 and Category 2 work means that the boundary between Category 1 and Category 2 workers is fluid. Category 1 and Category 2 work are differentiated by the amount of formal education required, the degree to which conceptualization and invention apply to the core tasks, and the complexity of the tasks or the number of system components to be integrated. But people entering IT through Category 2 work have opportunities to acquire the additional higher education (through evening, weekend, and online courses) and experience to qualify for Category 1 jobs. Furthermore, the culture of IT work is one in which education and training, as well as experience, are richly valued intrinsically and well rewarded monetarily.

For example, a small company with straightforward networking requirements would usually be able to meet its needs for the design, installation, and administration of a local area network (LAN) with workers who do primarily Category 2 work, because the requirements would fall within the conventional application parameters already anticipated and set forth by the hardware and software providers. However, expertise with such Category 2 work would provide a foundation for such workers to move to the design and management of enterprise-level LAN/WAN (wide area network), Web, or e-business applications that involve a large number of system components, a high level of risk, a large number of users, high data volumes, and a number of mission-critical and specialized applications. Such endeavors would naturally entail a greater degree of Category 1 work.

A similar situation might pertain to programming and software engineering. Category 2 work in this area would typically involve the routine job of writing code to specifications developed by designers, or modifying existing code to fix bugs in the software. Expertise in such work would provide a good foundation on which to develop further expertise with Category 1 work in this area, which might entail developing the specifications for the program itself, or authoring software tools for other programmers to use in producing end-user applications.

The close coupling of innovation and application is common in IT. The constant drive on the part of IT users to exploit new applications, or upgrade to the latest version of current applications, constantly challenges individuals doing Category 2 work, and staying current technically on the new features and attributes of applications software and network operating systems is important to such individuals. Thus, the coupling between innovation and application creates a robust array of career pathways that can lead to rapid advancement.

For ease of discussion, this report defines Category 1 workers as individuals whose responsibilities involve a greater amount of Category 1 work relative to Category 2 work, and Category 2 workers in the opposite manner. Both are essential to the IT sector and IT-intensive firms. Category 2 workers, who work primarily at the applications and user level, would have nothing to apply if there were no software developers or engineers, no system integrators or analysts, no one to develop new hardware, or no one to pioneer new languages or applications. (One need only look at the boost Java has given the Web applications for proof of this.) Commensurately, there would be little economic justification for investing in the Category 1 work if new developments could not be moved rapidly to users and effectively applied—the purview of Category 2 workers.

2.3 INTELLECTUAL AND KNOWLEDGE REQUIREMENTS

2.3.1 Formal Education and Type of IT Work[3]

Category 1 work generally requires more years of formal education in IT-related disciplines than does Category 2 work. Some Category 1 work (algorithm design, for example) requires mathematical concepts and skills. Research on and development of new technologies and new products require a high level of specialized technical knowledge and skills, grounding in research methods, and access to research facilities. Other Category 1 work needs people with well-developed conceptual and abstract reasoning ability. Systems integration, systems analysis, and network design, for instance, require persons who can visualize outcomes, anticipate problems, and manage projects, budgets, and people.

Historically, different kinds of formal education have been needed for different kinds of Category 1 work. Research in IT generally requires post-baccalaureate degrees in an IT-related field, as do certain types of development work (e.g., the development of software tools for use by others doing Category 1 work). But the general benefits of higher education (systems thinking, ability to generalize, abstract reasoning) have often enabled persons with baccalaureate degrees in disciplines ranging from mechanical engineering to music to be effective in many areas of Category 1 work, especially in IT-intensive firms. (The extent to which this historical trend will continue into the future is discussed in Chapter 7.)

Category 2 work involving installation, maintenance, repair, or modification of an IT artifact generally requires skills that are based more on the specific characteristics of the particular software or hardware than on

[3]This subsection draws on information in Freeman and Aspray (Freeman, Peter, and William Aspray. 1999. *The Supply of Information Technology Workers in the United States*. Washington, D.C.: Computing Research Association. Available online at <www.cra.org./reports/wits/>) and in NWCET materials.

abstract concepts and theoretical knowledge. Thus, Category 2 work often requires an associate's degree, professional/technical or vocational certificate, and/or vendor certification. Some Category 2 jobs are available to graduates from high school technical programs, but more commonly technically oriented high school graduates pursue additional education at a community or technical college.

These variations in the amount of formal education that is typically required for certain types of IT jobs affect the speed at which new supplies of IT workers can be provided. A significant increase in the supply of Category 1 workers is likely to take at least several years (i.e., the time needed for large numbers of these individuals to matriculate). Because Category 2 workers tend to require less formal education in IT, training efforts for these workers can—in principle—bear fruit in a matter of months, and jobs in Category 2 have been more open to people without formal education in the field but with experience.

2.3.2 Core Knowledge and Abilities for IT Work

Given the wide variety in IT occupations and the importance of "tacit" knowledge developed in the workplace, education and training programs for future IT workers should be designed to enhance flexibility. Individuals will have that flexibility if their initial education and training help them to develop a set of "core" or foundational IT knowledge and abilities. With this core knowledge as a foundation, workers can more easily develop additional skills related to particular technologies and/or occupations.

Several recent studies have attempted to identify the core knowledge and abilities needed for most kinds of IT work (in both Category 1 and Category 2). Although they differ slightly, the studies converge on the following list:

1. Intellectual abilities,[4] including the ability to
- Define and clarify a problem, and know when it is solved;
- Understand the advantages and disadvantages of apparent solutions to problems;
- Cope with unexpected consequences and troubleshoot;
- Think logically and reason quantitatively;[5]

[4]Computer Science and Telecommunications Board, National Research Council. 1999. *Being Fluent with Information Technology*. Washington, D.C.: National Academy Press.

[5]Adelman, Clifford. 1999. *Leading, Concurrent or Lagging? The Value of IT Education in IT Careers*. Washington, D.C.: U.S. Department of Education, p. 11.

- Observe, and learn from one's observations;[6]
- Conceptualize, gather, organize, and analyze data; and
- Manage complexity.

2. Understanding of basic concepts supporting IT, including
- Algorithms and finite mathematics,
- How information is represented digitally, and
- Basic concepts of physics and electronics (if hardware is involved).[7]

3. Social abilities, including
- Communications skills,
- Teamwork,
- An understanding of one's own personality and learning style, and
- Translation competency (the ability to translate between the world of technology and the world of IT users).

In addition to these core or "enduring" skills, IT workers will require varying degrees of knowledge and skill in different types of technology. As IT continues its rapid pace of change, some of these more specific skills may only be required for short periods of time. This suggests a typology of skills for IT work (Table 2.1). Within both the "enduring" and "perishable" categories are skills that are "hard," or technological, and skills that are "soft," or more general.

2.3.3 The Role of Experience and Situated Learning and Knowledge

Formal education alone does not make a productive worker. In addition to the widely recognized explicit, or "formal" knowledge, all workers—including IT workers—also rely on implicit, or "informal" knowledge. Formal knowledge includes facts, principles, theories, algorithms, and so on. Because it is abstract, formal knowledge can be (and is) codified in the form of university textbooks, work manuals, and company policies. Most education and training programs are designed to enhance formal knowledge. Informal knowledge, on the other hand, is "situated" and includes work styles and "situated understandings about materials, tools, and techniques."[8] This knowledge is tacit and seldom recorded. It exists primarily

[6]Northwest Center for Emerging Technologies. 2000. *Skill Standards for Information Technology v2.0: The Millennium Edition Skill Standards*. Bellevue, Wash.: NWCET, p. 22.

[7]Northwest Center for Emerging Technologies. 2000. *Skill Standards for Information Technology v2.0*.

[8]National Research Council. 1997. Bonalyn Nelson, "Should Social Skills Be in the Vocational Curriculum? Evidence from the Automotive Repair Field," pp. 62-88 in *Transitions in Work and Learning: Implications for Assessment*. Washington, D.C.: National Academy Press.

TABLE 2.1 Types of Knowledge Required for IT Work

	Enduring	Perishable
Hard (technological)	Intellectual abilities, including logical reasoning and the ability to apply algorithms to solve problems	Knowledge of particular hardware or software languages or systems (e.g., COBOL, client servers, Java)
	Understanding of basic physics and electronics concepts supporting IT	
Soft	Social abilities, including the ability to learn from others and develop "tacit" knowledge	Knowledge of a particular company or industry
	Ability to translate between technology experts and users	
	Knowledge of basic business practices	

in the collective memory and work practices of a local "community of practice."

Cognitive scientists have found that expertise in many fields (including mathematics and computer programming) is "conditional"—it is based on the ability to quickly apply content knowledge in response to a situation or problem.[9] In this view, skills are an integral part of a social system (either at work, in school, or elsewhere), and skill requirements, distribution of work, and other factors are strongly influenced by the social context and cannot be defined in isolation. Learning and skills are "contextualized," and skills learned and used in one context may be difficult to transfer to another context. It is this problem of "contextualization" that makes some employers reluctant to hire IT workers (or any workers) based on their school grades or on successful completion of a training course.

Studies of IT workers illustrate the importance of this "informal" knowledge to effective job performance. For example, Lee's surveys and focus groups with IT workers indicate that "interpersonal communica-

[9]National Research Council. 1999. *How People Learn: Brain, Mind, Experience, and School.* Bransford, John D., Ann L. Brown, and Rodney R. Cocking, eds. Committee on Development in the Science of Learning. Washington, D.C.: National Academy Press.

tion accounts for the most important means of knowledge transfer in technological work."[10] Salzman finds that informal knowledge goes a long way toward helping individuals without college degrees or formal training in computer science to work in very technical areas.[11] Such recent findings reprise earlier studies conducted in the early 1990s, which also found that for personal computer support technicians and in-house database programmers in some companies, academic credentials for these individuals were neither required nor customary, and that half had no formal technical training. Instead, they gained—and used—contextual knowledge by solving problems, receiving informal coaching, and perhaps most importantly by listening to "war stories" that encode lessons learned by colleagues, discussing problems face-to-face with on-site colleagues, and sharing information through journals and computer networks with others off-site, forming a "community of practice."[12]

Another, more quantitative analysis illustrates the power of on-the-job learning. Boehm (Box 2.3) has estimated the impact of experience on the productivity of software developers engaged in developing large software systems.[13] He finds that about a year of experience in a programming language and with a particular system environment (what Boehm calls a "virtual machine," consisting of the complex of hardware and software that supports the task being programmed) is necessary for a worker to develop an average level of productivity, and that more years of experience in these areas (up to about 3 years) enhance productivity further. However, beyond 3 years, additional experience with a system environment or with a programming language has no impact on productivity.

The story is different for the individual's experience in the particular applications domain of the programming problem. Boehm's data indi-

[10]Lee, David, Suffolk University, "Knowledge/Skill Requirements and Professional Development of IS/IT Workers: A Summary of Empirical Findings from Two Studies," paper prepared for Committee on Workforce Needs in Information Technology, December 9, 1999.

[11]Salzman, Hal, University of Massachusetts-Lowell, "Information Technology Labor Markets," commissioned paper prepared for the Committee on Workforce Needs in Information Technology, March 2000.

[12]Barley, Stephen R. 1993. "What Do Technicians Do?" EQW Working Papers, National Center on the Educational Quality of the Workforce. Philadelpia, Pa.: University of Pennsylvania.

[13]Today's software environment is notably different from that characterized by the software projects on which Boehm based his estimates of the impact of experience on productivity. Specifically, many projects in today's environment—even if they serve important business purposes—are not of the size or scale of those examined by Boehm. Thus, Boehm's data should be taken only as an illustration of how experience affects productivity and not used as the basis of specific conclusions or inferences about work in today's software environment.

BOX 2.3
The Impact of Experience on Productivity

The basic COCOMO model is an empirical model that predicts the time needed to complete a large software project as a function of its size. Refinements to the model include different dimensions of a large-scale programming project as "multipliers" to the project completion time predicted by the basic COCOMO model. Table 2.3.1 provides Boehm's multipliers for parameters related to the experience of personnel on the project (applications experience, experience with the programming language involved, and so on). A multiplier of 1.0 represents a nominal impact (average impact on productivity). Multipliers of less than 1 indicate the advantage of more experience, because they multiplicatively reduce the time needed to complete the project.

For example, the data indicate that a very novice programmer with only 1 month of experience in a given programming language is less productive than one with a year of experience. One with 4 months of experience is more productive, but still does not match the one with a year of experience. Programmers with 3 years of experience are more productive than those with 1 year, but experience after 3 years does not appear to increase their productivity.

TABLE 2.3.1 Multipliers Relating Experience of Project Personnel to Time Required for Project Completion

	Applications Experience	Virtual Machine Experience[a]	Language Experience	Personnel Experience (product)
1 month	1.29	1.21	1.14	1.78
4 months	1.29	1.10	1.07	1.52
1 year	1.13	1.00	1.00	1.13
3 years	1.00	0.90	0.95	0.86
6 years	0.91	0.90	0.95	0.78
12 years	0.82	0.90	0.95	0.70

[a]A "virtual machine" consists of the complex of hardware and software that supports the task being programmed.

SOURCE: Boehm, Barry. 1981. *Software Engineering Economics*. Englewood Cliffs, N.J.: Prentice-Hall, Table 29-12, p. 530.

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cate that average productivity is reached after 3 years of experience, but unlike systems (virtual machine) experience or language experience, increasing levels of applications experience bring increasing improvements in productivity. Furthermore, the range of productivity variation as a function of applications experience is much wider than for either systems experience or language experience.

The "situated" view of experience also helps to explain observed workplace differences between individual performance and team performance. All team managers know that a brilliant individual may—or may not—work well with a team. This is because the brilliant individual's ability to interact successfully with others, to build on and to draw on the commonly shared tacit or informal knowledge of his or her particular work team, will greatly influence the success of the group.

Finally, the situated view of experience explains the importance of contextualizing IT work for specific applications. It is well-known in IT-intensive firms that IT workers with specific business experience and/or an understanding of how those businesses work can make significant contributions. Understanding the business context provides the worker with the "big picture," and it reduces significantly the amount of explicit communication and direction that would be necessary if he or she lacked such understanding—thus reducing the amount of higher-level direction needed for such a worker.

2.4 CHARACTERIZING THE IT WORKFORCE

In the discussion below, the committee focuses primarily on the Category 1 IT workforce. This is not because of any conclusion that one category is more or less important than another, but rather because the range of occupations spanned by Category 2 is so diffuse that it is nearly impossible to reach a consensus on which occupations to include in the definition, and because data are not available on many of these occupations.

2.4.1 Size of the IT Workforce

Analysts who have recently examined the size of the "IT workforce" have developed a wide range of estimates that have varied from just under 2 million to more than 10 million (see Appendix B). The different methodologies underlying these estimates can be explained, but the numerical estimates themselves cannot be precisely reconciled.

- Estimates of the IT workforce depend on the definition of "IT worker" used. For example, estimating the number of Category 1 or "core" IT workers (see Table B.1, Appendix B) would yield a very different result than would estimating the combined total of Category 1 and 2 workers (see Table B.2, Appendix B). Similarly, estimating the number of individuals in software occupations would be a different exercise than estimating the number of individuals in both software and hardware occupations.

• Estimates depend on the data set used in the analysis and, of critical importance, the occupational categories in that data set used as a proxy for the analyst's IT worker definition.

• Estimates depend on whether the analyst focuses on the number of individuals employed, the number of individuals in the labor force (employed plus unemployed who are seeking), or the number of positions a firm has (filled or vacant) in a particular occupational category or set of categories.

Because they use different data sets and count different populations, it is impossible to reconcile the varying estimates of the size of the IT workforce produced by various analysts drawing on U.S. government or private data sources. Nevertheless, it is the judgment of the committee that the size of the Category 1 workforce is very likely now, or soon will be, in the range of 2.5 million or more. This figure includes those who categorize themselves as computer systems analysts and scientists, computer programmers, computer science teachers, and electrical and electronic engineers.[14] It is also the judgment of committee that the Category 2 workforce is at least equal in size to the Category 1 workforce, and may well be larger. Thus, the overall size of the IT workforce is at least 5.0 million, with approximately 2.5 million Category 1 workers and a number of Category 2 workers that is at least as large.

More details on the various ways of estimating the size of the IT workforce are contained in Appendix B.

2.4.2 Growth in the Category 1 IT Workforce

Despite the drawbacks of using U.S. government data (these drawbacks and the data themselves are described in Appendix B), the committee used government data sets to examine trends in the IT workforce over time. Such an examination requires data collected according to a consistent methodology that can be used to support a time-series analysis. U.S. government data satisfy this requirement, and no other estimates brought to the committee's attention share this characteristic. Thus, the discussion of growth below is based on these U.S. government data.

The primary data source used in the trend analysis below is the Current Population Survey (CPS), because it has the most current data, an established time series, and a broad set of variables. When CPS data are

[14]As discussed in Appendix B, not all electrical and electronic engineers are engaged in doing IT work. Appendix B argues that about 52.6 percent of electrical and electronic engineers are doing IT work, and it is this fraction of such engineers that is included in the overall estimate of 2.5 million.

inadequate, the committee has used the National Science Foundation's SESTAT data system.[15,16] SESTAT data cover only workers who have a bachelor's degree or above in a science or engineering field from a U.S. institution and a few individuals who are working in science and engineering occupations or have science and engineering degrees who were in the United States in 1990 or earlier. Despite this limitation, the SESTAT system is useful because of its large sample size and its broad range of variables related to occupation and education.

For example, the SESTAT estimate of those employed in IT in 1997 with a bachelor's or higher degree is approximately 1.2 million. This figure compares to the CPS estimates of 1.36 million individuals in 1999 with a bachelor's or higher degree working in positions such as computer systems analysts and scientists and computer programmers and of 1.64 million who work in these occupations or as computer science teachers or computer engineers.

U.S. government data indicate that employment growth for the IT occupations they measure was higher than employment growth in the overall economy during the late 1990s, particularly in certain occupational groups. This provides one important indicator of a dynamic IT labor market with strong demand for workers.

- Annual employment growth in the collection of workers in several occupational groups—computer systems analysts and scientists, computer programmers, computer science teachers, and electrical and electronic engineers—was larger than growth in the labor force as a whole during the 1990s, according to the CPS. (Note that this collection of occupations also includes electrical and electronic engineers not doing IT work, and so is somewhat larger than the Category 1 workforce per se.) From 1992 to 1999 the number employed in this collection of occupations increased from 1.8 million in 1992 to 2.8 million in 1999 (Figure 2.1). Thus, as a percentage of total employment in the United States, employment in these occupational groups grew from 1.5 percent in 1992 to 2.1 percent in 1999.
- Annual growth for these occupations (computer systems analysts and scientists, computer programmers, computer science teachers, and electrical and electronic engineers) averaged 6.9 percent from 1992 to 1999.

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[15]The NSF's SESTAT integrated databases each contain records on more than 100,000 college graduates who have an education and/or an occupation in a natural science, social science, or engineering field. At this writing, there are about 12 million scientists and engineers in the United States.

[16]Note that the use of NSF data does not imply NSF endorsement of the research methods or conclusions contained in this report.

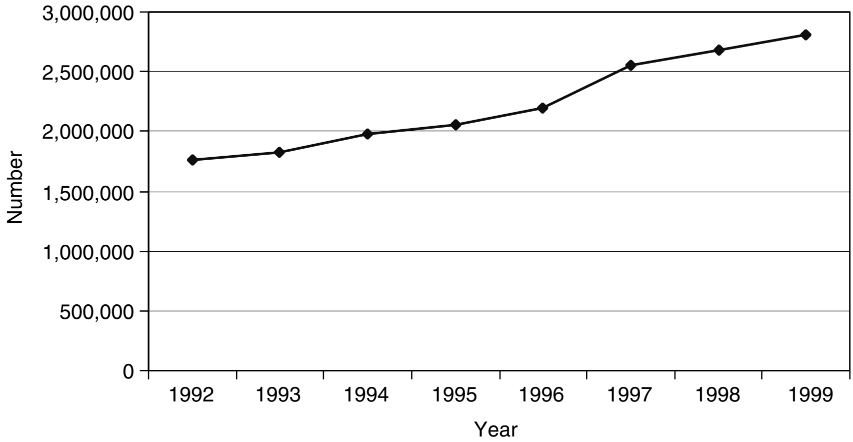

FIGURE 2.1 Total employment in Category 1 IT occupations from 1992 to 1999, as tabulated by CPS. "IT occupations" includes computer systems analysts and scientists, computer programmers, computer science teachers, and electrical and electronic engineers. SOURCE: U.S. Department of Labor, Bureau of Labor Statistics, Current Population Survey, March 1992 to March 1999, special tabulation.

The average annual growth rate for these occupations excluding electrical and electronic engineers and computer science teachers was 8.8 percent for this period. These rates are substantially higher than the average annual employment growth of 1.9 percent in the U.S. economy as a whole from 1992 to 1999. They are also substantially higher than the 3.5 percent annual growth in employment among professional occupations during this period.

• Average annual growth in employment for these occupations was higher still after 1995. The annual change was greatest between 1996 and 1997, when employment in Category 1 occupations increased 16.3 percent. Annual growth then declined to just 5 percent between 1998 and 1999.

• As shown in Figure 2.2, growth in the number of computer systems analysts and scientists has generated much of the overall growth in IT employment as tabulated by the CPS. From 1992 to 1999, employment of computer systems analysts and scientists grew at an annual rate of 11.7 percent; employment of computer science teachers, a much smaller group, grew at 11.8 percent. Employment of computer programmers grew at 3.8 percent annually and employment of electrical and electronic engineers, at 2.4 percent

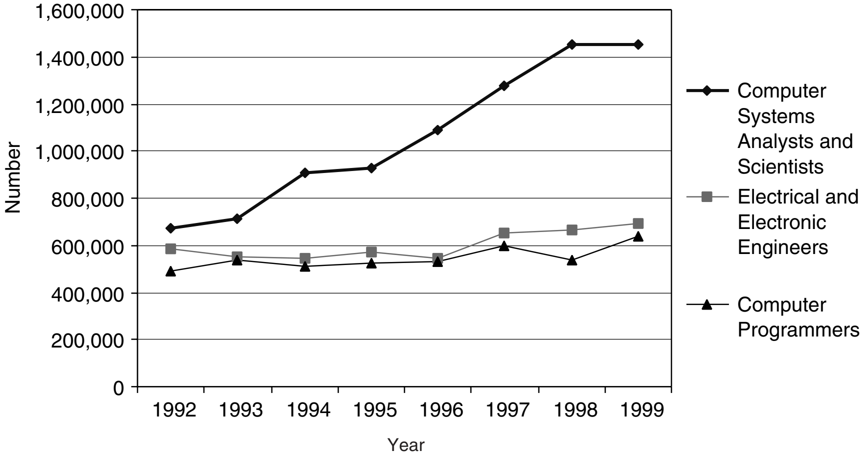

FIGURE 2.2 Employment in Category 1 IT occupations by occupational category, 1992 to 1999. SOURCE: U.S. Department of Labor, Bureau of Labor Statistics, Current Population Survey, March 1992 to March 1999, special tabulation.

- Since CPS data are rather coarse, it is highly likely that within the large categories of computer systems analysts and scientists, computer programmers, computer science teachers, and electrical and electronic engineers are jobs that require new kinds of skills that have had much higher growth rates. Anecdotal evidence suggests that recent growth rates within these subcategories may be in excess of 20 percent per year, and SESTAT data show that employment of computer engineers working on software grew annually at a rate of approximately 15 percent from 1993 to 1997, whereas employment of electrical engineers and computer engineers working on hardware was relatively flat during that period.
- Similarly, as shown in Figure 2.3, data from the Occupational Employment Survey (OES), a survey of public and private employers conducted by the Bureau of Labor Statistics, indicate that employment in computer occupations (even excluding computer engineers, a group for which employment grew even faster) increased more than 10 percent between 1997 and 1998, a greater increase than that experienced by workers in other science and technology occupations.
- The OES data in Figure 2.4, however, indicate that the overall increase in IT professionals between 1997 and 1998 was led by increases of almost 20 percent for computer engineers and "other computer scientists" and almost 15 percent for computer programmers.

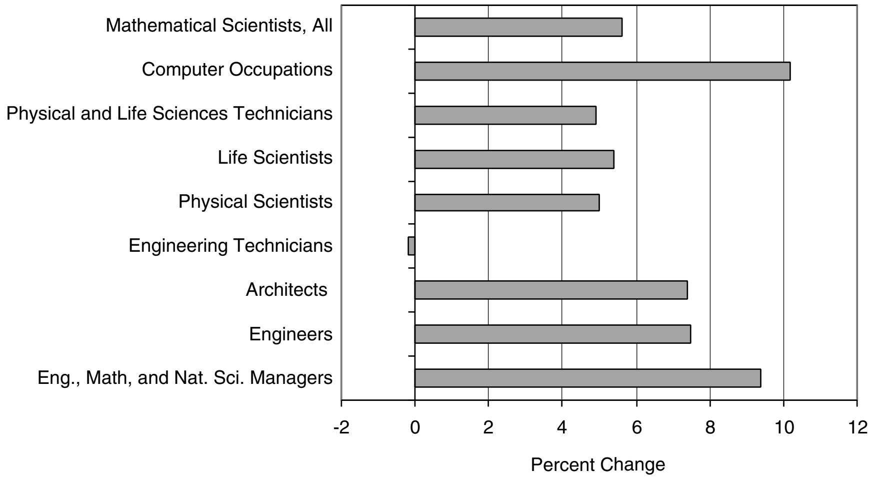

FIGURE 2.3 Change in employment, selected science and technology occupations, 1997-1998. In this figure, computer engineers are included in the category "engineers," not in "computer occupations." SOURCE: U.S. Department of Labor, Bureau of Labor Statistics, Occupational Employment Survey, 1997-1998, special tabulation.

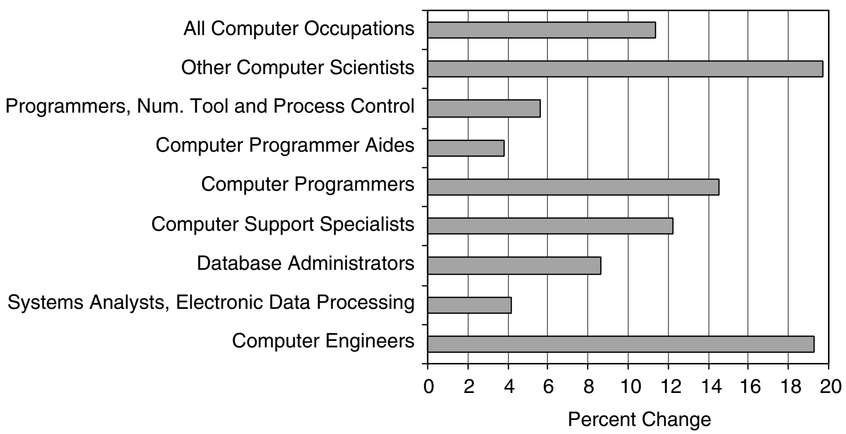

FIGURE 2.4 Change in employment, Category 1 computer occupations, 1997-1998. In this figure, "all computer occupations" includes computer engineers. SOURCE: U.S. Department of Labor, Bureau of Labor Statistics, Occupational Employment Survey, 1997-1998, special tabulation.

2.4.3 Demographics of the Category 1 IT Workforce

Demographically, the Category 1 IT workforce can be characterized as predominantly white, male, young, educated, and U.S. born. Trends indicate that the IT workforce is becoming increasingly diverse in terms of race and ethnicity and place of birth, but perhaps less so in terms of gender. It is also aging. Important characteristics follow:

- The Category 1 IT workforce is predominantly white. However, the CPS indicates that from 1995 to 1999, whites decreased from 86 to 77 percent of the Category 1 IT workforce. Asian and Pacific Islanders increased from 5.6 to 9.9 percent, while underrepresented minorities (blacks, Hispanics, and Native Americans) increased from 8.5 percent to 12.4 percent. SESTAT data indicate, however, that underrepresented minorities with a bachelor's or higher degree who are employed in Category 1 occupations remained stable at 7 percent from 1993 to 1997.
- The Category 1 IT workforce is also predominantly male. CPS data indicate that about 77 percent of Category 1 IT employees were male in 1995 and 1999, compared to 53 percent of all employed individuals and 46 percent of those employed in professional specialty occupations.[17] Similarly SESTAT data indicate that the IT workforce was 71 percent male in 1993 and even increased to 75 percent in 1997.
- The Category 1 IT workforce is relatively young, but aging. According to SESTAT, the median age of the IT workforce increased from 35.6 years in 1993 to 37.5 years in 1997, yet it is about 4.5 years younger than the total workforce, which had a median age of 40.3 years in 1993 and 41.6 years in 1997. This difference in the age distribution and aging of the IT workforce is shown in Table 2.2. The CPS shows similar trends. In 1995, 37 percent of Category 1 IT workers were age 40 or over, while 42 percent were in 1999. Even with the trend in aging, IT workers were younger than individuals employed in professional specialty occupations, 54 percent of whom were age 40 or over in 1999.
- Category 1 IT workers are overwhelmingly U.S. born. However, the percentage of individuals employed in Category 1 IT occupations who are foreign born—a term that lumps together naturalized citizens, permanent immigrants, and temporary nonimmigrants—increased from about 13 percent in 1995 to 17 percent in 1999. By comparison, foreign-

[17]Professional specialty occupations include a broad list: engineers, mathematicians, computer scientists, physical scientists, health diagnostic professionals, health assessment and treatment occupations, postsecondary teachers, elementary and secondary teachers, social scientists and urban planners, social and religious workers, lawyers and judges, writers, and artists.

TABLE 2.2 Percentage, by Age Group, of Science and Engineering Graduates Employed in IT and Non-IT Occupations, 1993 to 1997

	1993		1995		1997	
Age Group	IT	Non-IT	IT	Non-IT	IT	Non-IT
21 to 30	20.2	15.8	16.8	15.4	15.5	16.2
31 to 40	43.3	31.0	42.2	28.8	40.1	25.9
41 to 50	26.8	32.0	29.8	33.0	30.9	33.1
Over 50	9.7	21.2	11.2	22.8	13.5	24.8

SOURCE: Derived from the National Science Foundation's SESTAT data, which cover only workers with bachelor's degrees and higher in all science and engineering fields received from U.S. universities. Estimates in the text of the IT workforce are based on the assumption that the percentage distributions derived from SESTAT data approximate those of the Category 1 IT workforce as tabulated by the CPS.

born individuals constituted about 10 percent of all individuals employed in the United States in 1999. This proportion of foreign-born workers in the IT workforce is not unusual for technical fields. In addition, foreign-born IT workers who are permanent and temporary residents have higher levels of formal education than do native-born IT workers.[18] And foreign-born IT workers tend to be more concentrated in a relatively small number of states that have large immigrant populations, which in turn may lead to networks of immigrants developing to promote and support immigrant enterprises.

- Insight into the composition of the non-U.S. citizen portion of the IT workforce—either permanent immigrants or temporary nonimmigrants—is difficult to obtain, because most of the available data sets do not disaggregate foreign workers into these categories. (Chapter 5 contains additional comments on this point.)
- About two-thirds of Category 1 IT workers in both 1995 and 1999 had at least a bachelor's degree. This fraction compares to about one-

[18]Ellis reports that 15 percent of native-born IT workers have a master's degree or above, whereas 40 percent of foreign-born IT workers have such degrees (Ellis, Richard, and B. Lindsay Lowell. 1999. "Foreign-Origin Persons in the U.S. Information Technology Workforce," Report III of the IT Workforce Data Project, United Engineering Foundation, available online at <www.uefoundation.org>). Note that U.S. visas for permanent and temporary residents specify certain minimum educational requirements, most often a bachelor's degree or equivalent. And, to the extent that foreign-born permanent and temporary residents receive the bulk of their formal education in the United States, they become known by and are accessible to U.S. employers. For example, about 22 percent of H-1B holders have previously held student visas (U.S. Immigration and Naturalization Service. 2000. *Characteristics of Specialty Occupation Workers (H-1B)*. Washington, D.C.: INS, February).

TABLE 2.3 Distribution of the Category 1 IT Workforce by Employment Sector

	Total (% of total)		
	1993	1995	1997
Academia	64,218 (5.4)	63,842 (5.5)	61,795 (5.0)
Industry	930,209 (78.4)	925,236 (79.7)	1,010,939 (81.3)
Government	113,173 (9.5)	101,794 (8.8)	98,415 (7.9)
Self-employed	38,888 (3.3)	34,095 (2.9)	33,502 (2.7)
Nonprofit	39,771 (3.4)	35,862 (3.1)	39,189 (3.2)

SOURCE: See source line, Table 2.2.

third of all employed individuals and three-quarters of all employed in professional specialty occupations in the United States. More discussion on this point is contained in Section 2.4.5.

• Across the different employment sectors, the vast majority of IT workers are in industry, with a small fraction in the other sectors (Table 2.3). It is also interesting to note that the percentages in each sector, except for industry, have been declining, and the greatest decline has been in government, both the number and the percent. This decline in the number of IT workers in government may reflect better pay in industry for similar skills.

2.4.4 Compensation in the Category 1 IT Workforce

One important indicator of a dynamic labor market with strong demand for workers is rising compensation. Rising compensation levels may indicate strong demand that leads to bidding up of the amount that employers are willing to pay at the margin for labor. Data from U.S. government and private sources provide evidence that annual salaries—one component of compensation—for IT workers have been growing at a faster rate than employee salaries in the economy generally. As a rule, those employed by IT-producing and IT-intensive firms hold high-wage jobs, and the earnings gap between wages for these jobs and average wages (even of skilled workers) continues to grow. A Department of Commerce study[19] indicates that wages for those employed by IT-producing firms are significantly higher and have grown faster than

[19]Henry, David, Patricia Buckley, Gurmukh Gill, Sandra Cooke, Jess Dumagan, and Dennis Pastore. 1999. *The Emerging Digital Economy II*. Washington, D.C.: U.S. Department of Commerce, June. Available online at <http://www.ecommerce.gov/ede>.

average wages across all private sector industries, particularly so for workers in the IT software and services industries. Similarly, as shown below, annual salaries for employees in the Category 1 IT occupations as surveyed by the CPS have been increasing faster than employee salaries in the economy generally. Salary growth rates for IT occupations, however, vary over time, among types of IT workers, and among geographic regions. Of note is that compensation is rising fastest for employees who are able to bring current "hot" skills to their employers.

At the outset, it is important to point out that data from government and private sources are gathered and aggregated according to different definitions and methods, and—in general—demonstrate different results. Because of differences across surveys in definitions (especially with regard to occupational titles) and methodologies, the committee believes that it is not appropriate to compare salary growth rates obtained by different surveys. However, it is reasonable to draw conclusions from differences among occupations and regions within a given survey.

For example, data from private sources tend to indicate higher rates of annual salary growth for IT workers—especially those in certain occupations—than do government data.[20] Government data sets such as the

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[20]These occupations were not limited exclusively to Category 1 occupations; they included CIO/vice president, IS director, manager (systems analysis and programming), manager (systems programming/tech support), network manager LAN/WAN, systems analyst/programmer/project leader, database admininstration manager, manager telecommunications, e-commerce director, data center manager, pc workstation manager, senior software engineer, software engineer, senior database analyst/administrator, year 2000 analyst, object-oriented/GUI developer, WWW/Internet developer, network administrator LAN/WAN, senior systems analyst programmer, systems analyst programmer, senior systems administrator/UNIX, senior client server programmer/analyst, client server programmer/analyst, senior Mid/MF programmer analyst, Mid/MF programmer analyst, telecommunications specialist, PC applications specialist, quality assurance analyst, and security specialist.

Barnow et al. point out that while the CPS weekly earnings series shows only average wage growth among IT workers, other salary surveys and anecdotal evidence on wages of IT workers suggest much higher levels and higher growth in wages, especially among the most highly skilled computer workers. In a survey of compensation conducted for ITAA, William M. Mercer found that average hourly compensation for information technology workers had increased substantially between 1995 and 1996. A survey conducted by Deloitte & Touche Consulting Group revealed that salaries for computer network professionals rose an average of 7.4 percent between 1996 and 1997. Coopers and Lybrand found that the average salary increases at 500 software companies were 7.7 percent in 1995 and almost 8 percent in 1996. Computerworld's annual survey found that in 11 of 26 positions tracked, average salaries increased more than 10 percent from 1996 to 1997. According to this survey, systems analysts' salaries increased by 15 percent, programmer/analysts' salaries were up by 11 percent, and directors of systems development had salary increases of 10 percent. In 1997, starting salaries for graduates with bachelor's degrees in computer science had increased to an average of $36,666, while experienced programmers received salaries in the range of $45,000 to $75,000. The wage rates and wage growth reported in the Mercer

CPS and OES are based on job titles that are consistent from year to year and provide data that support time-series analysis—an approach that works especially well for long-established industries that change relatively slowly and in which the job responsibilities encompassed by various job titles are relatively clear and stable. However, in a rapidly changing industry such as IT, job titles appear and disappear quickly, and a given job title can cover a broad range of responsibilities. Thus, data on wages for job titles that are consistent from year to year, as in BLS surveys, may well mask wage indicators for different jobs subsumed within those titles. By contrast, private surveys—because they are not intended to support time-series analysis—are more likely to use job titles that are more highly differentiated and more closely reflect the current set of IT occupations, including those that have emerged more recently.

Government data indicate that annual growth rates for IT salaries in the late 1990s were higher than those of most other professional occupations in general and other science and technology jobs in particular. For example, the average annual increase in income (in constant dollars) from 1996 to 1999 for professional specialty occupations was 3.2 percent, according to the CPS (Figure 2.5). For all those employed who held at least a bachelor's degree, the average annual increase was about 3.4 percent. The categories "computer programmers" and "computer systems analysts/scientists" each had higher than average annual increases (in constant dollars) of 3.8 and 4.5 percent, respectively, during this period. According to the OES and as shown in Figure 2.6, mean annual salaries in constant 1999 dollars for computer occupations (even excluding computer engineers, whose salaries grew still faster) increased by more than 5 percent from 1997 to 1998, faster than the growth in mean salaries for other science and technology occupations.

While salary growth rates for IT occupations have been and remain strong relative to those of other professional groups, available data suggest that the rate of salary growth for IT occupations overall may be tapering off. As shown in Figure 2.7, data collected by the National Association of Colleges and Employers (NACE)[21] on beginning salaries for

study are far higher than not only the CPS weekly earnings data but also the data from other private surveys and the BLS employer survey data. (See Barnow, Burt, John Trutko, and Robert Lerman. 1998. *Skill Mismatches and Worker Shortages: The Problem and Appropriate Responses*. Draft final report for the Urban Institute, Washington, D.C., Task Order #21, February 25).

[21]The NACE salary survey collects data on beginning base salary offers (not acceptances) from 343 career planning and placement offices of colleges and universities across the United States. NACE salary survey data for a given year represent a compilation of data on offers received from September 1 of the previous year through August 31 of the survey year. The reports consist of salary offers made to new graduates by employing organizations in business, government, and nonprofit and educational institutions.

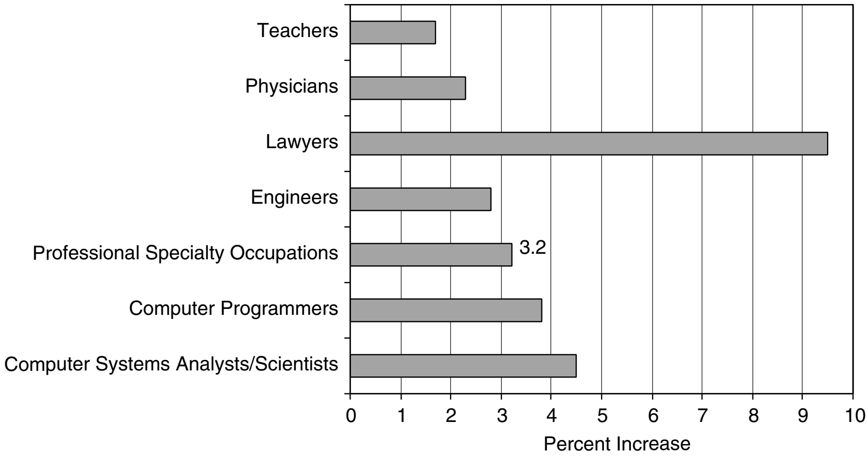

FIGURE 2.5 Average annual increase in income for Category 1 IT and other selected occupations, 1996 to 1999 (constant 1999 dollars). SOURCE: U.S. Department of Labor, Bureau of Labor Statistics, Current Population Survey, March 1996-March 1999, special tabulation.

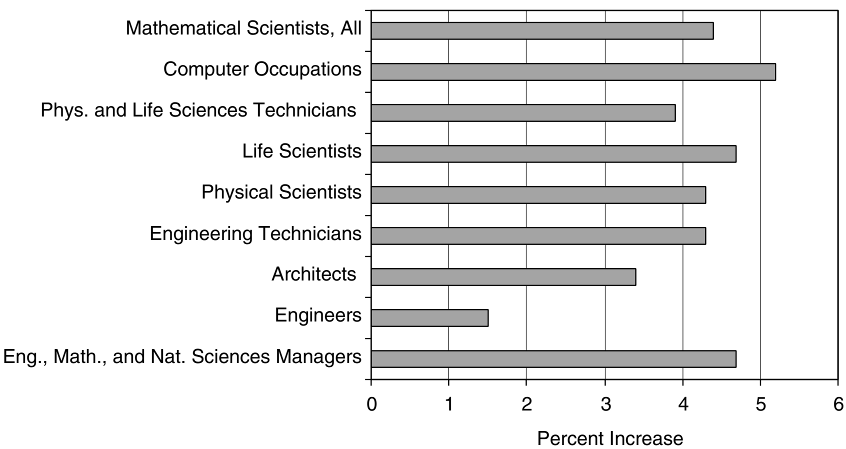

FIGURE 2.6 Increase in mean annual salary, science and technology occupations, 1997-1998 (constant dollars). SOURCE: U.S. Department of Labor, Bureau of Labor Statistics, Occupational Employment Survey, 1997-1998, special tabulation.

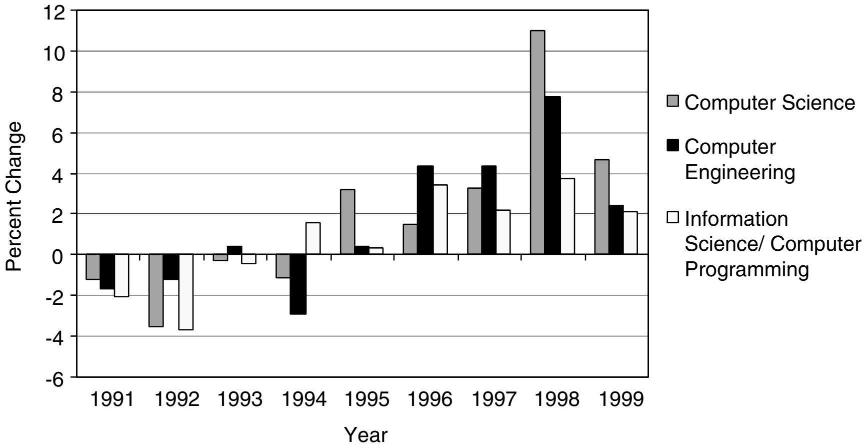

FIGURE 2.7 Annual change in beginning salaries for bachelor's degree recipients in computer science, computer engineering, and information science/computer programming, 1991 to 1999 (constant 1999 dollars). SOURCE: National Association of Colleges and Employers (NACE). 1999. *1998-99 Salary Survey* [and the corresponding reports for the years 1991 through 1998]. Bethlehem, Pa.: NACE.

new bachelor's degree recipients indicate that while beginning salaries for new degree holders in computer science, computer engineering, and information science/computer programming have been more robust than for new bachelor's degree holders in other professional fields, they follow an overall pattern similar to that for other fields: flat or down in the early 1990s, turning upward in 1995 with peak annual increases around 1998, followed by a lower, but still positive, increase in 1999. The annual Computer Industry Salary Survey conducted by DataMasters, which tracks salaries by IT occupation and region, indicates a similar peak in the annual change in median salary for all IT occupations in 1998.[22] As seen in Figure 2.8, the annual change in IT salaries was still positive from 1998 to 1999 and from 1999 to 2000, but at a progressively lower rate.

While salaries have been increasing for IT occupations generally, there are important differences among various specific IT occupations. For example, OES data show that computer engineers and computer programmers led other occupational categories with a 5.8 percent increase from 1997 to 1998 (Figure 2.9). Close behind at 5.7 percent were employ-

[22]The DataMasters survey is conducted for DataMasters by Dowden & Company, a firm that does research on compensation. The year 2000 data were gathered from more than 900 employers of information systems professionals, including corporations of all sizes, in every industry group, from every U.S. region. More information is available online at <http://www.datamasters.com/survey.html>.

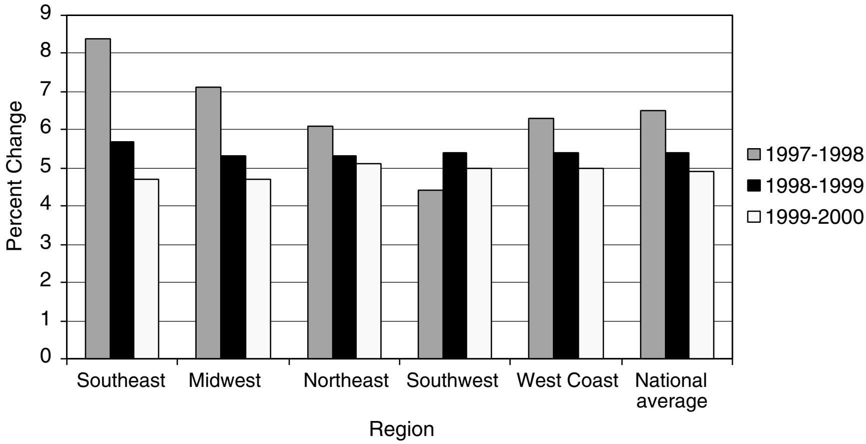

FIGURE 2.8 Average change in median annual salary for information technology occupations, by region, 1997 to 2000. The job titles included in the DataMasters survey are as listed in the main text. SOURCE: DataMasters Computer Industry Salary Survey, 1997-2000. Available online at <http://www.datamasters.com/survey.html>.

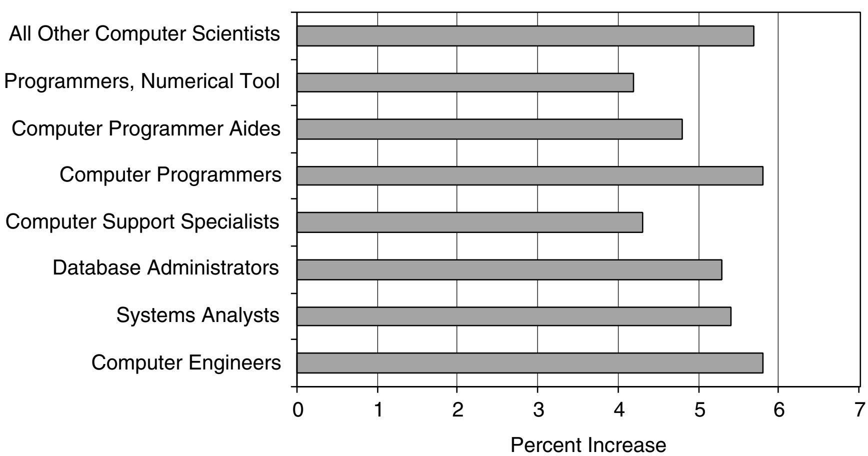

FIGURE 2.9 Increase in mean annual salary, science and technology occupations, 1997-1998 (constant dollars). SOURCE: U.S. Department of Labor, Bureau of Labor Statistics, Occupational Employment Survey, 1997-1998, special tabulation.

ees in the category "all other computer scientists." Data from the 1999 *Information Week* salary survey also show that from 1998 to 1999 a handful of IT occupations continued to have higher salary increases than did other IT occupations (Figure 2.10).[23] Staff specialists, senior programmers, Webmasters, and systems administrators all had annual increases of more than 8 percent. Systems analysts and systems programmers had annual increases in excess of 9 percent. The increase in median annual salary for senior Webmasters was 10.7 percent.

In some instances, the differences in annual salary growth also translate into differences in the rate of change in salary growth. For example, according to the CPS, annual increases for computer programmers fit a pattern seen in private data, with a peak increase in 1997 and smaller but still positive increases in 1998 and after (Figure 2.11), but the CPS data also show that computer systems analysts and scientists have experienced progressively larger salary increases, including a 1-year increase in annual salary of almost 14 percent from 1998 to 1999 (Figure 2.12). This rate of change could perhaps be explained by the large ongoing salary increases for individuals with specific skills. Indeed, the DataMasters survey shows that IT workers who specialize in Web design are currently experiencing not only rapid salary growth but also, as shown in Figure 2.13, accelerating annual salary increases that buck the trend of lower annual increases across other IT occupations.

It is important to note that differentiation by the rate of salary growth across IT occupations is compounded by significant differences in salary levels across geographical regions (Figure 2.14 through Figure 2.17). Of special note is that in 1998 computer programmers in San Jose (Silicon Valley) received salaries that were 131 percent of the mean annual salary of computer programmers nationally (Figure 2.15). For certain occupations in certain locales, job markets may be seen to be especially tight.

Finally, another component of compensation widely associated with IT workers is the opportunity to exercise stock options. Data from the National Center on Employee Ownership indicate that computer programming and software firms may provide for their technical staff options on stock whose average value is higher than that of the stock made available to employees by other industry groups. Similarly, according to the NCEO data, just one other industry group in addition to "computer programming/ software" provides more of its stock options to nonmanagers than to managers. (Additional comments on stock options are made in Chapter 3.)

[23]Mateyaschuk, Jennifer. 1999. "1999 National IT Salary Survey: Pay Up," *Information Week Online*, April 26. Available online at <http://www.informationweek.com/731/ salsurvey.htm>. This survey is based on the responses of more than 21,000 online responses. While the number of respondents is significant, the survey may be subject to biases related to coverage and sampling that are often typical of online surveys.

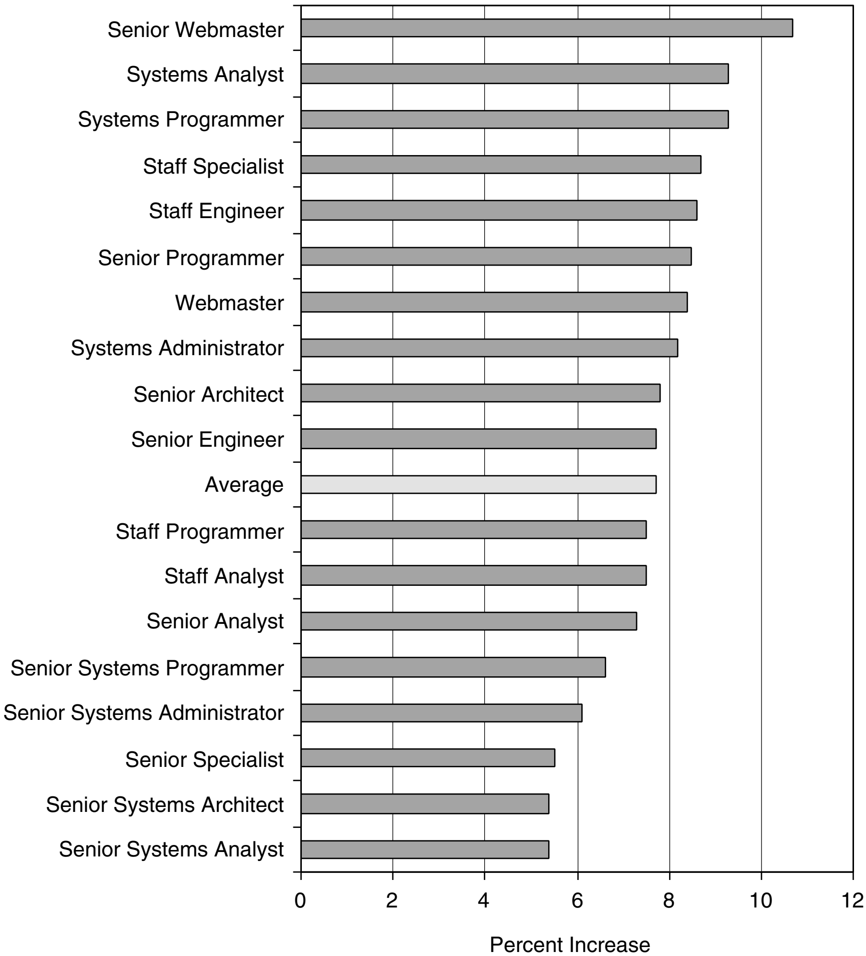

FIGURE 2.10 Annual change in median salaries for selected information technology occupations, 1998-1999 (constant 1999 dollars). SOURCE: *Information Week*, 1999 National IT Salary Survey. Available online at <http://www.informationweek.com/731/salsurvey.htm>.

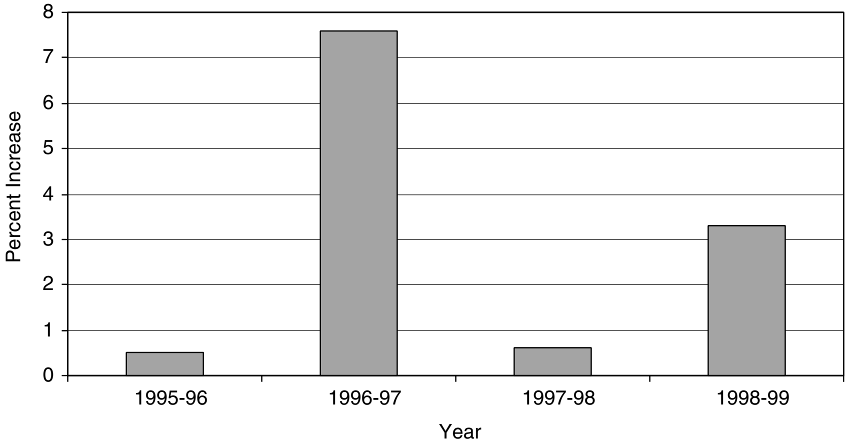

FIGURE 2.11 Annual increases in mean income for computer programmers, 1995 to 1999 (constant 1999 dollars). SOURCE: U.S. Department of Labor, Bureau of Labor Statistics, Current Population Survey, March 1996-March 1999, special tabulation.

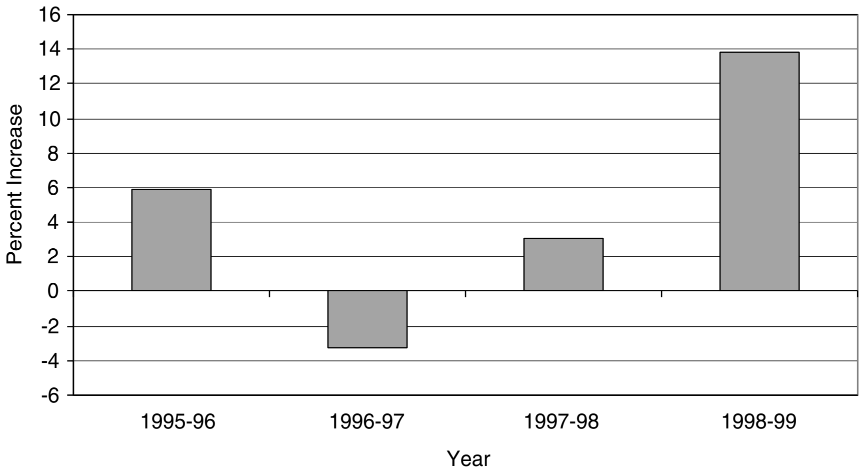

FIGURE 2.12 Annual increases in mean income for computer systems analysts and scientists, 1995 to 1999 (constant 1999 dollars). SOURCE: U.S. Department of Labor, Bureau of Labor Statistics, Current Population Survey, March 1996-March 1999, special tabulation.

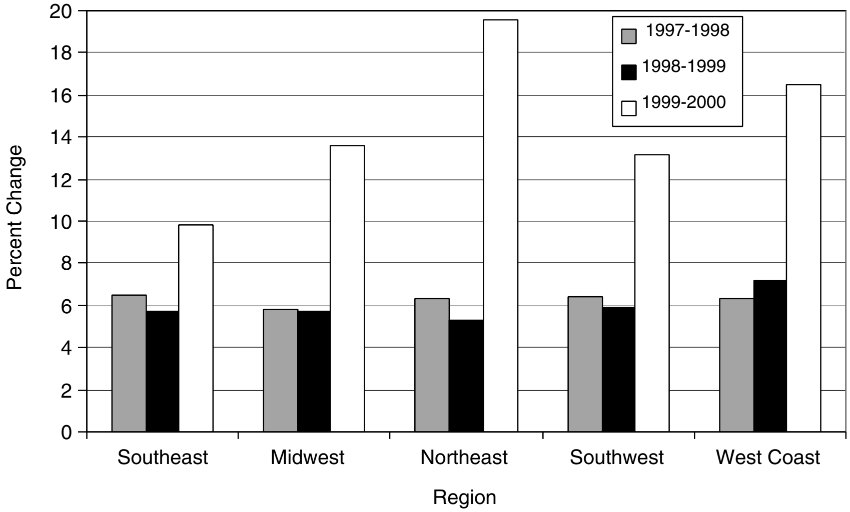

FIGURE 2.13 Change in median annual salary for World Wide Web/Internet developers, by region, 1997 to 2000. SOURCE: DataMasters Computer Industry Salary Survey, 1997-2000. Available online at <http://www.datamasters.com/survey.html>.

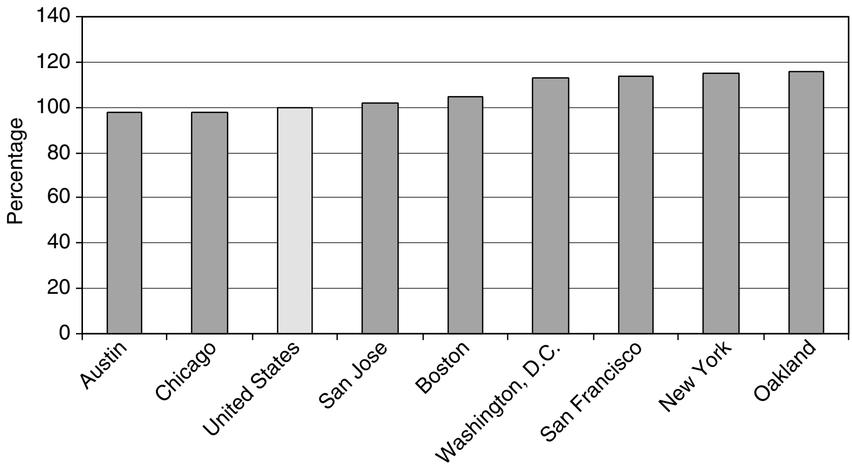

FIGURE 2.14 Mean annual salary of systems analysts in high-technology metropolitan areas as a percentage of the mean annual salary of systems analysts nationally. SOURCE: U.S. Department of Labor, Bureau of Labor Statistics, Occupational Employment Survey, 1998, special tabulation.

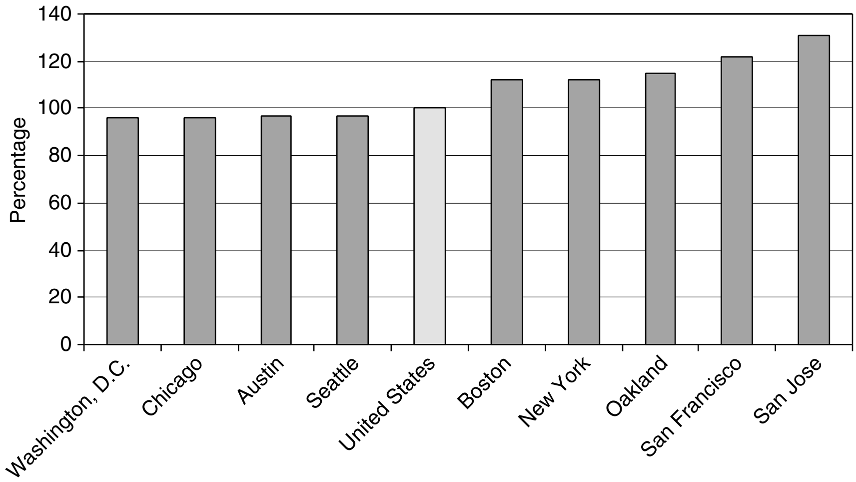

FIGURE 2.15 Mean annual salary of computer programmers in high-technology metropolitan areas as a percentage of the mean annual salary of computer programmers nationally. SOURCE: U.S. Department of Labor, Bureau of Labor Statistics, Occupational Employment Survey, 1998, special tabulation.

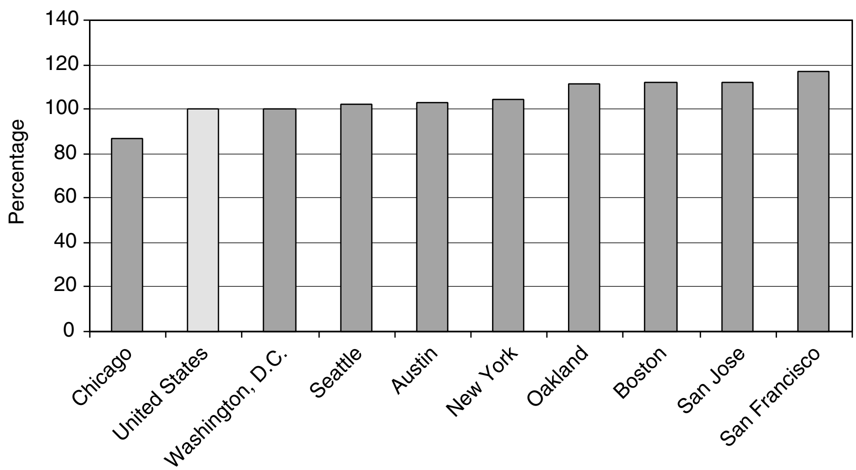

FIGURE 2.16 Mean annual salary of computer engineers in high-technology metropolitan areas as a percentage of the mean annual salary of computer engineers nationally. SOURCE: U.S. Department of Labor, Bureau of Labor Statistics, Occupational Employment Survey, 1998, special tabulation.

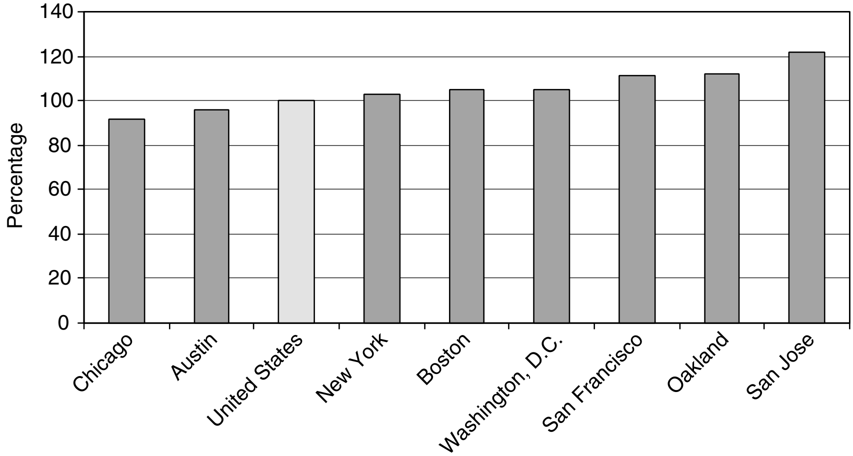

FIGURE 2.17 Mean annual salary of electrical and electronic engineers in high-technology metropolitan areas as a percentage of the mean annual salary of electrical and electronic engineers nationally. SOURCE: U.S. Department of Labor, Bureau of Labor Statistics, Occupational Employment Survey, 1998, special tabulation.

2.4.5 Educational Background

The Category 1 IT workforce as tabulated by CPS is highly educated, with at least two-thirds having completed at least a bachelor's degree in some discipline from a U.S. institution. In 1998, only 6 percent of these workers had only a high school diploma, 26 percent had associate's degrees, 48 percent had bachelor's degrees, and 19 percent had master's or other postgraduate degrees.[24] However, the correlation between field of education and employment as an IT worker in a CPS Category 1 IT occupation is not very tight. Of those working in a CPS IT occupation in 1997, about 59 percent did not have a formal IT background (19 percent had an engineering background in a non-IT field).

Of those with a formal IT background, about 21 percent in 1997 were not working as computer scientists, computer programmers, or systems analysts. These individuals were employed in a variety of occupations, but most, about 75 percent, were not working in science and engineering

[24]These figures are based on BLS data for IT workers in four "core" occupations in 1998: computer scientists, computer engineers, systems analysts, and programmers. See tabulations by Ellis, Richard, and B. Lindsay Lowell. 1999. "Core Occupations of the U.S. Information Technology Workforce," Report I of the IT Workforce Data Project, United Engineering Foundation. Available online at <www.uefoundation.org>.

fields. They could be working in sales or other service occupations, and a small percentage, about 5 percent, were in management outside of IT. The fraction of IT-educated workers taking jobs as computer scientists, computer programmers, or systems analysts upon receipt of their degree increased from about 71 percent in 1993 to about 74.5 percent in 1997.[25]

In general, individuals can develop in a variety of ways the skills and abilities needed to work successfully in certain IT jobs, especially those in Category 2. Career paths are changing across the entire economy, diverging from the traditional linear model in which young people became full-time students to qualify for long-term careers with one or only a few employers.[26] Today, many more employed adults, including IT workers, are developing their skills both on and off the job. To meet this growing demand, formal education is becoming more flexible: universities and community colleges are offering for-credit and noncredit classes at a variety of times and places, while public and private providers of education and training often offer courses on the Internet. One popular route to a career or advancement in IT occupations is self-study leading to industry certification, as described in Chapter 7.

The number of individuals with a formal education in IT-related fields has grown in the past few years, but it is difficult to estimate what will occur in the future. While enrollment at the undergraduate level is difficult to estimate, the Taulbee survey, which collects data on computer science and computer engineering programs at Ph.D.-granting institutions, shows that the number of undergraduates entering full-time study in those institutions doubled over the 5-year period from 1995 to 1999, rising sharply in 1996 and 1997 and then leveling off in 1998 and 1999 (Table 2.4). However, data from the same survey on total undergraduate enrollment in computer science and engineering indicate a decline from 59,049 students in 1998 to 54,366 students in 1999.

The increased enrollments in computer science and engineering in the mid-1990s resulted in an increase in awarded bachelor's degrees from about 7,500 in 1995 to about 12,700 in 1999, for a gain of about 10 percent each year, except for a 25 percent increase from 1998 to 1999 (Table 2.5). Whether these increases in the number of bachelor's degrees will be sustained is questionable considering the leveling off of undergraduate enrollments. The total number of degrees awarded at the associate's and bachelor's levels reflects a pattern of decline in the late 1980s followed by an approximately constant level of production through the mid-1990s

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[25]NRC staff analysis, based on NSF SESTAT data from 1993, 1995, and 1997.

[26]Freeman, Peter, and William Aspray. 1999. *The Supply of Information Technology Workers in the United States,* "Chapter 5, Supply—The Degree Programs." Washington, D.C.: Computing Research Association. Available online at <http://www.cra.org/reports/wits/>.

TABLE 2.4 New Students Entering Computer Science and Computer Engineering Departments in U.S. Institutions Awarding Doctoral Degrees in These Fields, 1995 to 1999

New Students	1995	1996	1997	1998	1999
Undergraduate	8,207	11,972	16,197	16,075	16,605
Master's	1,191	3,101	3,085	3,955	4,862
Doctoral	992	1,283	1,354	1,697	1,808

SOURCE: See source line, Table 2.2.

TABLE 2.5 Degrees Granted in Computer Science and Computer Engineering in U.S. Institutions Awarding Doctoral Degrees in These Fields, 1995 to 1999

Degree	1995	1996	1997	1998	1999
Undergraduate	7,561	8,411	8,063	10,161	12,692
Master's	4,425	4,260	4,443	4,934	5,579
Doctoral	1,006	915	894	933	852

SOURCE: See source line, Table 2.2.

(Figure 2.18). Based on the Taulbee data for 1996 to 1999 and the fact that about one-third of all 4-year computer science students attend institutions that offer advanced postgraduate study leading to a Ph.D.,[27] the committee estimates that the total number of bachelor's degrees may increase to about 36,000 entering 2000.

Table 2.4 also shows significant increases over the period from 1995 to 1999 in the number of new entrants into master's and Ph.D. programs in CS&E, with nearly a fourfold increase at the master's level and a doubling at the Ph.D. level. Data on total enrollments at the master's level, available only for 1998 and 1999, indicate that about 12,200 were enrolled for 1998 and 13,800 for 1999. According to the Taulbee data, the actual number of master's degrees awarded was constant at about 4,400 to 1997

[27]The Taulbee surveys are taken from various issues of *Computing Research News*, published by the Computing Research Association (available online at <www.cra.org>). The 1995 CRA Taublee survey can be found in the March 1996 issue (Vol. 8, No. 2); the 1996 survey, in the March 1997 issue (Vol. 9, No. 2); the 1996-1997 survey, in the March 1998 issue (Vol. 10, No. 2); the 1997-1998 survey, in the March 1999 issue (Vol. 11, No. 2); and the 1998-1999 survey, in the March 2000 issue (Vol. 12, No. 2).

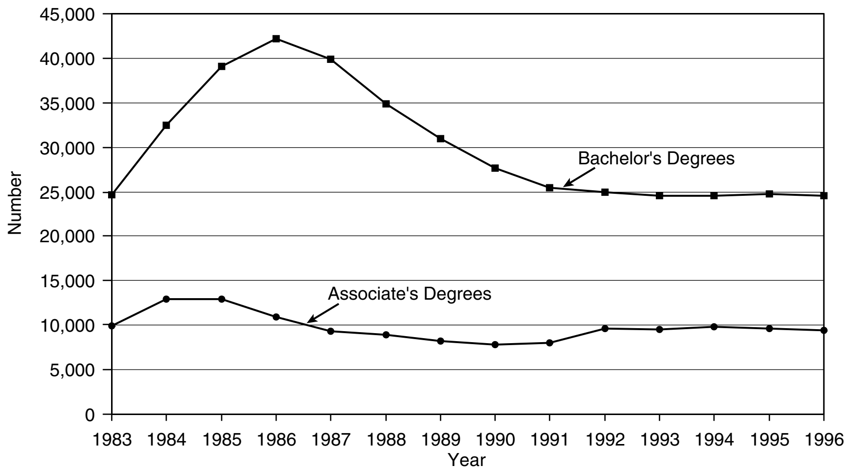

FIGURE 2.18 Bachelor's and associate's degrees awarded in computer science, 1980 to 1996. SOURCE: NRC staff analysis.

and then increased significantly in the next 2 years, to about 5,600 in 1999 (see Table 2.5). Such increased enrollments may indicate additional increases in degree production at those levels in the coming years.

The picture at the Ph.D. level, however, is very different, as indicated by the declining number of doctorates awarded from the mid-1990s to 1999 (see Table 2.5). Total enrollment has also declined over the same period, from about 7,900 full- and part-time students in 1995 to about 7,100 in 1999 and a low point of 6,800 in 1997. Although the disparity between new enrollments and the number of Ph.D. degrees awarded may simply reflect the time required to earn a doctorate, it might also indicate that students are dropping out of Ph.D. programs to take employment in a very good job market.

Across all institutions the number of degrees awarded in the mid-1990s was constant at about 10,000 for master's degrees and 1,100 for doctorates. If the Taulbee data on computer science and engineering enrollments can be extrapolated to enrollments across all institutions, then growth at the master's level to about 12,500 by the end of the 1990s might be anticipated. However, significant increases at the doctoral level in the late 1990s are unlikely, given that the Taulbee and the National Science Foundation data show no increases. It is possible, then, that at the start of the 21st century, the number of trained computer scientists added to the workforce yearly may stand at 36,000 with bachelor's degrees, 12,500 with master's degrees, and 1,100 with doctorates.

2.4.6 Distribution of Category 1 IT Workers by Size of Employer

In 1997 in all industries, almost one-half of the Category 1 IT workforce (44.7 percent) was employed in large companies (more than 5,000 employees), and only 18 percent worked in small companies (fewer than 100 employees), as noted in Table 2.6. By contrast, about 36.6 percent of Category 1 IT workers working in companies that produce information technology or provide computer services are employed in large companies, and 26.9 percent are employed in small companies.

As indicated in Table 2.6, in 1997 well over one-half of Category 1 IT workers (63.8 percent) were employed in companies with over 1,000 employees that were not IT companies such as Intel or Cisco, but were large product- or service-oriented companies. At the other end of the spectrum, small companies with fewer than 25 employees account for a substantial percentage of Category 1 IT employment (16.9 percent). Table 2.6 also shows that in 1997 the distribution of Category 1 IT workers in IT industries was very similar to that for all workers across all U.S. industries.

TABLE 2.6 Number of Category 1 IT Workers and All Workers in Industrial Employment by Size of Company, 1997

	Category 1 IT Workers		
Size of Company	In All Industries (% of total)	In IT Industries (% of total)	All Workers in All Industries[a] (% of total)
Under 10 employees	68,416 (6.3)	58,871 (11.3)	775,727 (13.1)
10–24 employees	36,040 (3.7)	29,097 (5.6)	442,816 (7.5)
25–99 employees	72,361 (8.0)	52,369 (10.0)	654,231 (11.1)
100–499 employees	126,841 (12.3)	77,356 (14.8)	856,354 (14.5)
500–999 employees	56,344 (6.0)	31,014 (5.9)	340,300 (5.8)
1,000–4,999 employees	167,979 (19.1)	82,685 (15.8)	841,662 (14.2)
5,000 plus employees	446,585 (44.7)	191,332 (36.6)	1,999,429 (33.8)
Total	974,566 (100.0)	522,724 (100.0)	5,910,519 (100.0)

[a]"All workers" includes only those with bachelor's and higher degrees from U.S. educational institutions; the "industries" category does not include government or nonprofit employing institutions.

SOURCE: See source line, Table 2.2.

2.4.7 Unemployment of Category 1 IT Workers

According to the SESTAT data set, the rate of unemployment for graduates of computer science and computer engineering programs declined from 2.7 percent in 1993 to 1.2 percent in 1997. This low level of unemployment was comparable to that for all graduates—2.8 percent in 1993 and 1.4 percent in 1997. The data also indicate essentially no difference in unemployment among Category 1 IT workers of different age cohorts. However, the percentage of computer science and engineering degree holders who are unemployed and not seeking employment has been consistently held at 4 percent but has stood closer to 7 percent for all graduates. This lower rate for CS&E degree holders may imply that there is a smaller proportion of the unemployed computer science and computer engineering graduates who have given up looking for work and hence, a greater demand for such graduates than for others.

Because BLS-measured "unemployment rates" count only unemployed individuals who are seeking work, they set a floor on the number of individuals who would be available to take IT work. Other categories of individuals who might be available for IT work include those with previous work experience in IT who currently hold jobs in other, non-IT fields that pay less than their previous job in IT and those who have become "discouraged" and are no longer (technically) looking for work and thus are not counted in official unemployment statistics.

An examination of the SESTAT database in the period from 1995 to 1997 indicates that the number of Category 1 IT workers who took jobs in non-IT occupations is approximately twice the number of unemployed Category 1 individuals.

2.4.8 A Note About the Hardware Subsector Within Information Technology

Although this report comments on workforce needs in hardware when possible, it devotes more attention to the software side of the IT sector. One reason is that the data sources available to the committee largely focus on aspects of the software and applications workforce. A second reason is that while IT hardware provides the platforms on which software and applications build, a very large number of different kinds of software and applications can be built upon a much smaller number of hardware platforms. Finally, many firms whose product lines were originally dominated by hardware production are increasingly involved in providing IT-related services. For example, Dell, originally a company that derived most of its revenues from hardware sales, is now beginning to provide Internet-based IT services. Thus, it is not surprising that the number of people engaged in software and applications work is significantly larger than the number engaged in hardware work. See Box 2.4 for more commentary.

2.4.9 Characteristics of the Category 2 IT Workforce

Occupational clusters developed by the Northwest Center for Emerging Technologies (NWCET)[28] provide a broad, up-to-date list of occupations that generally map the expansive territory of the Category 2 IT workforce. These clusters include occupations in database development and administration, digital media, enterprise systems analysis and integration, network design and administration, programming and software engineering, technical support, technical writing, and Web development and administration (Table 2.7). Unfortunately, it is almost impossible to try to map the list of NWCET occupations onto the occupational categories covered in the large, government data sets, such as the CPS, that provide demographic information about the U.S. workforce. The data illustrate the widely varying characteristics of individuals in a small set of CPS occupations who hold Category 2 jobs, although the committee emphasizes that generalization to the overall Category 2 IT workforce is not necessarily possible based on these data.

- Technical writers and data-processing equipment repairers are rapidly growing occupational groups. The number of technical writers, a group that includes both IT and non-IT workers, grew at a rate of 13.3 percent per year, from 33,000 in 1992 to more than 78,000 in 1999. The rate for data-processing equipment repairers was 12.6 percent annually, with an increase from about 146,000 in 1992 to more than 335,000 in 1999. Computer operators, by contrast, are a rapidly shrinking occupational group, with a decrease from about 641,000 in 1992 to 340,000 in 1999. The number of electrical and electronic technicians grew at a rate of 5.5 percent per year, from 316,000 in 1992 to 461,000 in 1999.
- Technical writers are well educated. In 1999, 59 percent held a bachelor's degree and 23 percent held master's degrees. By contrast, 76 percent of data processing equipment repairers and 86 percent of both

[28]Based at Bellevue Community College in Washington State, the mission of the Northwest Center for Emerging Technologies is to advance information technology (IT) education to improve the supply, quality, and diversity of the IT workforce by preparing and educating versatile knowledge workers of the future. As part of this work, it has developed comprehensive skill standards designed in part to ensure that current 2-year IT education matches the requirements of the labor market. These are discussed at greater length in Chapter 7.

BOX 2.4
Size of the Hardware IT Workforce

The number of people working in hardware in the IT sector is much more difficult to estimate than the number working in software. The Bureau of Labor Statistics (BLS) captures software workers as "computer scientists, systems analysts, and computer programmers," all of whom can work for software vendors or other IT-intensive firms that make use of software. IT does not, however, capture any IT occupations that are unique to IT hardware.

The National Science Foundation's SESTAT database does include the category "computer hardware engineer," but that category does not necessarily include the circuit and chip designers, manufacturing engineers, process control specialists, and other professionals who fabricate the components of IT hardware systems and integrate them into computer and telecommunications systems. Nor does it include any of the important support occupations associated with installing and maintaining hardware. SESTAT data on the number of individuals employed in this category in the mid-1990s are given in Table 2.4.1.

Because IT-intensive firms generally do not produce hardware, professionals whose occupations are associated with hardware are generally found in IT-producing firms; these are generally Category 1 workers. But IT-intensive firms do employ many individuals whose role is to support hardware deployments (Category 2 workers).

An upper bound on Category 1 workers in hardware is provided by BLS statistics on total employment in the semiconductor, telecommunications equipment, and computer equipment sectors (Table 2.4.2); however, these figures include lawyers and janitors and administrators as well as the technical workers who are the primary focus of this report.

Informal estimates from senior industry executives in the semiconductor industry indicate that the fraction of technical professionals is about 22 percent, and the fraction of technical support workers about 44 percent. Estimates of the distribution for the telecommunications and computer equipment sector were unavailable, but if the fractions are comparable, a rough estimate as shown in the two right-hand columns of Table 2.4.2 can be made of the size of the hardware workforce. However, the Category 2 column total almost certainly understates the total number of workers with hardware support responsibilities, because the BLS baseline "total employment" figures shown do not include employees in IT-intensive firms.

Clearly, Category 1 workers in hardware constitute a much smaller group than the Category 1 workers in software (among IT vendors) and applications (among

electrical and electronic technicians and computer operators had less than a bachelor's degree.

• In 1999, technical writers and computer operators were relatively older, with each group having a median age of 44 years. The median age of electrical and electronic technicians was 35 and that of data-processing equipment repairers was 31.

IT-intensive firms). And it is likely, though less certain, that the Category 2 workers in hardware are similarly outnumbered by their counterparts in software and applications.

TABLE 2.4.1 Employment in the Category "Computer Hardware Engineers"

	Year		
	1993	1995	1997
Total	44,970	47,799	47,368

SOURCE: National Science Foundation SESTAT data, 1993, 1995, 1997.

TABLE 2.4.2 Estimating the Size of the Hardware Workforce

Sector	Upper Bound, BLS Data on Total Employment[a] (June 2000)	Category 1 IT Estimate[b]	Category 2 IT Estimate[b]
Semiconductors and related devices (SIC code 3674)	282,400	62,100	124,300
Telephone/telegraph apparatus (telecommunications equipment) (SIC code 3661)	123,000	27,000	54,000
Computer equipment (computers, storage devices, computer peripherals) (SIC codes 3571, 3572, 3577)	305,300	67,200	134,300
Total	710,700	156,300	312,600

[a]Includes administrators and nontechnical personnel; figures are not seasonally adjusted and can be obtained from <http://stats.bls.gov/ceshome.htm>.
[b]Estimates derived by the method described in the text.

• In 1999 in each of the above four occupational groups, fewer than 10 percent of the workers were foreign-born. By contrast, 17 percent of individuals in Category 1 occupations were foreign-born.

• For each of the above four occupational groups, the large majority of individuals are also white, but the percentage varies widely by group. In 1999, 96 percent of technical writers, 82 percent of data processing

TABLE 2.7 NWCET Occupational Clusters and Related Skill Standards

Career Cluster	Representative Job Titles	Sample Critical Work Function
Database development and administration	Data analyst, database administrator	Analyze and design database
Digital media	Animator, 2D/3D artist, media specialist	Produce visual and functional design
Enterprise systems analysis and integration	Systems analyst, systems integrator	Define customer requirements
Network design and administration	Network technician, network engineer	Perform monitoring and management
Programming/software engineering	Applications analyst, programmer/analyst, software engineer, software QA specialist	Implement program
Technical support	Analyst, help desk technician, PC support specialist	Perform troubleshooting
Technical writing	Technical writer, document specialist	Design document
Web development and administration	Web page developer, Web site developer	Perform content and technical analysis

Sample Key Activity	Sample Performance Indicator	Sample Technical Knowledge	Sample Skills for Employability
Perform research and analyze requirements	Business objectives and goals for project are well defined	Knowledge of basic business objectives and requirements analysis	Ability to identify key sources of information
Determine media types and delivery platform	Chosen media elements and delivery platform support project goals and scope	Knowledge of media types and capabilities	Ability to present technical information
Identify and document customer requirements	Constraints are properly identified	Knowledge of continuous quality improvement tools	Ability to compare multiple viewpoints and analyze communication
Monitor and report component, security, and connectivity problems	System is closely monitored and outages are reported in a timely manner	Knowledge of network architecture, topology, hardware, and software	Ability to interpret and evaluate data
Write code	Code is developed using efficient software design processes	Knowledge of programming language required for application	Ability to write simple documents
Analyze problem and research solutions	Problem is correctly identified	Knowledge of troubleshooting methods	Ability to analyze and prioritize information
Select style and tone	Style and tone are appropriate for purpose, medium, and audience	Knowledge of different writing styles	Ability to present information persuasively and objectively
Research content	Content is properly indexed and weighted by importance	Knowledge of indexing and weighting techniques	Ability to interpret communication and compare multiple viewpoints

TABLE 2.8 Annual Rate of Change in Mean Wages for Selected Category 2 Occupations

Selected Category 2 Occupation	Annual Average Rate of Growth (loss)
Technical writer	16.9%
Electrical and electronic technician	5.6%
Computer operator	4.4%
Data processing equipment repairer	(–1.6%)

SOURCE: Current Population Survey, March Supplement 1996 to 1999.

equipment repairers, 78 percent of computer operators, and 69 percent of electrical and electronic technicians were white.

- An increasing percentage of technical writers are female, up from 46 percent in 1995 to 62 percent in 1999. The percentages of females among computer operators has been relatively stable and was 63 percent in 1999. Electrical and electronic technicians and data-processing equipment repairers, however, were overwhelmingly male, at 86 and 82 percent, respectively, in 1999.
- Mean wages (in constant 1999 dollars) in the Category 2 occupations of technical writers, electrical and electronic technicians, and computer operators grew annually by amounts ranging from about 4 percent to 17 percent between 1996 and 1999, while wages for data-processing equipment repairers declined by almost 2 percent (see Table 2.8).

2.5 RECAP

"Information technology" is a broad term encompassing computer and communications technology. For purposes of this report, IT workers are those persons engaged primarily in the conception, design, development, adaptation, implementation, deployment, training, support, documentation, and management of information technology systems, components, or applications.

IT work is highly diverse. Most IT jobs require a mixture of conceptual ability, knowledge of theoretical IT constructs and frameworks, and applied technical skills. The mix depends on the extent to which the job requires creativity and the invention of original work (Category 1 work) as compared to the extent that it requires application of previously developed skills in typical situations (Category 2 work). Some types of work, such as implementation of a concept, can reasonably be characterized as both Category 1 and Category 2 work. Furthermore, expertise in IT (as in many other domains) depends on both formal knowledge (that can be acquired in the context of formal education) and situated knowledge that is specific to a work or problem situation.

Because most jobs require a mix of Category 1 and Category 2 work, the boundaries between Category 1 and Category 2 workers is fluid. That said, Category 1 work tends to require more years of formal exposure to IT-related disciplines than does Category 2 work. This difference suggests that a significant increase in the supply of Category 1 workers is likely to take at least several years (i.e., the time needed for large numbers of these individuals to matriculate), while training efforts for Category 2 workers can—in principle—bear fruit in a matter of months.

The size of the IT workforce is difficult to estimate. However, the committee estimates that the overall size of the IT workforce is at least 5.0 million, with approximately 2.5 million Category 1 workers and a number of Category 2 workers that is at least as large. The IT workforce has grown rapidly in the last 8 years, with the "core" Category 1 workforce nearly doubling. Demographically, the Category 1 workforce is predominantly male, white, and younger than the workforce in general. And the Category 1 workforce is highly educated, with most Category 1 workers having at least a bachelor's degree (though frequently not in an IT-related discipline). Real wages have grown in Category 1 occupations overall at a rate of about 3.8 to 4.5 percent annually since 1996, although this figure masks much more substantial growth in certain subspecialties and also does not include the impact of stock options and equity stakes on total compensation.

3

Characterizing the Workforce Problem

3.1 FRAMING THE PROBLEM IN CONTEXT

Issues related to the IT workforce are controversial. To better understand the issues at hand, it is helpful to start with what has become the most common formulation of the problem:

1. IT employers of all kinds report having considerable difficulty in hiring workers for their open IT positions.
2. A shortage of IT workers is inferred from these difficulties.
3. Remedial actions are taken and/or proposed to increase the supply of IT workers.

There is much about this common formulation that is useful and valid. But each element of the logical chain must be scrutinized carefully. At the end of careful analysis, a much more nuanced and qualified picture emerges.

The third point concerning remedial actions is the subject of Chapters 6 and 7. Note, however, that the appropriateness of any given remedial action depends also on how one sees the origin of that problem, and the intent of this chapter is to focus on the first and second propositions.

3.2 REPORTS OF DIFFICULTY IN HIRING

The reports of IT employers that have considerable difficulty in finding workers for their open IT positions are based on

- Large numbers of vacancies,[1]
- High turnover,
- Long times to fill positions, and
- Low unemployment rates for IT workers.

While the committee believes that employers are accurately reporting their difficulties in hiring, these reports must be framed against a number of important contextual factors. In particular, high turnover rates and long times to fill positions requiring particular skills mean that significant vacancies will occur even if the supply of qualified workers is equal to the demand for them.

Perhaps the most important consideration is the definition of a vacancy. The number of vacancies is sometimes used as a measure of the difference between supply and demand. But vacancy counts suffer from a number of problems. For example, data sources are not reliable. IT employers are increasingly turning to advertising job openings on the Internet. To the extent that vacancy counts are based on the amount of help-wanted advertising done in print (and if each help-wanted print ad represents one real open job), vacancy counts will understate the actual number of vacancies. Conversely, the lack of a posted vacancy may not indicate the lack of a position. Many IT employers have stated that they would be willing to hire an outstandingly talented individual even if no opening were immediately available, because s/he would be regarded as a strategic asset. Furthermore, advertised positions may not reflect immediate hiring needs, but may rather be posted in order to speed up hiring anticipated in the future (so-called "evergreen" positions for which IT employers are always recruiting).[2] Or, advertising may reflect positions with particularly high turnover. Posted ads may reflect jobs that are contingent upon funding, for example, or on the presumed outcome of certain decisions that are out of the control of the immediate hiring manager.

[1]Large vacancy rates are not surprising given the low levels of unemployment in the IT sector. As a rule, vacancy rates tend to move in inverse relation to the unemployment rate and positively with the employment and population rate. See, for example, Katz, Lawrence F., and Alan B. Krueger. 1999. "The High-Pressure U.S. Labor Market of the 1990s." *Brookings Papers on Economic Activity,* Vol. 0, No. 1). Available online at <http://www.irs.princeton.edu/pubs/working_papers.html>.

[2]In some cases, vacancy counts may also reflect multiple countings of single openings. For example, consider *N* companies bidding on a large government contract. For planning purposes, it is prudent for each company to anticipate winning the contract—and it is a small step from that anticipation to anticipating the need to staff the project. But if all companies act in this way, and only one company can win the contract, then the number of anticipated openings is *N* times the number of openings that will actually be realized with the contract award.

A conceptual source of difficulty with the notion of "vacancy" is the fact that the number of jobs that "need" to be filled is not necessarily a well-defined quantity. By changing production modes, improving productivity, and so on, a firm may be able to do the same work with fewer workers. (This subject is addressed further at the end of this chapter but can include such measures as reorganizing workers into teams, improving management, organizing work and training workers to improve productivity and product quality, and using automated tools.[3])

A second major factor is the variation in hiring difficulty by type of worker sought. Demand is particularly high for some types of IT workers and less high for other types. In the aftermath of the Y2K programming problem, demand for COBOL programmers is declining, while demand for e-commerce specialists and Java programmers is increasing. In general, the time to fill a position varies with the position, but not surprisingly, positions requiring workers with "hot" skills take longer to fill. And, in the absence of data across the different types of position in the IT sector and in IT-intensive industries, advocates often make statements that imply uniform difficulty in finding workers. While an undifferentiated approach does not necessarily provide a misleading description of tightness in the market, policy remedies that are premised on the assumption of homogeneity may be misdirected.

Finally, the variation in patterns and severity of difficulty experienced by individual employers is considerable, although the committee has not encountered an IT employer who has said that he or she has no difficulties in hiring. For example, the committee has heard reports of turnover rates—a contributor to vacancy rates—that vary from 5 percent to 50 percent per year, as against a national average rate of 11.7 percent per year for non-IT workers (Box 3.1). High turnover in a single job can result in an inflated number of vacancies. Consider, for example, a company of 100 employees experiencing no growth and with a turnover rate of 10 percent per year and an average time to fill a position of 6 months. This company will create five vacancies over the course of the year without an increase in the demand for IT work.

With all that said, it is possible to make a rough quantitative estimate of the vacancy rate. If the vacancy rate V is defined as the number of jobs open, measured as a fraction of the workforce (i.e., open jobs divided by

[3]As noted in Section 3.7.5, the extent to which tools, management, and organization can be used to reduce personnel needs is the subject of some controversy within the information technology community.

BOX 3.1
Two-Year Turnover Rates for IT and Non-IT Workers with Bachelor's Degrees and Higher, from 1995 to 1997

High turnover characterizes many firms in the IT sector and IT-intensive firms, especially the former. From 1995 to 1997 the turnover in IT positions by individuals with a bachelor's degree or higher who either changed employers or changed jobs for the same employer was 38.3 percent (for a turnover rate of 19.2 percent per year), with the rate being almost 60 percent (30 percent per year) for those 30 years of age or younger (Table 3.1.1). The comparable rate for non-IT workers with an equivalent educational level was 23.4 percent (11.7 percent per year) with about a 50 percent (25 percent per year) turnover rate in the 30 and under age group. Comparison of the rates for the other age groups shows a significant increase for IT workers, at least to the age of 60. The primary reasons for the turnover are pay, at 25.4 percent for IT workers and 13.7 percent for non-IT workers, and working conditions, at 14.8 percent for IT workers and 9.0 percent for non-IT workers. Other reasons for turnover are similar for both groups, except that being laid off accounts for 6.7 percent of IT worker turnover and 4.7 percent of non-IT worker turnover. There is little difference in the layoff rate for non-IT workers across age groups, but for IT workers over the age of 40 years the rate rises to 7.7 percent.

TABLE 3.1.1 Rates of Turnover by Age Group, 1995 to 1997

Age Group in Years	IT Workers	Non-IT Workers
30 or Under	58.3%	52.4%
31 to 40	41.3%	28.8%
41 to 50	34.1%	19.2%
51 to 60	29.9%	15.8%
Over 60	18.7%	10.5%
Total	38.3%	23.4%

SOURCE: NRC staff analysis, based on NSF SESTAT data from 1995 and 1997.

the number of jobs in the workforce), the following relationship can be used to estimate V:

$$V = (T + G) \times F,$$

where T is the rate of turnover (measured as percent of workforce turned over per year), G is the rate of net of growth in employment in the industry (measured as percentage of growth per year), and F is the average time to fill an open position (measured in years).

As described in Section 7.2, the Bureau of Labor Statistics (BLS) estimates a growth rate in Category 1 IT professions of about 8 percent per year. Joint Venture: Silicon Valley Network indicates a value for *F* of 3.7 months for "high-tech jobs" and further estimates that the turnover rate in Silicon Valley is twice the national average.[4] The national turnover rate for all workers is about 14 percent.[5] All of these numbers give a vacancy rate of about 11 percent in these IT professions, if the conditions that characterize the Silicon Valley IT workforce obtain nationally. But, of course, they do not—the IT labor market is much tighter in Silicon Valley than elsewhere—and, as noted in Chapter 2, the majority of employers of Category 1 IT professions are not IT-sector firms (and not in Silicon Valley either).

Note also two important characteristics of this model:

- Turnover and growth are portrayed as independent parameters. For the purpose of estimating vacancy rates as a function of turnover and growth, this is a reasonable portrayal. However, in fact turnover and growth are not likely to be independent of each other; that is, increased growth rates may well contribute to rising turnover rates as well. Such pressure arises from the fact that a worker may well leave a job in search of higher compensation—and in times of high growth in the IT sector and/or in IT-intensive industries, higher compensation may well be easier to find.
- In this model, vacancies due to turnover are three times the vacancies due to growth (i.e., 24 percent turnover per year divided by 8 percent growth per year). Workers who leave one position are available for another one. Put differently, if turnover could be reduced, say by a factor of 3 (from 24 percent to 8 percent), the vacancy rate would be half of what it currently is—a rate that would surely result in less concern. As noted above, high growth may also lead to higher vacancy rates, but because workers may leave a job for reasons other than higher compensation offered elsewhere, employers have a variety of nonfinancial as well as financial options for reducing turnover.

A more refined model separates out the IT sector (employing about 25 percent of the Category 1 IT professionals) from the IT-intensive com-

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[4]Joint Venture: Silicon Valley Network. 1999. *Joint Venture's Workforce Study: An Analysis of the Workforce Gap in Silicon Valley.* Palo Alto, Calif.: Joint Venture: Silicon Valley Network.

[5]The Bureau of National Affairs estimates that the turnover rate for all employees in 1998 averaged 1.1 percent per month, or about 14 percent per year. See Bureau of National Affairs. 1999. *Turnover Holds at Highest Levels of the 1990s, BNA Survey Finds.* Washington, D.C., March 17. Available online at <http://www.bna.com/press/trn98r1.htm>.

panies (employing the remainder). For this latter group, estimating the rate of employee turnover *T* as 20 percent per year, employment growth *G* as 8 percent per year (per BLS), and position time-to-fill *F* as 2 months (1/6 year) yields a vacancy rate of 5 percent for the workforce of the IT-intensive companies. Assuming that the Silicon Valley calculation for vacancy rate above is valid for IT-sector companies in all geographic regions (which it is not), a composite vacancy rate of about 6 to 7 percent is indicated.

3.3 THE INFERENCE OF A WORKER SHORTAGE

Accepting that most employers are indeed having some nontrivial difficulty in finding workers for their IT jobs, it is another conceptually distinct step to infer that there is a shortage of IT workers. An employer sees the workforce issue from the perspective of an individual firm. From this perspective, what matters is how many jobs are unfilled and how hard it is to attract workers to fill those jobs. But "shortage" is a concept that applies more broadly to the entire universe of firms that use IT workers and compares overall supply with overall demand for these workers. Thus, the relevant question is the extent to which the latter can be inferred from many individual employer reports regarding their difficulties.

Furthermore, part of the issue is terminological—the term "shortage" has many emotional connotations, and there is no uniformly accepted definition of the term among economists, to say nothing of common usage in discourse among employers. (Box 3.2 provides several definitions that have been presented to the committee in various forms.)

BOX 3.2
Concepts of an Occupational Labor Shortage

Perhaps surprisingly, there is no standard definition of an occupational labor shortage. In the "social demand model," members of society believe that the labor market outcome results in too few workers in an occupation; in "market disequilibrium models," the amount of labor demanded exceeds what is supplied at the prevailing wage rate.

The Social Demand Model

Some analysts consider a shortage to be present if the number of workers in an occupation is less than what is considered the socially desired number. Under this

continued

BOX 3.2 continued

definition, a shortage of engineers exists if the analyst making the determination concludes that society would be better off if there were more engineers. This type of definition does not imply that the labor market is in disequilibrium; instead it describes a situation where the person who claims there is a shortage does not like the market's results. To quote Arrow and Capron, "Careful reading of such statements [of shortage] indicates that the speakers have in effect been saying: There are not as many engineers and scientists as this nation should have in order to do all the things that need doing such as maintaining our rapid rate of technological progress, raising our standard of living, keeping us militarily strong, etc. In other words, they are saying that (in the economic sense) demand for technically skilled manpower *ought* to be greater than it is—it is really a shortage of *demand* for scientists and engineers that concerns them."[1]

Market Disequilibrium Models

The committee uses the term "market disequilibrium models" to describe situations where the number of workers willing to work in an occupation is less than the number of workers employers would like to hire at the prevailing wage rate and where something prevents an adjustment that results in the market achieving an equilibrium. An equilibrium exists when the number of workers willing to work at the market wage rate is exactly equal to the number of workers employers would like to hire at that wage.

Why might we have market disequilibrium occupational shortages? One possibility is that government or institutional forces restrict wage rates or entry into an occupation. For example, if the government wage structure limited the salary of IT workers in the federal government to half of what they could receive in the private sector, the number of workers demanded would exceed the number willing to work in the federal government, and there would be a shortage.

Another reason that shortages might exist is that market changes occur faster than labor supply can adjust. In occupations such as IT, where it takes a number of years for people to gain the skills necessary to participate, sustained increases in the demand for labor can prevent supply from "catching up," at least for a period of several years. A number of studies have developed formal models and applied them to the market for engineers, scientists, and IT workers.[2] What these models have in common is that so long as demand grows more rapidly than supply grows, it is impossible for the market to reach equilibrium.

[1]See Arrow, Kenneth J., and William M. Capron. 1959. "Dynamic Shortages and Price Rises: The Engineer-Scientist Case," *Quarterly Journal of Economics* (73)2:292-308.

[2]See, for example, Arrow and Capron, 1959, "Dynamic Shortages and Price Rises: The Engineer-Scientist Case"; Blank, David J., and George J. Stigler, 1957, *The Demand and Supply of Scientific Personnel*, New York, National Bureau of Economic Research; Radner, Roy, 2000, "A Simple Model of Aggregate IT Labor Market Dynamics," Stern School, New York University, May 7; and Ryoo, J., and S. Rosen, 1996, "The Market for Engineers," National Bureau of Economic Research, summarized in *Forecasting Demand for and Supply of Doctoral Scientists and Engineers*, Office of Scientific and Engineering Personnel, National Research Council, Washington, D.C.: National Academy Press (forthcoming).

3.3.1 The Overall Labor Market

It is important to frame any discussion of shortages in the IT labor market in the context of tightness in the overall labor market. The labor market is tight across the entire economy, not just in IT. Thus, individuals (incumbent workers, those entering the labor force, and those that may leave the labor force) have many more options available to them than when the overall labor market is more slack. Therefore, individuals who might be motivated to move into IT for economic reasons have many other fields in which they may work productively. (Of course, tightness in the overall labor market depends on the state of the economy, now in an unprecedented tenth year of expansion. It is anyone's guess when the economy will experience a downturn, but such a downturn would inevitably affect analysis of the workforce situation.)

Note also that tightness in the labor market for IT workers is felt the world over (Box 3.3).

3.3.2 The Size of the Applicant Pool

The size of the labor pool available for, and willing and qualified to do, IT work is a central issue in assessing the balance between supply and demand. Perhaps the most critical point is that the size of the relevant labor pool is not fixed—many factors affect it (e.g., compensation and wages, employer willingness to provide training for new hires[6]). But there is no direct measure of this pool, and much of the controversy about tightness in the labor market involves just this point.

The number of applicants for an open IT job is often cited as an indication that there are large numbers of skilled workers currently available.[7] However, most individuals seeking employment in IT apply for multiple jobs. From the job seeker's perspective, it makes sense to send out many applications, to increase the likelihood that a promising contact will be established. The job seeker may also apply for jobs for which s/he is only marginally qualified, or even unqualified, on the theory that a high probability of rejection is better than the certainty of rejection if the individual does not apply at all for a given job. And even individuals who are employed may be "testing the market," if nothing else to main-

[6]As discussed at greater length in Chapter 7, employers are often concerned that they will not reap the full benefits of investments they make in training employees because employees are generally free to leave for other employment. Thus, they may be less willing to provide training than they might otherwise be.

[7]Matloff, Norman, "Debunking the Myth of a Desperate Software Labor Shortage," testimony to the U.S. House Judiciary Committee Subcommittee on Immigration, April 1998.

BOX 3.3
Tightness in the IT Labor Market Around the World

"To get one man, Erik Masing bought a whole company. . . . Mr. Masing's experience shows the extent to which lawmakers and bureaucrats [in Germany] have tried to slam the door on foreign high-tech professionals even as the nation's employers bemoan a shortage of engineers and programmers." (Zachary, G. Pascal. 2000. "As High-Tech Jobs Go Begging, Germany Is Loath to Import Talent," *Wall Street Journal*, January 17, pp. A1, A10)

"The information technology industry faces a common problem of global proportions: Plenty of work to do and not enough people to do it. . . . [CIOs and IT executives around the world say that if the acute skills and labor shortages aren't addressed, national IT sectors will lose their competitive edge, economies will suffer, and innovation will slow.] The problem appears to be most threatening in Europe and Asia, where the scarcity of IT workers could stifle hopes for long-term economic growth. In Germany and the U.K., there's a 25 percent gap between jobs created and jobs filled. That's quite a disparity, considering that the countries together account for half of Europe's total IT production, according to the German Information Technology Association." (Busse, Torsten, and Mary Brandel. 1998. "The Skills Struggle," *Computerworld Global Innovators*, December 7, pp. 12-13)

". . . [T]he skills shortage remains one of the greatest bottlenecks to building a broad Asian base of new technology development. . . . " (Guth, Rob, et al. 1998. "Despite Rampant Unemployment, Lack of IT Skills Threatens Asian Growth," *Computerworld Global Innovators*, December 7, p. 15)

"In Venezuela . . . the demand for skilled IT professionals has skyrocketed in the past two and a half years . . . says Jorge Mora, IS manager." (Perez, Juan Carlos. 1998. "In Most Regions, Labor Supply Can't Meet Skyrocketing Demand," *Computerworld Global Innovators*, December 7, p. 17)

"While we are again showing how not to have the right conversation about foreign-born high-tech workers . . . the rest of the developed world is waking up to the fact that America's cherry-picking of international tech talent amounts to an enormous competitive advantage . . . Our competitors are doing something about it. Germany, Canada, the United Kingdom and Australia, among others, have already entered or are preparing to enter the sweepstakes for high-tech workers." (Papademetriou, Demetrios G. 2000. "The Global Fight for Talent," *Washington Post*, March 21, p. A25)

tain an understanding of trends in the sector in which the job seeker is interested and knowledge of his/her market worth.

Furthermore, the trend toward multiple applications has been fueled by the ease of posting resumes on the Internet. The use of electronic resumes and Internet-based recruiting is increasingly common in many sectors of the economy, and is especially common in the IT sector. The number of job-related Web sites is growing rapidly, and the number of resumes posted already runs in the millions (4.9 million electronic resumes were posted in

1999, and this figure is forecast to grow to over 16 million by 2002).[8] It is not unusual to receive hundreds or thousands of resumes in the process of filling desirable IT jobs.[9] As a result, while an individual employer may in fact receive many applications from different individuals, a group of employers may be receiving applications from the same pool of applicants, and so the size of the overall applicant "pool" is not as large as it might appear extrapolating from the experiences of individual employers.

Analysts also sometimes point to the number of individuals graduating yearly with computer science or related degrees and to the magnitude of layoffs in the IT sector. In the first case, the fact that many IT occupations—especially in Category 2—do not require significant amounts of formal IT training suggests that the number of computer science (CS) graduates produced yearly is not a good indicator for the labor supply as a whole taken across all IT occupations. On the other hand, it is difficult if not impossible to determine how many non-CS graduates have the skills to enter the IT workforce immediately.

As for layoffs in the IT sector, they are considerable. For example, the outplacement firm of Challenger, Gray, and Christmas reported that, over the first 11 months of 1999, the computer industry had laid off 60,000 employees.[10] This number is equal to approximately 3 percent of total employment in the "computer services" industry, as defined by the Bureau of Labor Statistics.[11] Whether these individuals constitute a ready, immediate, and usable source of supply is unclear. On the one hand, they may not necessarily have IT skills, because, like all companies, IT firms employ many support staff, clerical staff, building maintenance staff, and others. And, even if those laid off are technical workers, they may or may not have the skills needed by employers that are growing and hiring. On the other hand, some organizations such as SAIC and the Communications Workers of America have demonstrated that to a certain extent, retraining of laid-off "employees" (i.e., ex-military personnel) to undertake IT work can be possible. The supply of "qualified" workers made available by layoffs may well depend on the efforts that are undertaken to enhance their technical skills.

Finally, the size of the relevant applicant pool depends greatly on policy

[8]Vaas, L., A. Chen, and M. Hicks. 2000. "Web Recruiting Takes Off." *PC Week*, January 17, pp. 57-68.

[9]Murphy, Kevin, and Zinta Byrne, "Applications of Structured Assessment in the IT Workforce," commissioned paper prepared for the Committee on Workforce Needs in Information Technology, March 2000.

[10]*USA Today*, December 10, 1999, p. A-1.

[11]BLS uses the North American Industrial Classification System, which defines "computer-related business services" as companies that provide software services, data processing, and information services, and rental, maintenance, and other computer-related services.

decisions that regulate the number of foreign IT workers who may work in the United States. These include skilled IT workers on H1-B temporary visas (who must have at least a bachelor's degree), permanent immigrants, and foreign students graduating from U.S. colleges and universities.

3.3.3 Skills Shortages Versus Worker Shortages

If there is a "shortage," what is in short supply? In the common formulation described at the start of this chapter (and most often articulated by IT employers), the shortage is one of workers. But in the IT workplace, not any warm body can be an IT worker, nor are IT workers interchangeable with each other. Attention must also be paid to the ability of putative workers to do IT work. Thus, any shortage in fact refers not to IT workers but to qualified IT workers—with all of the discussion and nuance that relates to the definition of "qualified." Specifically, critics of employer practices believe that the job definitions used by employers overstate or exaggerate the qualifications that are actually needed to perform the work required in job openings. Further, they argue, the employer demand for a "perfect" fit between an employee and a posted job opening creates artificial difficulties in finding human resources who would be able to do the work of a posted job with only a "little bit" of training.

3.3.4 Compensation

Compensation must figure prominently in any discussion that relates the supply of labor to demand. The basic economic model is the following: Demand for labor relates the number of jobs that are available as a function of the compensation that employers are willing to offer for those jobs. Supply of labor relates the number of people willing to work as a function of the compensation that employers are willing to offer. When demand exceeds supply in a particular occupation, compensation tends to rise relative to compensation in other occupations that require similar education, effort, and working conditions. Rising compensation attracts into a field more people who are willing to work (increasing the current supply), decreases demand for those workers, and signals to those capable of being trained to begin studying for these jobs (increasing the future supply of new entrants).[12]

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[12]One caveat is needed. To the extent that high school students take courses of study that make it more difficult to study IT-related subjects in college, such students will be unable to respond effectively to market signals indicating the desirability of the IT field. While these students may not be precluded from undergraduate study in IT-related areas, they may well have to take remedial courses after high school—and thus the entry of these students into IT work is likely to be delayed even further.

To the extent that compensation does not rise, the signal is not sent to labor market entrants, and thus the potential labor force for these occupations is sparser than it would otherwise be. Potential workers seeing rising compensation in IT will move preferentially into the IT field by preparing themselves by education (in the case of students selecting courses of study[13]) or by retraining in the appropriate disciplines for IT work (in the case of workers in other occupations). Typically, the greater are the incentives provided by employers to induce workers into the occupation of interest, the quicker and greater will be the response by potential entrants. This phenomenon works to restore equilibrium, and over time, a new equilibrium is reached at a new intersection of the labor supply and demand curves (with higher compensation and more workers).[14]

As a rule, rising relative compensation is seen by economists as the most reliable indicator of tight labor markets or shortages. As noted in Chapter 2, Current Population Survey (CPS) data indicate average annual wage increases in constant dollars of 3.8 and 4.5 percent for computer programmers and for computer systems analysts and scientists, respectively, during the period from 1996 to 1999, rates somewhat higher than the average annual wage increases of 3.2 percent for professional specialty occupations.

Does such an increase in wages over this time period warrant a conclusion of an IT labor shortage? Because there is no universally accepted wage indicator of shortage, this question does not have a definitive answer. A common view held by those who do not believe that there is a "real" labor shortage of IT workers is that employer difficulties in finding

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[13]First-year college students will often choose majors based on what they expect demand to be for those majors when they graduate. While it is highly unlikely that college students select majors on the basis of BLS wage data, media coverage of the information technology sector has often highlighted the riches that are available to those working in it, and it is not implausible that students are influenced by such coverage. In addition, students may well choose their major based on factors such as "word of mouth" regarding compensation and other benefits. (See, for example, Freeman, Richard B., 1973, "A Cobweb Model of the Supply and Starting Salaries of Engineers," *Industrial and Labor Relations Review* 30(2):236-248, which documented undergraduate engineering students behaving as though they know—in relatively short order—highly precise variations in the wage data.)

[14]Note that in general, demand is more elastic for firms than for an industry or the entire economy (see, for example, Eherenberg, Ronald, and Robert Smith. 1993. *Modern Labor Economics: Theory and Public Policy*. Fifth Edition. New York: Harper Collins). An individual firm can quickly obtain all the workers it wants by raising compensation to a sufficiently high level, because it can recruit workers from other firms who have similar positions and comparable skills and experience. Of course, other individual firms can react by matching the increased levels of compensation, so that any market advantage gained by raising compensation is transient. The industry as a whole does not have this alternative, and so it is fair to say that the labor market for a firm is generally more elastic (compensation-sensitive) than the labor market for an industry as a whole.

suitable workers stem primarily from an unwillingness to invest more in human capital, both in the form of higher salaries and other compensation and in the form of training (and retraining). They further believe that employers' desires to minimize labor costs lead them to favor younger workers and foreign workers because their services can be acquired less expensively than would be the case if older workers and/or permanent U.S. workers were hired.

While the data indicate an increase in wages for IT workers in the late 1990s when economic theory would predict one, a historical perspective is obtained by comparing this increase to increases for other occupations at a time of strong demand for new workers. For example, demand for nurses was strong during the late 1980s. The committee's analysis of data from the CPS indicates that from 1987 to 1990 the average annual increase in hourly wages for nurses was 29 percent higher than that for women in professional specialty occupations. The average annual increase in income for computer systems analysts and scientists was 41 percent higher than that for individuals in professional specialty occupations from 1996 to 1999, while the average annual increase in income for computer programmers was 19 percent higher than that for individuals in professional specialty occupations during that period.

In any event, there are several practical difficulties with using wage data to determine the existence of a labor shortage. For example, raising wages may be one of the last things employers do to respond to a shortage,[15] so the evidence for tightness in today's labor market may not be reflected in the data cited. An employer may be reluctant to raise wages for incoming workers because of concerns over equity and morale within the firm.[16] Most serious, though, is the fact that BLS wage data are incomplete.[17]

In particular, BLS data on base wages do not reflect the complexity of compensation packages—they do not reflect variable pay such as project bonuses, hiring bonuses, overall company bonuses, or senior personnel retention bonuses. Respondents to the BLS questionnaire may—or may not—report total cash payments rather than wages, and there is no way to

[15]See Barnow, Burt, John Trutko, and Robert Lerman. 1998. *Skills Mismatches and Worker Shortages: The Problem and Appropriate Responses.* Draft Final Report. Washington, D.C.: Urban Institute. February 25.

[16]Barnow et al., 1998, *Skills Mismatches and Worker Shortages*.

[17]The significance of the incompleteness is not entirely clear. In particular, though the BLS data do not include nonwage compensation (which affects the overall level), the impact of this omission on inferences based on trends over time is not clear. There are good reasons to believe that the omission does affect these inferences (e.g., because of rising value for stock options and equity stakes), but this effect has not been conclusively established.

disaggregate these responses. Furthermore, because the wage signal of increasing tightness in the labor market is a trend of increasing compensation (implying comparisons over time), BLS data themselves cannot signal trends if cash payments other than base wages constitute a changing fraction of total compensation. Similar comments apply to stock options and equity stakes, which the BLS data also do not include, and which are also important elements of compensation in much of the IT sector and in some IT-intensive firms as well. Indeed, for individuals highly motivated by financial incentives, stock options and equity stakes are far more likely than wages to be the road to riches.

Some data on total compensation packages are provided by a private survey,[18] which indicates that nonsalary cash awards and long-term incentives such as stock options range from 23 percent of total compensation (6 percent cash awards, 17 percent long-term incentive) for technical staff such as software design engineers, software operating systems engineers, and research scientists to 48 percent (6 percent cash awards, 42 percent long-term incentive) for managerial staff such as software engineer managers and research scientist managers. Further, data from this private survey, presented in Box 3.4, suggest that the growth rates in base salary for technical staff in the software sector are approximately consistent with the growth in wages as indicated in the BLS data. However, growth rates in total compensation are higher than growth rates in base salary by 40 percent (2 percentage points) for technical staff. (Technical staff are approximately those represented in the BLS job titles of computer scientist, systems analyst, and computer programmer.) In addition, Box 3.4 provides some evidence that growth rates in base salary and total compensation are significantly higher for managerial staff in the software sector than for technical staff. This information would suggest that tightness in the managerial labor market is significantly higher than tightness in the technical labor market.

The committee notes that the bias induced by the lack of data on nonwage compensation is likely to be larger for smaller companies where, at least until recently, many workers have taken equity stakes or stock options in lieu of greater base pay. Such a bias would tend to understate

[18]Summary results from a private survey were provided to the committee. The data used for this study were taken from the SC/CHiPS Professional & Managerial (P&M) Total Compensation Survey for 1999, 1998, and 1997. Now in its eleventh year, SC/CHiPS is led by a steering committee of firms and is managed by a partnership between Executive Alliance, an information technology human resources consulting firm, and Buck Consultants, an international firm specializing in actuarial and benefits services. The universe of firms participating in the 1999 version of the survey included approximately 180 high-technology companies, ranging from Microsoft, Apple Computer, Intel, IBM, and Oracle to medium-size and smaller firms as well.

BOX 3.4
Growth in Total Compensation for IT Workers from 1997 to 1999

Table 3.4.1 provides annualized growth rates for the period from 1997 to 1999 for the three different components of compensation studied. Each component of the total compensation package is valued in terms of pretax annualized dollars. "Base salary" is the weighted mean base salary as of April 1 of the year surveyed. "Cash awards" is the weighted mean short-term incentive award paid to the incumbents reporting, excluding $0 awards, during the annual period ending April 1 of the year surveyed. "Long-term incentives" is the weighted mean value of long-term incentives awarded, including $0 awards, during the annual period ending April 1 of the year surveyed, using the Black-Scholes Option Pricing Model.

Note that a rational valuation of stock options is highly problematic for companies that have not yet gone public. While the Financial Accounting Standards Board (FASB) has established rules for valuing stock options provided by such companies (see FASB, Statement No. 123: *Accounting for Stock-Based Compensation*, October 1995), making a reasonable estimate of the likelihood that any specific company will be able to go public is next to impossible.

TABLE 3.4.1 Annual Rate of Growth in Three Components of Compensation for IT Workers, 1997 to 1999

	Base Salary	Cash Awards	Long-Term Incentives	Total	Number of Incumbents (1999)
Technical staff—software	5.12%	15.85%	36.79%	7.15%	35,022
Technical staff—all high-technology firms	5.24%	–3.35%	44.06%	7.01%	264,429
Managerial jobs—software	6.76%	32.28%	95.77%	24.95%	5,339
Managerial jobs—all high-technology firms	4.59%	7.45%	66.32%	14.27%	37,042

SOURCE: SC/CHiPS Professional and Managerial Total Compensation Survey for 1999, 1998, and 1997, published by Executive Alliance. Available online at <http://www.executivealliance.com/services/surveys/services-surveys-default.htm>.

compensation for workers in this category, who tend to work in the smaller companies. By contrast, some larger, more established firms report increasing pressure to raise base salaries rather than stock options, indicating a different trend from that generally seen in the compensation pattern of small companies. Many new workers at the larger companies view the large gains in stock prices of the past as unsustainable and thus value them less as part of the compensation package. Thus, at some very successful companies new entrants are demanding higher salaries, but total compensation may not be higher.

3.3.5 Time to Reach Equilibrium

When supply and demand are not in balance, labor markets will take some time to reach equilibrium. (Box 3.5 describes some reasons that markets may take a longer rather than a shorter time to clear.) But the argument that a labor market will eventually reach equilibrium is of little comfort to IT employers, who operate in a competitive and fast-paced environment (as described in Chapter 1) and are concerned primarily with the short term. In the short run, supply to employers as a whole is relatively inelastic, meaning that the number of workers willing to work at a particular wage does not change much when the wage is increased. However, employment needs must be met rapidly (on time scales of weeks and months, not years) if they are to be relevant to the business. How these needs are met in the short run, however, can have important implications for the long-term adjustment of supply.

In addition, economic theory predicts that there are some circumstances in which the demand for labor continually increases faster than the supply of labor, and the market does not even approach an equilibrium. In this situation, the problem is not necessarily that workers or employers cannot adjust; rather, the problem is that they do not adjust fast enough, or do not predict the future sufficiently well.[19]

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[19]Several authors have developed models of labor market equilibrium and disequilibrium. Arrow and Capron (1959) describe a situation in which demand rises (the demand curve shifts up) but supply does not rise (the supply curve does not shift), and the wage rises at a rate that is proportional to the size of the gap between demand and supply. As the wage rises, the quantity demanded falls, and asymptotically (in infinite time) a new equilibrium is reached with a higher wage and the quantity demanded back at its original value. In contrast, the present paragraph describes a situation in which demand rises, causing wages to rise, and supply also rises in response to the rise in wages. If demand eventually levels off, then supply will eventually catch up (although maybe only asymptotically). If demand continues to rise, then supply may never catch up. In the model of Radner (2000), this happens because the supply increases at a rate that is proportional to the gap between the current wage and the wage of workers in other occupations (skill categories) with comparably long education and training. As demand continues to increase, the wage gap also increases in magnitude, and hence so does the gap between demand and supply (although the gaps may remain constant in percentage terms). On the other hand, in the model of Ryoo and Rosen (1996), supply may catch up to a continually increasing demand, because potential entrants have "rational expectations" about the labor market and exactly the right number plan ahead to enter the labor market in order to equilibrate it. (For full references to the cited articles, see the footnotes to Box 3.2.)

BOX 3.5
Factors Impeding the Clearing of Labor Markets

Labor markets constantly experience changes in supply and demand that cause them to deviate from equilibrium. As a result, firms and workers will take actions that will move the labor market toward equilibrium. But the time scale on which equilibrium can be restored is short only when the market operates with near perfection. Two important factors that may delay the market in reaching equilibrium are described below.

- *Slow response time or small responses by employers*. Even after a firm recognizes that the labor market is tight, it may well wait until it believes that the labor market will continue to be tight. Waiting to respond, or limiting the extent of the firm's response, is rational even when the market is tight because most responses have significant costs. For example, a serious training program requires a major commitment from the firms to plan and implement. Wage increases that might be necessary to attract new workers must usually be passed on to incumbent workers as well; thus, a firm may well attempt to limit the magnitude of a wage response.
- *Slow response time by workers*. Once workers are aware of opportunities in IT, their response will depend on the time required to qualify for the positions and the costs and benefits of obtaining any needed qualifications, applying for the positions, and changing jobs. Typically, the greater are the incentives provided by employers to induce workers to enter the occupation of interest, the quicker and greater will be the response by potential entrants.

The responsiveness of workers depends on two factors:

—*Training time*, which is the time needed to train or educate an individual to do IT work. As noted in the text of this chapter, training time depends on both the kind of work that an individual is being trained to do and the background and experience that the individual brings to the training or education.
—*Training capacity of the relevant institutions*, which include all of the institutions devoted to formal education and learning (both those that produce degrees and those that do not) and the businesses that provide situated "on-the-job" training.

Assuming constant demand, it is not unreasonable to expect the market to clear on a time scale governed by training time and training capacity.

SOURCE: Barnow, Burt, John Trutko, and Robert Lerman. 1998. *Skills Mismatches and Worker Shortages: The Problem and Appropriate Responses.* Draft Final Report. Washington, D.C.: Urban Institute, February 25.

3.4 THE COMMITTEE'S VIEW OF THE IT LABOR MARKET

Issues related to the IT workforce attract many advocates, who have different interests, objectives, and perspectives. It is perhaps the nature of an intense political argument that these various advocates spend a significant amount of energy in attacking the positions and views of those who disagree with them. Nevertheless, it is the committee's view that all of these parties have legitimate perspectives that can shed useful light on the relevant issues, even though no one party has a monopoly on the "truth."

The committee has chosen the term "tightness" rather than "shortage" for several reasons. First, there is no universally accepted definition of "shortage." Second, the use of the term "shortage" can imply a binary condition—either there is or is not a shortage. But the term "tightness" can encompass "shortage" as its limiting case—the condition in which employers find it impossible to find qualified workers no matter what they pay or how long they wait—and still account for the continuum nature of the phenomenon. Third, the committee feels that "tightness" is a broader and more encompassing term that does better justice to the complexity of the issue.

Thus, the committee's characterization of the IT labor market is the following:

Today, the IT labor market is tight, though the nature and extent of such tightness vary by employer, by type of IT work involved, and by geographical locale. The fundamental driver of this tightness is growth in the use of IT throughout a strong economy, a tightness that is significantly exacerbated by the currently low unemployment rate in the overall labor market.

As for the implications of the available wage data, they are consistent with the committee's characterization of the issue. BLS data show wages across the Category 1 IT professions rising more rapidly than wages for scientific and engineering occupations generally, but not at a dramatically rapid rate. This is consistent with some degree of tightness in the overall IT labor market, though it also suggests that extreme tightness does not characterize the entire IT labor market. But BLS data are highly aggregated, and indeed lump together many market segments within "core" IT professions. On the other hand, private market surveys do indicate much more rapidly rising wages in certain segments, for certain types of employers, and for certain specialties within these professions. Accordingly, these data suggest that the IT labor market is highly segmented, and that certain segments experience much higher degrees of tightness in the overall market.

3.5 SEGMENTATION OF DEMAND FOR IT WORKERS

The term "demand for IT workers" or "tightness in the IT labor market" masks nuances that are critical for understanding the IT labor market. Labor market dynamics are very different in different segments—and different enough that discussing the IT labor market in an undifferentiated manner glosses over important characteristics and features.

For example, growth in the demand for IT workers is not uniform across all IT occupations. Coarse as they are, BLS job projections through 2008 indicate the most significant growth in the demand for computer scientists, computer engineers, and systems analysts, with much less significant growth in demand for computer programmers.

A second distinction is the nature of the skills that are in demand. Today, Category 1 workers involved in the design and creation of software and hardware systems are in particularly great demand. Recent studies and field hearings of the committee also indicate tightness in labor markets for computer programmers experienced in applying Enterprise Resource Programs (ERPs) and object-oriented programming languages (e.g., Java). In addition to these workers, Internet specialists and workers experienced in e-commerce are in great demand, as are faculty to educate the next generation of IT workers.

The segments of greatest workforce demand vary depending on technology and trends in the industry, and these segments can manifest themselves rapidly with little warning. For example, the explosion of Web activity in recent years has created a huge demand for Web-savvy IT workers. The movement to "network computing" and applications service providers—while somewhat slower than the expansion of Web activity—is likely to lead to a large demand for IT workers who understand and are proficient in mainframe computing. Similar comments apply to skills required for using different types of software products. Using new packages or languages poses a problem of finding adequate numbers of trained workers because of lag time in training and education and lack of formal skill development systems, coupled the recent rapid expansion in these development and application areas. As a rule, emerging and broadly useful technologies create high and rapidly increasing demand for skills (and experience) with that technology. Shifts such as these in workforce demand cannot be anticipated with any precision (because the precise path of future technological developments is uncertain), but such shifts are bound to occur.

Another skill set in high demand is nontechnical skills in otherwise technically qualified people. These skills include communication and the social skills and ability to work in a team. These skills have become more important for a number of reasons. The technology has become more complex and more ubiquitous, especially in mission-critical applications, forcing system development to occur in a team environment; the needs of the end user play an increasingly important role in defining system performance requirements, forcing developers to better understand a user's needs (even when he does not understand them himself); and the methodology of development has changed in many cases, now emphasizing the use of cross-functional teams that must interact with each other.

Industry type also affects the types of skills in demand. For example, software development firms generally seek individuals with tool development experience. Furthermore, "brilliance" is in high demand among such firms, and individuals with extraordinary talent can make huge differences in the productivity and output of a team. By comparison, IT-intensive firms tend to seek individuals with experience in implementing applications and with a good understanding of the firms' core business.

A third distinction is demand for certain types of workers. In particular, IT-sector and IT-intensive firms have a very strong preference for workers with real-world experience in the work of interest to those firms. In some cases, experience with applying a certain technology is the requirement. In other cases, the essential skill is project management coupled with deep technical knowledge.[20]

A fourth distinction is geography. Tightness in the labor market can be exacerbated by local conditions. For example, the lack of affordable housing in the Silicon Valley area is a disincentive for potential IT workers to relocate there.[21] (At the same time, many Silicon Valley firms capitalize on their proximity to other similar firms as a recruiting draw, offering the promise of exposure to the cutting edge of technologies being developed by many firms there.) Tightness has also been acute in the Seattle area, given the large-scale hiring needs of Microsoft and a range of Internet-based firms and the apparent historical pattern of the Seattle region as a net importer of IT workers. Other metro areas, too, have had tight IT labor markets that have pushed firms to recruit nationally and internationally. For example, in Austin, the committee heard that strong job growth, and not turnover, was responsible for the region's tight IT labor market. One firm in this burgeoning high-tech area that was brought to the committee's attention had grown from 120 to 800 employees in 1 year.

[20]This combined requirement for management skills and deep technical knowledge seems to be more characteristic of the IT sector than in other industries, where less technical or less technology-specific background is required for management (Salzman, Hal, "Information Technology Labor Markets," commissioned paper prepared for the Committee on Workforce Needs in Information Technology, 2000).

[21]Joint Venture: Silicon Valley Network. 1999. *Joint Venture's Workforce Study: An Analysis of the Workforce Gap in Silicon Valley.* Palo Alto, Calif.: Joint Venture: Silicon Valley Network.

Regional supply issues may also affect different types of workers differently. For example, systems development work tends to draw workers from a much more national market (with systems development personnel being more geographically mobile), while demands for network and systems administration work tend to be satisfied with labor recruited locally (from the local labor market and neighboring education and training institutions).

A fifth distinction is that the character of workforce demand is rather different for firms with different histories. For example, a start-up company generally faces a more uncertain economic future than does a well-established company. Employees at a start-up company may well receive smaller salaries than those they would be able to command at a more well-established company in return for greater degrees of equity stake.[22] (Though more risky than compensation offered as salary, equity stakes are, of course, the workforce equivalent of the "lottery-win" potential offered by initial public offerings, or IPOs.) Thus, an individual's degree of risk tolerance and/or financial ambition influence the labor pool from which a start-up company can draw. More generally, smaller companies are generally less constrained on compensation than larger companies by personnel structures and conditions and requirements to maintain pay scales and equity. (An exception is large consulting firms, which are generally able to pass on labor costs and staff for short-term project needs, and thus can offer compensation packages in excess of what their clients can offer—example: Peoplesoft implementation. Consulting firms also offer the opportunity to obtain a variety of experience and learn a range of skills, which is desirable for workers and increases their future market worth.)

Compared to larger, more established firms, small start-ups also tend to offer less regimented workplaces and the opportunity to work on technology frontiers. And because they are smaller, they provide opportunities for individuals to have a large impact that might not be available in larger companies. The flip side of smaller companies is that their workforces have less depth and less capacity to mitigate the impact of shortages—one open position has less impact on a project of 10 people than on a project of 3 people. Furthermore, a small start-up lacks an established market presence, and so the impact of workforce shortages on survival is more severe.

[22]More recently (in the last year or so), anecdotal evidence suggests that at least in some geographical areas, stock options and equity stakes provide insufficient financial incentives for certain workers in start-up companies, and so such workers command higher salaries than they might have in the more distant past, especially as compared with more well established firms.

3.6 A PERSPECTIVE ON THE FEDERAL GOVERNMENT AND WORKFORCE ISSUES IN IT

Although the U.S. government's need for IT workers is not a primary focus of this report, the committee believes that the U.S. government is itself a major stakeholder because it, just like enterprises in the private sector, is becoming increasingly dependent on information technology. The following description of challenges facing government agencies is based mostly on a public session held February 29, 2000, in Fairfax, Virginia, with the committee.[23]

3.6.1 Competition with the Private Sector

Government agencies are severely challenged in recruiting and retaining talented information technology workers, particularly workers with newer technology skills and those at entry-level jobs. Government compensation packages (discussed in more detail below) and widespread government use of information technologies that are not at the leading edge of technology create disincentives for many people to take government jobs in IT.

As a result, most agencies are operating with high vacancy rates and experiencing high attrition rates in their IT workforces. For example, the Department of Defense is budgeted to operate with a combined IT workforce of approximately 60,000 and reported a current vacancy rate of 10 to 12 percent, with expectations that that figure will rise in the coming years. The Office of Personnel Management (OPM) believes that across the federal government, demand outstrips supply in the IT field. It has projected that between now and 2006, there will be approximately 37,000 positions to fill. This calculation takes into account new job growth, attrition, and retirements.

To date, government has tended to experience the highest degrees of labor market tightness for qualified professionals seeking entry-level jobs. A survey conducted for the Treasury Department noted that recruitment efforts were not netting younger workers, ostensibly with newer or more unique technical skills, nor were recruits coming from the private sector.[24] For reference, in 1993, two-thirds of new IT hires at Treasury came from

[23]These challenges are also documented in the CIO Council report of June 1999 (Hobbs, Ira, and Gloria Parker. 1999. *Meeting the Federal IT Workforce Challenge,* Washington, D.C.: CIO Council Education and Training Committee, June. Available online at <http://www.cio.gov/docs/Documents.htm#itwork>).

[24]Thompson, Fred. 1999. "Responding to the Crisis in Information Technology Skills," report to the Secretary of the Treasury, February. Available online at <http://www.treas.gov/itwip>.

the private sector; that figure has shrunk to one in eight new hires. The federal government is churning its current IT workforce or promoting non-IT federal workers into IT positions. Those people coming into IT careers at Treasury are on average older than those who are already in those careers and have less formal training than those who are already in those careers. Treasury reported that it is trying to use the same tools and technologies that the private sector is using—Oracle, Peoplesoft—but there is an immense issue of a shortage of database administrators or security experts everywhere, which hampers federal recruiting efforts.

About half of the federal IT workforce will be eligible to retire over the next decade. For example, the Department of the Treasury has an IT workforce of approximately 9,300 employees (approximately 9 percent of the total federal IT workforce),[25] with an average age of 44 years, and there are more IT workers over 55 years of age than under age 30. At the Internal Revenue Service, there are nine times as many IT employees over 55 as there are under 30. If the private sector keeps offering incentives to federal workers with particular IT skill sets to leave, the federal government is at serious risk of losing staff at a time when more and more members of the public are asking for greater access to information from the government.

Competition with the private sector is manifested in other ways as well. In particular, government representatives testified to the committee that private industry is often suspicious of the government's interest in achieving greater degrees of technological sophistication—especially since expertise and sophistication are needed to exercise proper oversight over IT contracts with the private sector.

3.6.2 Incentives

As noted above, IT workers are motivated by many things other than money. Nevertheless, government service pay scales appear to be a key barrier to recruiting and retaining IT workers. It is axiomatic that government cannot offer stock options or equity stakes that promise riches. But the civilian pay scale is also significantly lower than what IT professionals can command in the private sector. The bonus system consists of about a 1 to 2 percent bonus based on merit. In comparison, the NACE Web site listed 1999 starting salaries for computer science graduates at $45,000. At the Department of Defense (DOD), CS graduates are ranked at GS-7 step 4 or 5, about $32,000. Furthermore, the system is based on seniority, so the first person to receive a reduction-in-force (RIF) notice tends to be the

[25] Thompson, 1999, "Responding to the Crisis in Information Technology Skills."

most junior person on the payroll, who probably has the most recent technology education and skills.

On the upper end of the scale, Army research laboratories hire Ph.D.s who can command salaries of $60,000 to $70,000, equivalent to a GS-13 or GS-14. However, this practice can create a morale problem when other employees with 20+ years of experience who are not GS-14s learn of a new hire with little work experience being hired at a higher grade. Some branches of the service, such as the Navy, have developed strategies to be able to offer market rate to employees and incentive bonuses for working in undesirable locations or other hardship situations. The Army is doing pay banding, whereby it can offer a wide range of starting salaries, but again, morale can be adversely affected by these procedures. Furthermore, agency budgets often do not have enough money appropriated to cover the civilian pay of people on board, much less vacancies, so agencies supplement with programmatic funds. This practice does not encourage funding bonuses or incentives, however.

The Office of Personnel Management has been asked to review IT jobs in government, particularly the classification of entry-level jobs to which the government would like to attract talent, as well as strategies to reward high-quality technicians with higher wages without obliging them to move into management. But this review has not been completed at this writing (August 2000).[26]

Some agencies have used retention incentives with some success. The Internal Revenue Service gave retention incentives of 10 percent of salary to about 900 of its Washington, D.C., area programmers. The immediate goal was to help through the year 2000, but it was seen as a strategy to retain a critical workforce, especially as a large proportion near retirement age.

In addition, testimony to the committee suggested that there are a number of nonmonetary incentives, both modest and elaborate, that might make the federal government more competitive with the private sector for IT workers. These included:

- Interesting work. NASA realized that it did not have the traditional levers to attract candidates to its ranks. So NASA staff went to universities and spoke with graduate students and enticed them by telling them that they could come to NASA to do long-term research. This has been an attractive magnet, and NASA has been able to recruit young graduates.
- Frequent-flier miles. Even such a modest perquisite as the right to

[26]For the draft classification standards for federal IT positions, see Office of Personnel Management, 2000, *Administrative Work in the Information Technology Group*, Washington, D.C., July, available online at <http://www.opm.gov/fedclass/html/whatsnew.htm>.

accrue frequent-flier miles for personal use would help to reduce the irritations of federal service.

• Flexible working conditions. Flexible scheduling, teleworking, flex time, flex place, and loaned computers are standard practice at many companies but are implemented on an ad hoc basis in the federal government. More systemic utilization of new business work models in place in federal guidelines could help to entice workers to join or remain in the federal workforce.

• Tuition reimbursement. In the private sector, tuition reimbursement is a common perquisite for attaining a degree or getting certification, but the federal government is far less generous.

3.6.3 Recruitment and Retention Issues

Bureaucratic barriers and the inflexibility of a lethargic hiring system are another challenge to government recruitment of IT workers. Often, the time between when a position is authorized and when that position is offered is about 6 months, which is not competitive with the private sector. Good candidates will not wait this length of time.

The work of the federal Chief Information Officers (CIO) Council, composed of top CIOs across government, has prompted greater collaboration with colleagues in the human resources arena to talk about recruiting issues, problems, and concerns. For instance, online recruiting is a common tool, yet is a very small percentage of how the government seeks new candidates. OPM has acknowledged the challenges and remarked that new efforts were being implemented, such as IPAs, term hires, various arrangements with universities, and co-op programs to bring in students at a much younger age, as well as the new Federal Cyber Corps, proposed by the White House, whereby students' costs are covered in exchange for service to a government agency for several years. Part of the scholarship program includes funding for faculty development, perhaps through actual funding of positions and other strategies to support faculty development and retention at the university level.

3.6.4 Coping with Tightness

In the short term, most agencies deal with their difficulties in hiring IT workers by contracting and outsourcing work. This effort challenges agencies to develop better project management skills among the federal workers. The CIO Council has spawned the STAR program (Strategic Tactical Advocates for Results), in which agencies work not only with IT people but also with business people to bring better project management skills to the fore. A significant number of DOD personnel are civilian contractors—even deployable units contain civilian contract staff. NASA has concentrated its work on its core competency and has pushed the bulk of its operations outside the agency. This has freed people to concentrate on IT research rather than on operations. At the Department of Energy, Office of Science, three federal employees manage about 25 contractors who are completing redoing DOE's architecture.

It is worth noting that the U.S. government can employ only U.S. citizens for many IT jobs, and hence foreign workers are not available to it. Moreover, many IT jobs in government require the job holder to have security clearances, which are not usually available to foreigners.

Finally, the CIO Council and OPM have identified career development as a key component of attracting, retaining, and improving the people in the federal workforce. They have challenged all agencies to spend at least 3 percent of their total IT payroll on professional development of their IT workforce, and many agencies are complying. The CIO Council also discovered that management has a tremendous influence on individuals' satisfaction in the federal workforce, so the Council has recommended that OPM craft a program to develop better managers and supervisors to work with new IT workers, who likely have many nontraditional work styles.

OPM has identified a number of longer-term actions that focus on education and training. It will institute a training initiative that would leverage training initiatives already in place at different agencies and from the private sector to train the current IT workforce and to bring up the levels of competence, specifically in the IT security arena. OPM will also institute a high school awareness initiative, in which OPM will reach out to the high schools to increase awareness, in both educators and students, about IT security and to help promote entry into the IT profession and into government service.

3.6.5 Security

Security is a particular challenge within the federal government. From the perspective of those who testified to the committee, security had two components: security in the sense of protecting classified information and security in the sense of providing greater security for computer systems. On the former, some reported difficulty in attracting qualified employees into jobs requiring security clearances.

On the latter, NASA plans to capitalize on information assurance and security to advance its efforts to create a more paperless agency and its effort to do enterprise management. NASA operations and systems administrators are mainly contractors, and the concern at NASA headquarters is how NASA will obtain the right skills in such an environment.

NASA IT workers not only need to know Cisco routers, but also must be experts in NT or another operating system, and must understand forensics and scanning tools. Work at NASA is complex, and finding people with the full suite of skills is challenging. NASA also needs senior management personnel who can oversee operations for IT security training.

The new Federal Cyber Corps program (mentioned above) was developed by OPM in direct response to the need for efforts to increase computer and infrastructure security. The Treasury Department has been successful in some areas that mirror the private sector, such as e-commerce, and pointed to the U.S. Mint, the Bureau of Engraving and Printing, and the Bureau of Public Debt Web sites that sell directly to the public as a prime example, but agreed that issues of privacy and security and authentication were still trouble spots. The latest rash of Web site sabotage (hacking of Amazon.com, eBay.com, and others) reinforced cyber security as the CIO Council's number one priority.

3.6.6 Concerns Expressed by Government Contractors

Contractors carry out a considerable amount of government IT work. Presentations to the committee from contractors indicated that in some areas government oversight of contracts has become counterproductive. Contract documents should focus on detailing functional requirements, but in many cases they are too specific as to how the work should be implemented. This overspecification discourages the innovative use of technology.

Contractors also reported that government agencies had become highly demanding in requiring specific skills and years of experience for each project member. Increasingly, government agency clients are requiring that their projects be staffed with personnel who have particular software and/or hardware skills, on the assumption that this will lead to faster and better project completion. Contractors hiring workers for such work are legally bound to hire on the basis of these contractually specified qualifications, regardless of whether or not they are in fact necessary for proper execution of the work under the contract. Given such requirements, there is less opportunity to "sprinkle" recent college graduates among highly experienced workers in project teams—the traditional way new hires at contractors gain experience.

Furthermore, the U.S. government—and specifically the U.S. government as represented by the contracting officers involved—generally insists as a contractual matter on approving individual personnel (in addition to specifying personnel requirements) to be hired under a project. A number of firms testified to the committee that U.S. government contracting officers had indicated to them disapproval of qualified job applicants from minority or other groups protected by antidiscrimination statutes. Yet as private employers, they are bound by all of the obligations imposed by such statutes.

Finally, contractors noted that agencies did not allow training of contract employees as a direct bill or as an allowable part of billable overhead unless the training was explicitly called for in the contract. This constraint discourages companies from maintaining the skills of their employees. Such provisions are a nontrivial disincentive to offering training for IT workers on these projects.

3.7 PROJECTIONS FOR THE FUTURE

3.7.1 The Relevant Time Horizons

What is the time horizon of today's tightness in the IT labor market? It is useful to distinguish between long-term trends (measured in decades) and more cyclic phenomena likely to occur in the shorter term.

Over the long term, continued growth in the IT sector and in the use of IT by IT-intensive firms is highly likely. But growth in any sector is rarely monotonic. All sectors—as well as the economy at large—experience periods of greater and lesser growth (or even contraction). When they occur, downturns in the IT sector and in the IT-intensive industries may:

- Reduce the amount of IT work that users are able to pay for,
- Increase the number of workers available to (or trainable for) IT work, and/or
- Reduce the value capital available (e.g., stock options) for compensation of IT workers.

The timing of these periods of growth and contraction is difficult to predict. Until contraction occurs, the current tightness being experienced by the IT sector and by many IT-intensive firms is likely to continue. But a downturn in the overall economy (e.g., as a result of inflation, significantly higher interest rates, or a stock market collapse) would have some effect by dampening demand to some extent for IT products and services, as well as a downward influence on wages.[27] On the other hand, there is some historical precedent for thinking that the IT sector might be affected less severely than other sectors by an overall downturn and even that IT

[27]For example, as noted in Chapter 2 (Figure 2.7), beginning salaries for bachelor's degree recipients in computer science experienced a downward trend in the early 1990s, a time that coincided with a downturn in the IT industry.

growth can continue during an overall downturn. Such an outcome was observed in the early 1990s, which saw an overall slowdown in the economy but continued capital spending on IT. An additional effect of an overall downturn would be a slackening in the overall labor market, a phenomenon that might make IT a more attractive employment choice for people not now in the IT sector or in IT-intensive firms and thus increase the potential supply of new IT workers.

Even absent a downturn, current growth rates in market capitalization, revenues (for those that have them), and numbers of job openings in some segments of the IT sector and in IT-intensive firms may well be unsustainable. For example, as firms complete their transitions to the Internet and e-commerce (likely on a time scale of years and perhaps decades), the personnel needed may move from those needed for transition (a larger workforce) to those needed for maintenance and sustainment (a smaller workforce).

Whatever the cause, a downturn in the IT sector (and to a lesser extent, in the IT-intensive industries) would most likely result in reduced demand for IT workers. As importantly, because the labor market takes time to adjust, periods of downturn are likely to result in slackness (as compared to today's tightness) in the IT labor market. For example, students who have been attracted to study IT in colleges and universities by a tight labor market may face a slack labor market by the time they graduate—and end up taking jobs in fields other than IT.

3.7.2 The Quantitative Outlook

The IT sector of the economy is strong and growing, as is true for many IT-intensive firms, and high demand for the Category 1 IT professions, as well as for support positions, is likely to continue. Bearing in mind that rapid changes in levels of tightness across occupations can be driven by currently unforeseen technological, business, or economic developments, the IT labor market is likely to remain strong for a long time to come. BLS projects that the fastest-growing occupations between 1998 and 2008 will be the group consisting of computer systems analysts, engineers, and scientists, projected to grow from 1,530,000 jobs in 1998 to 3,052,000 jobs in 2008, an increase of 99.4 percent (an average of 164,000 jobs per year, or 6.9 percent per year).[28] Jobs in computer programming

[28]The BLS forecasts are based on a number of commercial macroeconomic models that predict national spending in a moderate number of major components of the gross domestic product. The spending in these categories is attributed to each of a much larger number of commodities, and the demand for these commodities is then linked to final demand in each of a large number of industries using input-output tables. Employment by each industry is

are projected to grow by 29.5 percent, from 648,000 to 839,000. The projected growth across all occupations, both IT and non-IT, is 14.4 percent, or 1.3 percent per year.[29]

Within the group, jobs for computer engineers and scientists will increase by 103.4 percent, and those for systems analysts by 93.6 percent. Computer engineers and scientists are further broken down into computer engineers (107.9 percent increase), computer support specialists (102.3 percent increase), database administrators (77.2 percent increase), and all other computer scientists (117.5 percent increase).[30] Overall, the top five fastest-growing occupations between 1998 and 2008 are expected to be computer engineers, computer support specialists, systems analysts, database administrators, and desktop publishing specialists.

In recent years, BLS projections have consistently underestimated the number of IT jobs that the economy will create. In particular, it is possible to compare the BLS projections of computer programmers, systems analysts, and computer scientists and engineers made in 1996 for 1998 with the actual reported numbers for 1998.[31] An analysis of these 1996 BLS projections indicates that they were about 93 percent of the actual 1998 figures. Furthermore, the annual growth rate in these occupations (taken in aggregate) implied by the 1996 projection was 5.0 percent, whereas the growth in actual employment from 1996 to 1998 reflected a 9.6 percent annual growth rate.

What is responsible for such underestimation? While the BLS does provide comprehensive public-domain occupational forecasts, these forecasts are based on procedures that are subject to significant methodological criticism. For example, the procedures assume a fixed relationship in each industry between the number of jobs and total person-hours. This is

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then calculated by extrapolating the historical trend in the relation of industry person-hours employed to industry output. Person-hours are then converted to jobs in each industry by assuming a constant average hours per week in the industry. Employment by industry is converted to employment by occupation using a matrix showing employment in 513 detailed occupations in each of 260 detailed industries. This matrix has the characteristics of, although not the same content as, an input-output matrix. Finally, narrow demographic groups forecast labor supply as projections of the labor force based on past trends of participation. (Adapted from National Research Council, Office of Scientific and Engineering Personnel. 2000. *Methods of Forecasting Demand and Supply of Doctoral Scientists and Engineers: Proceedings of a Workshop*. Washington, D.C.: National Academy Press.)

[29]Braddock, Douglas. 1999. "Occupational Employment Projections to 2008," *Monthly Labor Review* 122(11):51-77. Available online at <http://www.bls.gov/opub/mlr/index.htm>.

[30]Braddock, 1999, "Occupational Employment Projections to 2008."

[31]For the source of the 1996 projections, see Silvertri, George T. 1997. "Occupational Employment Projections to 2006," *Monthly Labor Review* (11):58-83. For the source of the actual 1998 numbers, see Braddock, 1999, "Occupational Employment Projections to 2008."

clearly problematic, since very strong evidence exists that this relationship changes over time and will continue to change as the fixed costs of employment rise relative to variable costs and as the relative importance of overtime cost declines. Moreover, the assumption of such a fixed relationship amounts to an assertion of the interchangeability of persons and time worked, an assumption that is not valid in many sectors (including much of IT) in which team efforts are central. Finally, the BLS methodology neglects many dimensions in which adjustment may occur, including training and retraining, and especially response to changes in wages. None of the past changes in the relationships are assumed to have been affected by anything behavioral—everything is summarized in the time trend. For these reasons, it is likely that the underestimation of the growth in IT job categories will continue.[32]

The state of the labor market, of course, depends on more than demand—supply (by which is meant all sources of labor that could do useful IT work) matters as well. Elements of supply include individuals entering the IT workforce for the first time, individuals in the IT workforce who are inclined to leave the workforce unless given incentives to stay, individuals in the IT workforce who shift from areas of low demand to areas of high demand, individuals in other lines of work (or currently unemployed) who could move into the IT workforce, individuals currently working in a low-demand IT segment who could move into high-demand IT segments (perhaps with some retraining), and foreign IT workers who might be employed (either in the United States or abroad) to perform IT work on behalf of U.S. companies. Approaches to increasing supply are the focus of Chapter 7.

3.7.3 Skills for the Future

Because it is—by definition—impossible to predict discontinuous changes in technology, assessments of the specific skill sets needed in the future can be based only on what is known today. With that caveat, it is likely that the types of IT worker in greatest demand over the long run will fall into three categories:

• *Those who combine strong knowledge of a specific business with IT skills.* As IT applications to support effective decision making become ever more pervasive throughout business, industry, and government, organizations in these sectors are likely to realize the benefits of process reengineering.

[32]For more discussion of the limitations, see National Research Council, Office of Scientific and Engineering Personnel, 2000, *Methods of Forecasting Demand and Supply of Doctoral Scientists and Engineers*, the report from which this discussion is derived.

Effective reengineering of business processes requires good knowledge of what a firm is trying to do as well as good instincts for what IT can and cannot do. IT is becoming central to many fields, such as finance and health care, and thus a dual competency will be increasingly useful.

• *Those with the skills to work with recent information technologies that have broad-ranging business application.* Because information technologies change rapidly, those with the most recently acquired skills useful for technologies with broad application (or the ability to learn these skills quickly) are likely to be in very high demand. These individuals will be able to fit into a wide variety of organizational venues and businesses. And, because future applications will probably be more complex compared to the applications of today, those with the ability to manage complexity very well are especially likely to be in high demand.

• *Those with extraordinary mastery of hard-core technology skills*. There are always firms that need to squeeze the last bits of performance and functionality out of the information technologies that they use. While the number of such firms that are willing to pay large premiums for such efficiency is small (mostly because such efficiency is not necessary for most IT-sector or IT-intensive businesses), individuals with extraordinary mastery ("wizards") will be in high demand for those that are so willing.

3.7.4 Project-based Employment

For much of the latter half of the 20th century, many jobs were characterized by relatively high stability—long-term employment with one firm. Typically, these relationships involved assistance to employees for maintaining and upgrading skills to accommodate changing work assignments (because the firm perceives a stake in those skills) and salary structures that compensate junior or newer workers less than senior or older workers, in effect implementing a discount for lower productivity during the time new skills are being acquired early in a career. Of course, in practice, many workers did change employers, but such changes tended to be infrequent and measured in many years or decades.

In another mode of employment that this report calls project-based, the firm uses a worker (and compensates him/her, either directly or indirectly) for a specific task, without obligation to continue employment beyond that task. (For ease of discussion, it is helpful to distinguish between the firm that needs work to be done and the employer that actually employs the worker. These may or may not be identical.) Project-based employment can take several forms:

• A "regular" employee of the firm, receiving benefits (e.g., health insurance), pension, or stock options or equity stakes, but without the expectation that he or she will necessarily remain with the company after his or her stock options vest. Such an individual may well move from project to project within the firm, but must "job-hunt" within the firm once a given project has ended.

- An individual independent contractor ("self-employed") with very well defined (and usually time-delimited) responsibilities to the firm, which has no responsibility to the contractor other than paying the agreed-upon fee.
- An employee of a third party such as a personnel firm, a temporary help service, or a consulting or contracting firm. In such instances, the firm contracts with the employer for either an individual to work on projects of the IT firm's choosing or a product or service that the employer will deliver to or on behalf of the IT firm. This practice, often referred to as outsourcing, started to become more common more than 10 to 15 years ago.

In all of these instances, compensation for the worker is geared to the current worth of the worker to his or her employer for the duration of the task. The firm has no responsibility to the worker to ensure that his or her skills remain current or that he or she remains useful for another task for the same firm—skills are the worker's responsibility. Furthermore, in some instances, shorter job tenures are common, which may be due to the nature of the work in a sector in which workers can be displaced after a project ends.

Both firms and individual workers may have some incentives to prefer project-based arrangements.[33] For example, firms may obtain greater flexibility to address economic, strategic, and technological changes with project-based workers because they can more easily change the size and composition of their effective labor forces. Because such workers are not guaranteed jobs beyond their current project, the firm has opportunities to change workforce size and composition at the end of every project. Such arrangements can be useful in managing product cycles, during which personnel requirements are much larger before product release (i.e., during development) than afterwards, or in making conversions to new technology or products generally.

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[33]Much of this analysis is based on Kunda, Gideon, Stephen R. Barley, and James Evans, 1999, "Why Do Contractors Contract? The Theory and Reality of High End Contingent Labor," draft working paper, June. While the discussion in this section addresses incentives, it is silent on the downsides of high-mobility employment, since it is intended only to explain why high-mobility employment is increasing. The Barley paper discusses many of the downsides, as does the following popular press article: Downey Grimsley, Kirstin. 2000. "Independent Contractors' Victory in Microsoft Case May Have Wide Impact," *Washington Post*, January 16, p. H01.

In addition, the use of workers with varied job histories in the IT field enables firms to capture experience, intellectual sophistication, and knowledge that a new employee may have gained in working for a different firm (or on a variety of previous projects). While exploiting proprietary information belonging to competitors is illegal and unethical, a worker working at any given IT firm learns much that is not proprietary and that can benefit another IT firm. Moreover, the experience that a new worker can bring from a different IT firm means that the present IT firm does not have to subsidize the new worker's learning. This kind of human capital flow has been a feature of successful IT-focused regions, such as Silicon Valley.

Finally, through the use of some types of project-based employees, such as independent contractors or service firms, firms can avoid paying fringe benefits and employment taxes. Similarly, the use of contractors or service firms allows a firm to avoid many of the costs of recruitment, training, and termination incurred to comply with laws protecting regular employees. Also, the use of contractors and service firms is sometimes "off the books" from a firm-wide perspective, which enables individual managers to obtain additional labor without having to clear it through the company hierarchy.

Some workers also may find project-based employment advantageous, and their availability for such work can feed the growth of such employment.[34] Project-based employment allows a worker to obtain experience at multiple firms and learn new skills more quickly by being a "regular" employee of several different firms over a period of time. Another benefit of such varied experience may be financial: individuals who wish to build their own stock portfolio of pre-IPO shares may be able to diversify their holdings in order to improve their chances that at least one of the companies for which they have worked will in fact have a successful initial public offering. More generally, independent contractors may benefit from greater flexibility with respect to work schedules, the freedom to accept or reject assignments, or a greater range of insurance options (e.g., health plans). And, many "free agents" do well as high-end consultants or well-paid workers with skills in critical areas, because it is difficult for companies to find permanent employees with these abilities. At the same time, free agents with skills in less critical areas tend to make less than their permanently employed counterparts. Thus, the economic consequences of project-based employment are far from uniform. Finally,

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[34]A study conducted for the Kelly Services employment agency by EPIC/MRA, a marketing research consultancy, found that 64 percent of IT workers either want to work as a free agent or are open to the idea. According to the Kelly study, more than 36 percent of IT free agents earn more than $100,000 per year.

free agents must cope with occasional job instability and often receive fewer benefits than permanent workers.[35]

Because both workers and firms may perceive benefits to these more flexible arrangements, project-based employment appears to be increasingly common, and Web-based businesses have begun to emerge to provide matchmaking between parties offering and seeking work.

3.7.5 Reducing Relative Needs for Personnel Through Tools and Techniques for Greater Productivity

Historically, the personnel needs of many fields, e.g., agriculture and manufacturing, have been reduced by the use of machinery to displace labor. Indeed, many economic models of productivity[36] are built around the assumption that, to varying degrees, capital can substitute for labor. Different management approaches have also helped to improve productivity in certain instances. It is thus reasonable to ask if such approaches might be promising in the field of IT.

Tools

For IT, the analog of mechanized agriculture is tools that enhance individual productivity, noting that productivity is, by definition, the ratio of useful output to human work input to produce that output. In agriculture, for example, the use of tractors, threshers, and the like enables the production of far larger amounts of food for a given number of farming hours than would be possible with the use of oxen-drawn plows and scythes. In information technology, widely used operating systems, language compilers, debugging tools, performance analysis systems, environments for program maintenance and integrated development, component frameworks, rapid prototyping tools, and problem-solving systems have all helped to increase the productivity of Category 1 workers.

The development of more and better tools to enhance individual programmer productivity remains an active area of research and develop-

[35]Edwards, John. 2000. "Redefining IT Career Paths for the New Millenium," *IEEE Computer* 33(1).

[36]The committee notes that the term "productivity" is used in many different contexts. The basic definition of productivity, and the one used in this report, is the ratio of output per unit input. The term is also used in the context of describing an individual company's competitive edge (a company is productive if it can develop and sustain an edge over its competitors) as well as in the context of a workforce on the whole that can do more (a productive workforce is a "rising tide that lifts all boats").

BOX 3.6
Illustrative Tools for Increased Productivity

Software reuse is the systematic building of a family of products, drawing from a common core of elements including software code, design, domain expertise, and development processes. Reuse has the potential to reduce the amount of product development work that needs to be undertaken. However, software reuse is challenging because it entails deep understanding of the commonality of requirements that are at the core of the software development process.

End-user programming (of which spreadsheets and Mathematica are good examples) shifts IT work away from IT workers toward end users, thereby reducing or eliminating the need for the end user to interact with a specialized IT worker to formulate and/or program an end-user problem, with the effective result that fewer programmers are needed.

Industry and enterprise-wide software systems integrate functionality to support routine applications common to most firms in a given industry (e.g., systems to support common and generic hospital or banking operations). Such systems have the potential to reduce the need for large numbers of IT workers developing customized solutions and applications for specific firms. The primary challenges are in understanding the essential features common to most organizations in a particular industry or business without compromising the ability to specialize and customize that is the basis on which individual firms compete.

Applications service providers provide IT services to large numbers of client firms on a centralized basis. Much of the software in use today is locally installed and maintained, a fact that requires client firms to employ their own Category 2 workers to assist with and be responsible for such tasks. By providing software that is installed and maintained on servers that are remote to the user firms, a large amount of effort that is currently duplicated among user firms can be replaced with a smaller amount of effort by the applications service provider.

Implementation of the "ilities" has become increasingly important in today's complex software environment. Key properties of systems such as security, flexibility, reliability, manageability, quality of service, modifiability, and scalability—some of the "ilities"—have become more important as systems become bigger, more complex, and accessible (via the Internet) by more users. A better understanding of how to develop very large systems that encompass the "ilities" (as well as better implementation of what is already understood) is likely to reduce the number of people needed to develop and maintain systems.

ment. It is likely that such tools (as illustrated in Box 3.6) will indeed emerge as the result of continued research and development in the area, although the magnitude of the productivity improvements that can be expected from the use of tools is a matter of sharp dispute within the IT community.

Management and Organization

Management strategies and organizational approaches may result in higher productivity. Software development does not have a consistently good track record for quality, and from the earliest days of programming, there have been concerns about cost and time overruns and program reliability. As systems became larger, the opportunity for error became greater. Indeed, because the development of large systems requires teams, and all teams are organized in some manner, the role of organization and management is manifest.

Over the past few years, the Standish Group has surveyed a wide range of organizations on the outcome of their IT projects.[37] Overall the results are poor. In 1994, 31 percent of projects were canceled before completion, and a further 53 percent were completed over budget. Two years later, the corresponding results were that 40 percent of projects were canceled before completion and 33 percent were completed over budget, and in 1998, the results were that 28 percent of projects were canceled before completion and 46 percent were completed over budget. Although these results do show some improvement over time, the results for 1998 are still very unsatisfactory. Common sources of project cancellations and overruns include ill-defined or changing requirements, poor project planning or management, uncontrolled quality problems, unrealistic expectations or inaccurate estimates, and naive adoption of new technology.[38]

In addition, individual projects can be organized in ways that minimize personnel needs over the life cycle of a product. For example, software inspection for quality at the front end of the development process has been shown to reduce dramatically the amount of rework and debugging that otherwise needs to be done at the end of the process.[39] Thus, even though initial costs are higher, overall personnel needs can be lower.[40]

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[37]Johnson, Jim. 1990. "Turning Chaos into Success," *Softwaremag.com.* December. Available online at <www.softwaremag.com/archive/1999dec/Success.html>.

[38]McConnell, Steve. 1998. *Software Project Survival Guide.* Redmond, Wash.: Microsoft Press, pp. 20-33.

[39]See Wheeler, David A., Bill Brykczynski, and Reginald N. Meeson. 1999. "Software Peer Reviews," pp. 454-469 in *Software Engineering Project Management*, Richard H. Thayer, ed. Los Alamitos, Calif.: IEEE Computer Society Press.

[40]For various reasons, certain development environments militate against such an approach. For example, a small start-up company seeking to bring to market a single product against severe time-to-market pressures may not have the funding to make up-front investments in architectural design and quality assurance. Such pressure simply increases the importance of management discipline (e.g., in building such investments into the original business plan). (In some cases, pressures to be first to market can lead to

Finally, firms that use IT workers may outsource non-core competencies that involve IT to specialized service firms, thus reducing the need for in-house IT staff. Today, many non-IT companies, such as financial institutions, are reducing their need for whole categories of IT personnel because they cannot compete internally with what they can buy relatively cheaply on the outside; as a result, they have less need to build IT systems in house. With outsourcing, the same amount of work needs to be done through the economy as a whole, but a specialized service firm may well be able to undertake work more efficiently because of efficiencies of scale or greater experience and knowledge in providing the service.

Arguments about the importance of management practices in the development of IT software have been made for at least three decades. There is disagreement in the IT community about how much more can be gained by better management practices. Some believe that much can be gained if every project used the best management practices, for example. (See Box 3.7 for a discussion of illustrations.) Others feel, however, that while there is undoubtedly some productivity to be gained, there is no silver bullet in such an approach, largely because software development is an extremely complex process.[41]

The Likely Impact of Improvements in Productivity

For a fixed amount of work, the impact of productivity improvements, whether from tools or management techniques, is to reduce the number of personnel needed to perform that work. If the work that needs to be done (otherwise known as demand for labor) increases, then the impact of productivity improvements is to reduce the number of personnel needed below the number that would be needed in the absence of such improvements. Furthermore, to the extent that productivity improvements make it easier for people with less expertise and training to accomplish what previously took greater skill, such improvements may well serve as one stimulant of additional demand for IT labor.

Historical experience, compiled by Boehm,[42] suggests that the use of improved tools and improved management has resulted in an annual

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excessive neglect for the test and debug phases, making the end user the beta tester!) Some interesting commentary on these pressures can be found in Minasi, Mark. 1999. *The Software Conspiracy*. McGraw-Hill Companies. See also Computer Science and Telecommunications Board, National Research Council. 1999. *Trust in Cyberspace.* Washington, D.C.: National Academy Press.

[41]See, for example, Brooks, Frederick P., Jr. 1995. "No Silver Bullet," in *The Mythical Man-Month, Anniversary Edition,* Reading, Mass.: Addison-Wesley.

[42]Boehm, Barry W. 1999. "Managing Software Productivity and Reuse," *IEEE Computer* 32(9):111-113.

BOX 3.7
Elements of Software Engineering Management

Experience in software engineering suggests that many of the items described below characterize software development projects that have come in on time, on budget, and with the “expected” quality. Following these best practices—especially if they are “followed” but not implemented appropriately—is not a guarantee of success but may well increase the likelihood of project success, and many project failures can easily be traced to the absence of such practices.

- Have a clear vision, in which project teams work toward a limited and clear set of goals.
- Use prototyping tools that allow users to interact with system mockups. The use of such tools helps the user to understand what he or she wants the system to do, and thus addresses one of the most common risks—changing requirements after the system has been largely developed.
- Demand accurate estimates that reflect the true state of affairs. Under pressure of deadlines, it is often tempting to give time and effort estimates that are overly optimistic. To the extent that such estimates are believed by management, they set up a project for failure.
- Focus on quality from the start. Uncorrected product defects that occur early in the development process cost much more to fix than product defects that occur later. Under time pressures, quality control often falls by the wayside, but it is the role of management to ensure that this does not occur.
- When appropriate, implement projects in a known and familiar technology. New technologies can offer important and powerful new capabilities, but their use often reflects a high-risk strategy—because the expertise to exploit these capabilities properly is often not available.
- Avoid micromanagement, which is demoralizing to project teams. Management should be responsible for staffing, training, motivation, morale, and the work environment but should leave the technical people to do what they do best.
- Manage risk actively. Management should plan the project so that the largest areas of risk are worked on early in the project. After each increment of work, the project risks should be reassessed and a plan developed to address each remaining risk.

These items are not intended to be complete or exhaustive—they merely illustrate some of the things that are entailed in good management.

SOURCES: Construx Software (Bellvue, Washington): <http://www.construx.com>; Scott Ambler’s Web Site for Object-Oriented Developers: <http://www.ambysoft.com/processPatternsPage.html>; and Software Program Managers Network (Arlington, Virginia): <http://www.spmn.com/best_practices.html>.

growth rate in software productivity of about 7 percent for the past 30 years. If this trend can be extrapolated to the future, it will approximately compensate for the 8 percent annual increase over all of the "core" IT occupations over the next 10 years projected above. If this is true, the impact of productivity improvements will be to maintain the approximate status quo with respect to the current tightness in the IT labor market.

However, as noted above, recent comparisons of actual to projected demand indicate that U.S. government projections have underestimated the rate of job growth by almost a factor of 2. And, the rate of job growth in certain specialties is likely to be even higher. Boehm estimates that annual improvements in productivity of 10 percent are possible if new techniques are used more widely, though his analysis is qualified by both the fact that it uses equivalent machine language instructions as the output measure (a controversial measure in the IT community) and the fact that it is based on large software systems usually built on contract for the federal government (a point that may limit its applicability to many important software development efforts in the private sector).

These comments indicate that while productivity tools and techniques have a role to play in reducing personnel requirements below what they would otherwise be, they are not likely to play a decisive role in reducing the current tightness in the IT labor market.

3.8 RECAP

A primary manifestation of a tight labor market is the fact that many—perhaps most—employers of IT workers report large numbers of vacancies for IT positions. However, turnover and company growth contribute equally to the vacancy rate. Overall, today's IT labor market is tight, although the nature and extent of such tightness vary by employer, by type of IT work involved, and by geographical locale. The fundamental driver of this tightness is growth in the use of IT throughout a strong economy, a tightness that is significantly exacerbated by the currently low unemployment rate in the overall labor market.

The behavior of wages, a common indicator of labor shortages, presents a mixed picture. Base wages for Category 1 workers (apart from those in hardware, about which little is known) have been rising at a rate of about 4 percent per year in constant dollars. However, this overall behavior masks much more rapid wage growth in certain subspecialties and less rapid growth in others. Furthermore, the presence of unexercised and/or unvested stock options and equity stakes in the compensation of workers in a relatively new and growing industry may help to explain the fact that mean wages in the IT sector have risen only somewhat more rapidly than wages in other sectors of the economy. Because stock options and/or equity stakes that represent deferred compensation are an increasing part of worker compensation packages in IT, as suggested above, wages alone become a poorer measure of total compensation as time goes on. Thus, the omission of stock options and equity stakes is problematic in comparing wage trends in IT versus those in other sectors.

The federal IT workforce presents special problems. Many government functions depend on IT, but government's ability to respond as the market would respond is limited, especially with respect to the compensation packages it can offer.

The time horizons of the current tightness in the labor market are hard to predict. In the long term (measured in decades), continued growth in the IT sector and in the use of IT by IT-intensive firms is highly likely. On the other hand, all sectors—as well as the economy at large—experience periods of greater and lesser growth (or even contraction). When they occur, downturns in the IT sector and in the IT-intensive industries may reduce the amount of IT work that they can supply, increase the number of workers who are available to do (or are trainable for) IT work, and reduce the value of capital available (e.g., stock options) for compensation of IT workers. Such downturns are also likely to result in reduced demand for IT workers, with a consequent decline in the need for foreign temporary nonimmigrant IT workers and a slack labor market.

Current projections for job growth for Category 1 IT workers, which do not take into account the possibility of such downturns, indicate strong growth for the next decade, about 7 percent per year. Historically, such projections have understated actual growth rates by as much as a factor of 2.

Analytically, there are only a few ways of dealing with tightness in a labor market—to increase the productivity of individual workers so that a smaller number of workers can do the same work that a larger number of workers can do in the absence of productivity measures, and to increase the number of qualified workers. (Reducing demand for IT products and services, and hence the need for IT workers, is a third logical possibility, but one that contradicts the premise of continued growth in the use of IT.)

Productivity can in principle be increased through the use of tools (e.g., integrated programming environments) and/or the use of different organizational or managerial strategies (e.g., structuring projects with more "up-front" design effort to reduce "downstream" personnel needs). Over the past 40 years productivity gains have been achieved through new management paradigms and technology. Similar gains are likely in the future, although they are not likely to play a decisive role in reducing the current tightness in the IT labor market.

Approaches to increasing the supply of workers and making more effective use of the existing workforce are discussed in Chapters 6 and 7.

Part II

4

Older IT Workers and Possible Age-Related Discrimination

4.1 INTRODUCTION

Prompted by competing concerns and testimony from employers and displaced workers, Congress asked this committee to examine the existence and extent of age discrimination among information technology workers. As noted earlier in this report, employers describe profound worker shortages and thousands of open positions left unfilled for lengthy periods of time. Employers observe that their high costs of recruiting and retaining IT workers would make excluding workers because they are associated with a particular demographic category self-defeating and would constitute irrational business behavior.

In contrast, Congress and this committee have heard testimony from individuals who believe that age discrimination against older workers is widespread. For example, the committee received through electronic channels a substantial number of comments that involved age discrimination from individuals who believe older workers are more likely to be laid off than younger workers and then, once without a job, older workers are less likely to find new employment as well. As one (54-year-old) IT worker wrote, "I believe age discrimination is rampant. Several years ago I became unemployed and was only able to get interviews if I deleted the first 15 years of my experience from a resume."

Against this backdrop, the committee examined data from a variety of sources, reviewed some studies done on the topic of age discrimination, and took testimony at each of the sites visited.

4.2 LEGAL DIMENSIONS OF AGE DISCRIMINATION

4.2.1 The Definition of Age Discrimination

The Age Discrimination in Employment Act (ADEA) of 1967 makes it unlawful for an employer to fail or refuse to hire, or to discharge, any individual at least 40 years of age or otherwise discriminate against any individual with respect to his or her compensation, terms, conditions, or privileges of employment, because of the individual's age; or to advertise for employment indicating any preference or specification based on age. All claims under the statute, not just those involving discriminatory discharge, are subject to the age-40-and-above requirement. (In addition, many states have antidiscrimination laws that cover age discrimination, and in many cases, these laws extend protection to a broader class of individuals than those over 40.)

However, the ADEA does allow employers to take actions that would otherwise be prohibited when age is a bona fide occupational qualification that is reasonably necessary to the normal operation of the particular business, or where the differentiation is based on reasonable factors other than age. In addition, actions motivated by legitimate business reasons that also have disproportionate adverse effects on older workers do not necessarily constitute illegal age discrimination. Such business reasons may include the desire to reduce labor costs, to increase operating flexibility, or to seek workers with experience in new technologies.

Few employers today would state as a matter of company policy, "I won't hire you because your age is over 40." But one key purpose of the ADEA is to prevent employers from taking adverse actions against older workers based on stereotypes of what older workers are like. Thus, it is a violation of the ADEA to act on the assumption that an older worker would not fit into a workplace, would be slow to learn new skills or to understand the projects being developed, would not accept salaries at the level that characterize those of entry-level positions, or would not like the pace of the workplace, because of his or her age. Employers may not be aware that acting on such assumptions violates the law, but reliance on them as a factor in hiring or promotion decisions amounts to treating workers differently because of age.

As a rule, the courts grant employers reasonably broad latitude in defining job requirements as long as there is a plausible business case that those requirements are relevant, and the employer's legal responsibility is to refrain from disparately applying them. Historically, factors such as the number of years of experience, the salary level, the working hours, and the currency of an applicant's skills are all examples of requirements that the courts have found legitimate.

4.2.2 Legal Theories for Showing Age Discrimination

Given a statutory standard of the types of employer behavior that constitute employment discrimination, there are, in general, two theories[1] of how a given set of situation-specific facts and circumstances can establish that the employer's challenged actions were taken for reasons of age: disparate treatment and disparate impact.

To prevail under an analysis based on disparate treatment, the plaintiff must show that an adverse employment action (failure to hire, demotion, termination, etc.) was the result of the employer's deliberately discriminating against the plaintiff on the basis of age. In other words, the burden of proof is on the plaintiff to show that the employer's challenged actions were taken for reasons of age. The classic example of evidence of disparate treatment would be an employer that refuses to hire someone, saying "Although you are fully qualified, you are too old for this job." However, as discussed above, the Supreme Court has ruled that actions that have negative effects on older workers do not constitute disparate treatment if they are motivated by factors that are only indirectly related to age.[2]

To prevail under an analysis based on disparate impact, the plaintiff must first show that the effects of a facially neutral policy or practice disparately disadvantage members of a protected class. If disparate impact is thus shown, the employer must show that the employer's challenged employment actions were justified on the grounds of business necessity. Although it is widely used in cases of racial and sexual discrimination, the circuit courts are divided on the extent to which disparate impact may be used to demonstrate violations of the ADEA.[3] The Supreme Court has

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[1]In legal terms, a "theory" is used to establish how a particular factual situation does or does not meet a given legal standard.

[2]*Hazen Paper v. Biggins* (91-1600), 507 U.S. Supreme Court 604 (1993). In this case, the Supreme Court held unanimously that firing someone because his pension is about to vest is not age discrimination, even though age and pension vesting status are correlated positively with each other. Moreover, the opinion makes clear that even closer correlations would be subject to the same analysis.

[3]Five circuit courts have rejected the applicability of evidence of disparate impact to cases of age discrimination: the First (*Mullin v. Raytheon Co.*, 164 F.3d 696, 703 (1st Cir. 1999)), the Third (*DiBiase v. SmithKline Beecham Corp.*, 48 F.3d 719, 732-34 (3d Cir.), cert. denied (1995)), the Seventh (*Salvato v. Illinois Dep't of Human Rights*, 155 F.3d 922, 926 (7th Cir. 1998)), the Tenth *(Ellis v. United Airlines, Inc.*, 73 F.3d 999, 1008-09 (10th Cir.), cert. denied, 116 S. Ct. 2500 (1996)), and the D.C. circuit courts. Four circuit courts continue to recognize its applicability: the Second (*District Council 37 v. New York City Dep't of Parks & Recreation*, 113 F.3d 347, 351 (2d Cir. 1997)), the Eighth (*Lewis v. Aerospace Comm. Credit Union*, 114 F.3d 745, 750 (8th Cir. 1997), cert. denied, 118 S. Ct. 1392 (1998)), and the Ninth (*Mangold v. California Pub. Util. Comm'n*, 67 F.3d 1470, 1474 (9th Cir. 1995)). The Fourth Circuit Court appears to assume that evidence of disparate impact is available to age plaintiffs but has provided no supporting analysis. The same can be said for the Court of Appeals for the District of

not ruled on the use of disparate impact theory in age cases. However, it has held that "[o]lder persons, . . . , unlike those who suffer discrimination on the basis of race or gender, have not been subjected to a 'history of purposeful unequal treatment.' Old age also does not define a discrete and insular minority because all persons, if they live out their normal life spans, will experience it . . . . [A]ge is not a suspect classification under the Equal Protection Clause."[4] This debate over the courtroom viability of disparate impact theory in age cases calls into question the use of statistics alone to determine the existence (or absence) of age discrimination as defined by the ADEA.

Note that the distinction between disparate treatment and disparate impact cases can be quite subtle. If the employer says, "I won't hire older workers because they are likely to have higher salary histories and be disgruntled when they take a pay cut, even if they say they won't be," the case would be brought to court as a disparate treatment case. If the employer says, "I won't hire people who would be taking a pay cut to come here," and it turns out that older workers disproportionately have high salary histories, the case would be brought to court as a disparate impact case.

Finally, it is possible to bring a disparate treatment claim without the "smoking gun" of a facially discriminatory policy or an employer admission that it used age as the basis for a decision. The Supreme Court has upheld the principle that intentional discrimination in individual cases (another phrase meaning disparate treatment) can be proven by circumstantial evidence, and in a recent case, the Supreme Court held that "in appropriate circumstances, the trier of fact can reasonably infer from the falsity of the explanation that the employer is dissembling to cover up a discriminatory purpose."[5] In addition, another well-established approach to establishing disparate treatment, called "pattern and practice," allows proof of intentional discrimination by statistics (combined with anecdotal evidence) showing that discrimination is the employer's ordinary practice.

Columbia. See, e.g., *Koger v. Reno*, 98 F.3d 631 (DC Cir. 1996). Two circuit courts have questioned the viability of a disparate impact claim under the ADEA but have not ruled explicitly on the matter: the Sixth (*Gantt v. Wilson Sporting Goods Co.*, 143 F.3d 1042, 1048 (6th Cir. 1998)) and the Eleventh (*Turlington v. Atlanta Gas Light Co.*, 135 F.3d 1428 (11th Cir. 1998)). The Fifth Circuit Court has not addressed the issue—but its decision in *Rhodes v. Guiberson Oil Tools*, 75 F.3d 989 (5th Cir. 1996), in which it emphasizes the differences between Title VII and the ADEA, suggests that it would find the theory unavailable to those alleging age discrimination. Most recently, following a ninth circuit court decision upholding evidence of disparate impact, the employer has appealed the circuit court decision to the Supreme Court. It is possible that the Supreme Court will rule decisively on the matter of disparate impact in the future.

[4]*Kimel v. Florida Bd. of Regents,* 139 F.3d 1426 (11th Cir. 1998), aff'd, 120 S.Ct. 631 (2000).

[5]*Reeves v. Sanderson Plumbing Products, Inc*. (99-536), 197 F.3d 688, reversed (2000).

4.3 THE EMPIRICAL EVIDENCE ON THE LABOR MARKET EXPERIENCES OF OLDER AND YOUNGER IT WORKERS

This section reviews the available empirical data on the experiences of older IT workers. The committee emphasizes at the outset, however, that the data available to study the prevalence of age discrimination in the IT workforce are few and are insufficient to establish either the presence or absence of age discrimination in the IT sector. Nevertheless, the data may offer some explanation for the perceptions of age discrimination by some IT workers.

4.3.1 Data from the Equal Employment Opportunity Commission

The Equal Employment Opportunity Commission (EEOC) collects data on the incidence of discrimination (Table 4.1). For the most part, charges of discrimination filed by employees with the EEOC concern race and sex rather than age, and as the figures note, the rate of filing has decreased. Unfortunately for this report, no explicit data are available on the fraction of these reports that involve the IT sector or the sectors in which IT-intensive firms are found.

In addition, whether EEOC data overstate or understate the extent of age discrimination is unclear. Workers who have been terminated or job applicants who have not been called for interviews or hired may be more willing to attribute such actions to unfair or discriminatory behavior on the part of the employer than to take responsibility for personal actions, skill deficiencies, or other traits that may have prompted such action. Human resources managers often assert that such events happen, and they reported to the committee that allegations of discrimination may

TABLE 4.1 EEOC Complaints Filed Between FY1995 and FY1999

	FY1995	FY1996	FY1997	FY1998	FY1999
Total charges filed	87,529	77,990	80,680	79,591	77,444
Age-related charges filed (% of total filed)	17,416 (19.9)	15,719 (20.2)	15,785 (19.6)	15,191 (19.1)	14,141 (18.3)
Number of age-related charges resolved in a manner favorable to complainant (% of age-related filed)	2,153 (12.6)	1,590 (9.0)	2,130 (11.7)	1,957 (12.2)	2,675 (17.3)

SOURCE: Equal Employment Opportunity Commission (see <http://www.eeoc.gov/stats/adea.html>).

well reflect managerial or interpersonal problems. Thus, such behavior on the part of workers or applicants would tend to overstate the incidence of age discrimination. This belief is bolstered by the fact that the overwhelming majority of cases brought to the EEOC are dismissed by the agency without substantiating the complainants' claims. For example, Table 4.1 illustrates that from 1996 to 1999, 87 percent of all age-related cases brought before the agency were judged not to be meritorious to the claimant.

At the same time, workers (or job applicants) who have been the subject of adverse actions may not know that they have been targets of age discrimination even when the adverse action has been taken because of age. For example, an individual is often not told why she or he was not hired and most likely does not know who was hired instead, so comparison of ages, qualifications, and experience becomes difficult. Or, rather than recognizing discrimination, the person internalizes the dismissal or lack of promotion and blames it on himself or herself. Such behavior would tend to lead to underestimates of the incidence of age discrimination. Note also that some employers are now requiring employees to agree in advance to mandatory arbitration of discrimination claims as a condition of employment. Such agreements, if implemented (and upheld in court when challenged) on a large scale, would make EEOC filing rates even weaker indicators of the incidence of discrimination.

For these reasons, it is impossible to obtain an objective measure of the prevalence of age discrimination in IT employment from EEOC data.

4.3.2 Labor Market Survey Data from the Bureau of Labor Statistics

Because of difficulties in interpreting data regarding claims of discrimination (such as that from the EEOC), the committee turned to data from the Bureau of Labor Statistics (BLS) on the labor market experiences of older and younger IT workers. The committee sought to determine whether the labor market outcomes of older workers in IT relative to younger workers in IT were substantively different than the relative outcomes of older versus younger workers in the rest of the labor market. To the extent that there are relative differences (and that those differences are negative for older workers), it provides some evidence that could indicate age discrimination. To the extent that the experiences of older workers in IT are similar to those of older workers in other sectors of the economy, it is evidence that older workers are treated no differently in IT than in other occupations. However, neither circumstance establishes the presence or absence of age discrimination.

Based on this analysis of the available data from the BLS, the following appears to describe the IT workforce:

• *The Category 1 IT workforce is younger than that in other occupations with workers of comparable educational attainment.*

Figure 4.1 shows the age distribution of IT workers relative to workers in other professional specialty occupations in 1999. The IT workforce is somewhat younger: while 46 percent of those in professional specialty occupations overall are under the age of 40, 58 percent of IT workers are under the age of 40.

The age distribution alone cannot inform the question on the extent of age discrimination since one cannot determine whether the smaller proportion of older workers is due to employment decisions of employers (and if so, whether the decisions are legally justified or not) or to the decisions by workers themselves. For example, the age distribution may be the result of a legally permissible "work environment" among some employers that is not compatible with the needs or preferences of many older workers.

Another possible explanation is that the IT industry is a relatively young field, so that one would not expect to find as many older workers in IT as in more established engineering fields. Indeed, a number of IT job categories—Web master, Web designer, Java programmer, to name a

FIGURE 4.1 Age distribution of category 1 IT, category 2 IT, and professional specialty workers, 1999. SOURCE: U.S. Department of Labor, Bureau of Labor Statistics, Current Population Survey, March 1999, special tabulation.

few—did not even exist when older workers first entered the IT workforce or during much of their careers. Alternatively, older workers may—as a class—be less familiar with newer technologies than younger ones, who may well have "grown up" around technology. Workers born in 1960 and before used their first computer as adults. Workers born in 1980 and forward have used this tool and other related technology throughout their entire lives. In addition, the rapidly growing IT industry is attracting more recent college graduates, who tend to be younger, thus decreasing the age of the workers in the industry.

- *Older Category 1 IT workers (those 40 years and older) are more likely to lose their jobs than younger IT workers.*[6]

As indicated in Figure 4.2, older workers are at greater risk for losing Category 1 IT jobs than are younger workers. This difference becomes even more pronounced when compared to the fact that in the rest of the economy older workers are less likely to lose their jobs than are younger workers and is consistent with actions that have a disproportionate adverse impact on older IT workers and that are discriminatory against these workers.

However, this difference is also consistent with IT employers ending projects or product lines that rely on older technologies and skills (e.g., FORTRAN and COBOL) and beginning to invest in projects or product lines requiring newer programming approaches (e.g., object-oriented languages such as C++). And they are consistent with actions taken by employers motivated by the reduction of labor costs. For example, an employer that terminated more experienced (hence older), higher-salaried workers and hired less experienced (hence younger), lower paid workers would not necessarily be violating the statutes prohibiting age discrimination.

Without more information about the skills, qualifications, and job duties of the workers, it is impossible to distinguish these competing explanations.[7]

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[6]Based on Farber, Henry, "A Note on Job Loss Among IT Workers," unpublished manuscript, Department of Economics, Princeton University, May 18, 2000. Note that all statistics from Farber control for the education, race, and sex of the worker as well.

[7]The committee notes that estimates of the displacement rates are a reasonably good approximation unless employment in the occupation was changing rapidly over the 1990s. In particular, the estimate of the relevant pool of potentially displaced workers (the denominator in the displacement rate) is based on the number of workers employed as of the survey date (up to 3 years after displacement). In the IT sector, which has experienced rapid employment growth, this estimate of the denominator is likely to be too large, thus generating an estimate of the displacement rate that is too small.

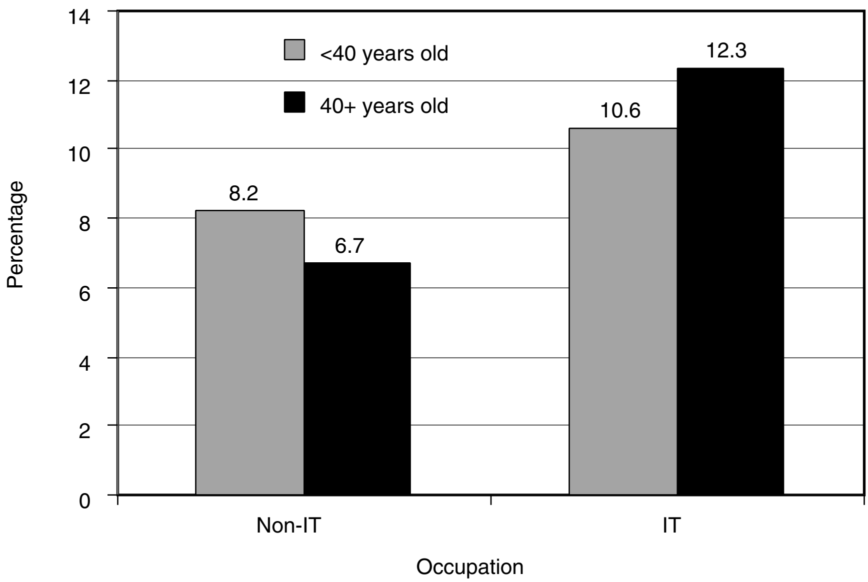

FIGURE 4.2 Percentage of workers who lost a job (but were not fired) within the last 3 years due to a business decision of the employer as of 1994, 1996, and 1998. A "displaced worker" is one who had 3 or more years of tenure on a job before losing or leaving it because of employer closings or moves, insufficient work, or the abolishment of the position. SOURCE: Data from U.S. Department of Labor, *Current Population Survey: Displaced Workers Supplement*, 1994, 1996, 1998. Also based on Farber, Henry, "A Note on Job Loss Among IT Workers," unpublished manuscript, Department of Economics, Princeton University, May 18, 2000.

• *Older Category 1 IT workers are just as likely to find new jobs as are younger IT workers. In addition, the length of time it takes for them to find new jobs is similar to that for younger Category 1 IT workers.*

About 82 percent of older displaced Category 1 IT workers find a new job within 3 years of being displaced compared to about 84 percent of younger Category 1 IT workers (see Figure 4.3); the older Category 1 IT workers fare better than comparable older workers in non-IT occupations (Farber 2000). In addition, although older displaced Category 1 IT workers take about 2.6 more weeks to find a new job than do younger displaced Category 1 IT workers, their length of unemployment is about the same as that of older displaced workers in the rest of the economy (Figure 4.4). Thus, the fact that it takes older Category 1 IT workers longer to find new employment is not unique to the IT sector.

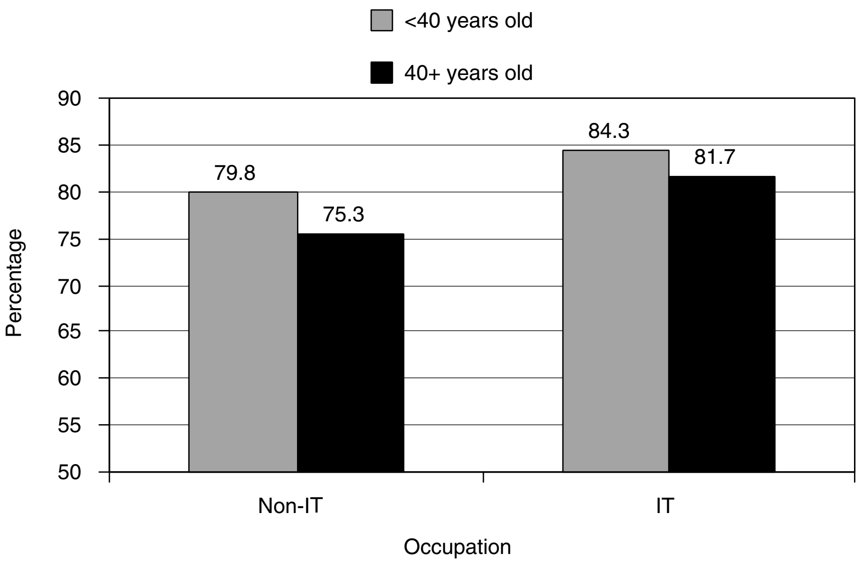

FIGURE 4.3 Percentage of workers ever employed within 3 years of displacement, as of 1994, 1996, and 1998. SOURCE: Data from U.S. Department of Labor, *Current Population Survey: Displaced Workers Supplement*, 1994, 1996, 1998. Also based on Farber, Henry, "A Note on Job Loss Among IT Workers," unpublished manuscript, Department of Economics, Princeton University, May 18, 2000.

However, there are some data suggesting that older displaced Category 1 IT workers find new jobs relatively quickly by being willing to take new jobs that do not pay as well as their previous jobs.[8] In particular, younger male displaced Category 1 IT workers experience a 6.6 percent wage gain on their new job; in contrast, older male displaced Category 1 IT workers experience a 13.7 percent wage loss on their new job—a difference between older and younger workers of 20 percentage points (Figure 4.5)

Note that the greater wage rate loss among older Category 1 IT workers than among younger workers is not entirely explained by the fact that older workers typically lose more after a job displacement because they were more highly paid to begin with due to seniority. One can see this by comparing the relative experience of older and younger workers in the IT

[8]However, Farber does not find that older IT workers are more likely than younger workers to take a part-time job, nor are they more likely to take a non-IT job, once displaced, than younger workers (Farber, Henry, 2000, "A Note on Job Loss Among IT Workers").

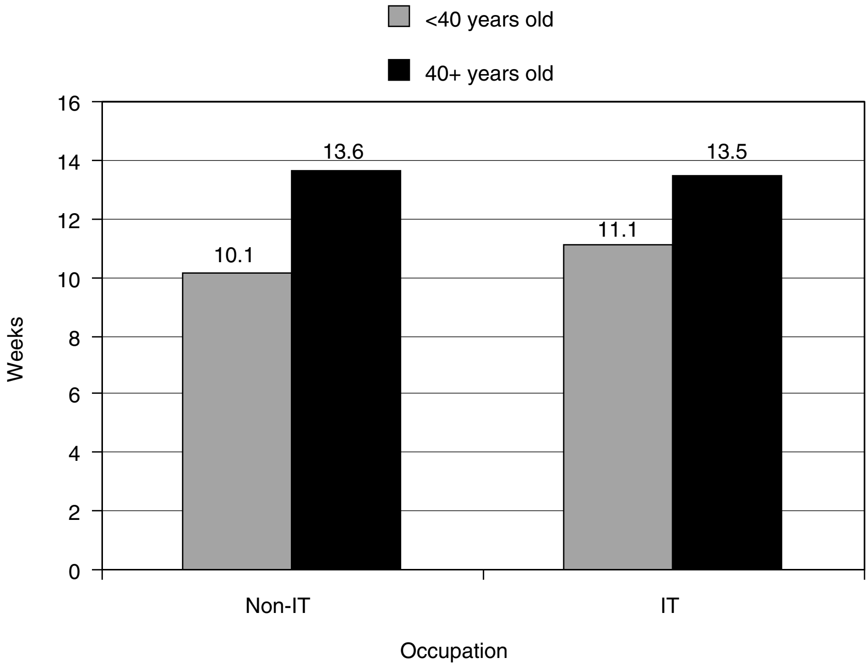

FIGURE 4.4 For displaced workers, mean number of weeks unemployed before finding a job, as of 1994, 1996, and 1998. SOURCE: U.S. Department of Labor, *Current Population Survey: Displaced Workers Supplement*, 1994, 1996, 1998.

sector to the relative experience of older and younger workers in other sectors.

It is important to emphasize, however, that this pattern is only suggestive because the sample sizes are so small that the differences are within the "margin of error." That said, the magnitude of the differences is large enough to warrant further investigation. However, without more information on the qualifications and skills of the workers one cannot distinguish an explanation of discrimination from an explanation that the older workers do not have the up-to-date skills demanded by their new employers. (More discussion of the point regarding more experienced workers and keeping skills up to date is contained in Chapter 7.)

Finally, younger displaced Category 1 IT workers experience gains of about 6.6 percent as compared to losses of 5.7 percent for younger displaced non-IT workers (a difference of 12 percent in favor of IT workers), while older IT workers lose almost 14 percent as compared to almost 20

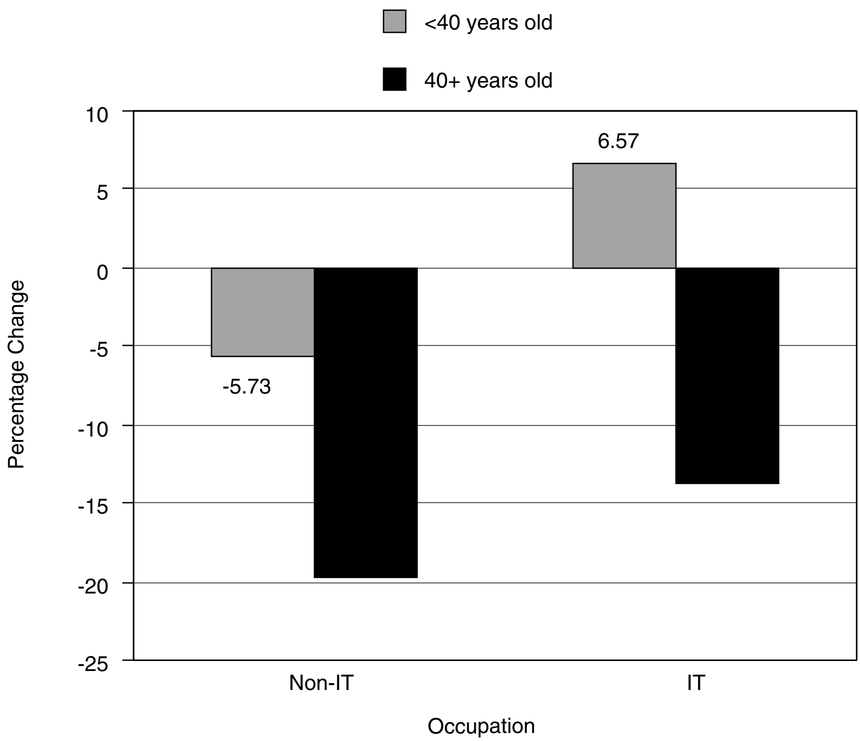

FIGURE 4.5 Mean percentage change in wages for displaced workers who found new jobs, as of 1994, 1996, and 1998. SOURCE: U.S. Department of Labor, *Current Population Survey: Displaced Workers Supplement*, 1994, 1996, 1998.

percent for older displaced non-IT workers (a difference of 6 percent in favor of IT workers). These differences are consistent with the tight labor market in IT, which should result in wage gains or smaller wage losses for Category 1 IT workers since IT employers have to pay more to hire displaced IT workers.

4.3.3 The AARP Audit Study

Because it is essential to account for differences in skills between workers when investigating discrimination (of any kind), many experts turn to experiments, called "audit studies," in which pairs of equally qualified individuals, who differ only by one characteristic (such as age), are sent for a job interview.[9] In 1994, the American Association of Retired People (AARP) conducted just such a study in which employers were presented with pairs of resumes containing equal qualifications, one-third of which were for an information systems manager.[10] The resumes—one for a 57-year-old and one for a 32-year-old—were mailed to a random sample of 775 large firms and employment agencies nationwide.[11] On average, younger applicants received a more favorable response, with older applicants receiving a less favorable employer response about 25 percent of the time when a position was vacant. However, the study also notes that highly successful companies (e.g., companies on *Financial World*'s list of 200 best growth companies) were significantly less likely to select younger workers disproportionately than less successful companies.[12]

While this AARP study contains some evidence of potential age discrimination in the IT sector, it was conducted 6 years ago and may be dated. In particular, it was conducted during a much slacker labor market—a situation that may facilitate a variety of discriminatory practices. Further, the study did not report results separately for the IT resumes such that the committee cannot determine whether they hold for the IT sector specifically.[13]

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[9]Although audit studies are widely accepted as a method for documenting discrimination, see Heckman (Heckman, James J. 1998. "Detecting Discrimination," *Journal of Economic Perspectives* 12(no. 2, Spring):101-116) for a critique of such studies.

[10]Bendick, M., C. Jackson, and J. Romero. 1996. "Employment Discrimination Against Older Workers: An Experimental Study of Hiring Practices," *Journal of Aging & Social Policy* 8(1):25-46.

[11]Resumes for both parties indicated 10 years of experience in the IT field as the most recent work experience. To cover for the age differential prior to that, the older applicant was given work as a high school math teacher. Ages were not explicitly stated but rather implied by date of college graduation.

[12]This result is consistent with the work of Edelman et al., who found that the size of a company correlates positively with the rate at which the company creates EEO grievance procedures, the likelihood of establishing an EEO recruitment program, and the rate at which EEO offices and antidiscrimination rules are created. See Edelman, Lauren B., Christopher Uggen, and Howard S. Erlanger, 1999, "The Endogeneity of Legal Regulation: Grievance Procedures as Rational Myth," *American Journal of Sociology* 105:406-454; Edelman, Lauren B., and Stephen Petterson, 1999, "Symbols and Substance in Organizational Response to Civil Rights Law," *Research in Social Stratification and Mobility* 17:107-136; and Edelman, Lauren B., 1992, "Legal Ambiguity and Symbolic Structures: Organizational Mediation of Civil Rights Law," *American Journal of Sociology* 97:1531-1576.

[13]In addition, an April 2000 study by Hirsch et al., based largely on data from the Current Population Survey, indicates that older workers ". . . face substantial entry barriers in occupations with steep wage profiles, pension benefits, and computer usage." However, this study does not look specifically at employment among IT workers and thus does not provide detailed insight into this matter. See Hirsch, Barry, David A. Macpherson, and Melissa Hardy. 2000. "Labor Market Transitions Among Older Workers: Job Opportunities, Skills, and Working Conditions," *Industrial and Labor Relations Review* 53(3):401-418.

4.4 DISCUSSION

Based on the available empirical data as well as testimony to the committee, it appears that some older IT workers' experiences with displacement and possibly with post-displacement income differ from those of younger workers. The IT workforce is younger than that in other occupations with workers of comparable educational attainment. In addition, the data also suggest that older IT workers (those 40 years and older) are more likely to lose their jobs than younger IT workers. On the other hand, older IT workers are just as likely to find new jobs as are younger IT workers, and the length of time it takes for them to find new jobs is similar to that for younger IT workers.

Much more problematic is the causality of these differences. The data available are insufficient to establish either the presence or the absence of age discrimination. In particular, the data do not permit the committee to determine whether these differences are the result of illegal age discrimination on the part of employers, legal conduct by employers that may be perceived as age discrimination, personal choices made by individual employees, or the ramifications of a rapidly changing industry. As a result, the committee cannot determine whether illegal age discrimination occurs either more or less in IT than in any other industry.

Audit studies provide a basis for further investigation on these points—but the 1994 audit study by the AARP is dated and may not reflect the hiring practices of employers in today's economy. Thus, more studies of this kind are needed to provide more definitive and up-to-date evidence on whether there is discriminatory behavior on the part of employers or whether perceptions of illegal discriminatory behavior are the result of other factors whose existence may be entirely legal.

The committee emphasizes that the analysis based on data from the BLS and presented in Section 4.3 gives overall averages for all Category 1 IT workers working for all employers in the United States. Such averages may well mask broad variations in the experiences of older IT workers compared to younger ones that may occur in different kinds of IT employers (e.g., those in the IT-producing sector and other IT-intensive firms, or large employers with formal procedures in place to guard against age discrimination versus small ones that may lack such procedures). For example, as noted above, the AARP study found that highly successful (and hence, perhaps, larger) companies were less likely than less successful companies to treat older workers differently from younger workers, suggesting that age discrimination is less likely to occur in the former. The possibility of such variations suggests that generalizations to the entire universe of the IT field are dangerous to make.

Although the current data are inconclusive, the committee acknowledges that, if it does exist, the discriminatory treatment of older workers is a significant issue for policymakers to address. This argument is not based on the idea—advanced by some—that the numbers of older U.S. workers who have been victims of age discrimination could have a significant effect on the tightness in the IT labor market in the long term. For, as noted in Box 4.1 given the number of vacancies in the IT workforce today and the number of jobs expected to be added to the Category 1 IT workforce yearly, elimination of all potential age discrimination in the IT workforce likely would not have a significant impact on tightness in the IT workforce in the long term, although it could have a small, but important, one-time effect. Rather, the argument is based on the fact that as a society we cannot afford to underutilize valuable resources, and differential treatment of older IT workers may be depriving IT employers of a valuable source of talent as well as creating perceptions of age discrimination in the industry.

Finally, older IT workers are in the minority today. But as the current IT cohort ages, those proportions will likely change. The implications for age discrimination will depend on cohort-specific labor market and recruitment issues that are difficult to predict. But given that older workers may become more important in IT work in the future than they are now, it may be in the long-term interest of IT firms and other employers of IT workers to begin to address the cultural and wage-structure concerns of older workers.

4.5 RECAP

The data available to the committee are insufficient to establish either the presence or the absence of age discrimination. These data do not permit the committee to determine whether differences between older and younger IT workers are the result of illegal age discrimination on the part of employers, legal conduct by employers that may be perceived as age discrimination, personal choices made by individual employees, or the ramifications of a rapidly changing industry. As a result, the committee cannot determine whether illegal age discrimination exists to a greater or lesser extent among employers of Category 1 IT workers as compared to employers of professionals in other occupations.

In addition, it should be noted that the committee was not constituted as a jury or a court to examine individual cases that may or may not have demonstrated evidence of disparate treatment; as a result it did not consider specific instances of illegal age discrimination. However, it would be naïve to assert that age discrimination never occurs, and many employers recognize that some managers and hiring teams operate from inaccurate assumptions and stereotypes about older people. At the same time,

BOX 4.1
Impact of Age Discrimination on Tightness in the IT Labor Market

The following calculation is a "back-of-the-envelope" calculation that provides approximate magnitudes; it is not meant to be mistaken for a rigorous analysis.

1. The Category 1 IT workforce of about 2.5 million is about 1.8 percent of the U.S. workforce (140 million).
2. The overall U.S. workforce is about 50 percent of the national population of about 275 million.
3. According to the U.S. Census, the number of individuals in the 15-year age bracket from ages 50 to 65 is about 40 million. Approximately 1/15 of this number, or about 2.7 million, enter this age bracket every year.
4. Thus, the number of IT professionals aged 50 to 65 is about 1.8% × 50% × 40 million = 357,000. (Note that this is an overestimate of this category, because IT is a field in which workers are relatively young.)
5. One published source indicates an unemployment rate of about 17 percent for programmers over the age of 50.[1] Thus, the number of unemployed IT professionals is 17% × 357,000 = 60,700. (Note that this number is much higher than the committee has been able to confirm.)
6. The 1994 AARP study referred to in the main body of the text indicated that about 25 percent of older applicants for information systems jobs were unfavorably treated because of their age. If all of the 60,700 unemployed programmers over 50 are capable of doing the work entailed by new jobs, the number of older programmers who are unfavorably treated because of their age and who can do the work required by new jobs is 25% × 60,700 = 15,200.

This number would increase yearly by 1/15 × 15,200, or 1,010 per year.

Conclusions

Even under the assumptions above that overstate the case for age discrimination, addressing all age discrimination issues in IT would not have any significant impact on tightness in the IT workforce in the long term. The fundamental reason is that the number of jobs expected to be added to the Category 1 IT workforce yearly is much larger than any plausible estimate of the number of age discrimination incidents against older IT workers. However, given the number of vacancies in the IT workforce today, elimination of all currently existing age discrimination in the IT workforce could have a small but important one-time effect on tightness in the workforce.

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[1] Didio, Laura. 1998. "Over the Hill?" *Computerworld*, January 12.

workers who lose their jobs for whatever reason (company mergers or acquisitions, downsizing, end of life of a product or service, obsolete skills, poor performance, and so on) may inaccurately attribute the cause of this action to age discrimination.

5

Foreign Workers in the IT Workforce

The IT sector and the IT-intensive industries are global: nations other than the United States consume and supply IT products and services, and nations other than the United States have individuals with the talent, motivation, and desire to work in the IT sector and IT-intensive industries. For this reason, it is necessary to understand the foreign dimensions of the IT workforce.

5.1 THE IMPACT OF FOREIGN WORKERS ON THE U.S. ECONOMY AND WORKFORCE

The impact of foreign individuals on the U.S. economy and workforce is a controversial subject, and the debate is complicated because of unspoken feelings and hidden agendas on the part of various stakeholders.

As the world's economy becomes increasingly global, so too does the workforce of many U.S. firms. Among the reasons for using foreign workers is the fact that the United States does not have a monopoly on productive, knowledgeable, and motivated individuals; rather, such workers are found all over the world. Foreign workers can make positive contributions to the U.S. economy in a number of different ways:

- Foreign IT workers may bring to the United States the language, cultural, or specialized engineering skills needed for the internationalization and localization of software products.[1]

- They bring knowledge and expertise obtained in their home countries for which the United States did not pay, certainly for K-12 education and in some cases for higher education. That is, the United States reaps the benefits of their education without paying its cost, because their home nations paid for their education.
- They facilitate trade with their countries of origin and links between domestic technology businesses and those in their countries of origin. Box 5.1 illustrates the impact of immigrants on an economically important region of the United States: Silicon Valley.
- They increase the level of talent in the U.S. workforce, because foreign workers coming to the United States for IT jobs tend to have higher educational levels compared to the average foreign (or U.S.) worker).[2]
- To the extent that companies need individuals with adequate formal training in computer science, they may well turn to foreign workers who have the necessary formal training if they are unable to find domestic workers with such training.
- U.S. firms may be able to reduce significantly their labor costs to the extent that foreign workers are willing to work for less than comparable U.S. workers when these foreign workers are located abroad in relatively low-wage countries. (Other reasons for U.S. firms to locate work abroad are discussed in Section 5.3.2.)
- They contribute to national output. To the extent that foreign workers specialize in activities that would not otherwise exist domestically (and given growing use of IT throughout the U.S. economy, they clearly play some role in meeting demands that arise from growth), the native population benefits overall because it can consume the output of that production.[3]

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[1]Specialized engineering skills could entail changes in the display routines of an operating system to allow Arabic or Hebrew characters to display from right to left, without any loss of formatting, hyphenation, and page breaks, or changes in drivers to accept input from a keyboard designed for Japanese characters (Kanji). (The Japanese keyboard uses Kana, a Japanese phonetic alphabet to prompt the display of several Kanji characters from which the user can select.)

[2]See, for example, Ellis, Richard, and B. Lindsay Lowell. 1999. "Foreign-Origin Persons in the U.S. Information Technology Workforce," Report III of the IT Workforce Data Project. New York: United Engineering Foundation. Available online at <http://www.uefoundation.org>.

[3]See, for example, National Research Council. 1997. *The New Americans: Economic, Demographic, and Fiscal Effects of Immigration*. James P. Smith and Barry Edmonston, eds. Washington, D.C.: National Academy Press.

BOX 5.1
Illustrative Contributions of Immigrants to the U.S. Economy

"[F]oreign-born engineers in Silicon Valley's technology industry make a substantial and growing contribution to regional job and wealth creation . . . . The entrepreneurial contributions of these skilled immigrants are impressive. In 1998, Chinese and Indian engineers, most of whom arrived in the United States after 1970 to pursue graduate studies, were senior executives at one-quarter of Silicon Valley's new technology businesses. These immigrant-run companies collectively accounted for more than $16.8 billion in sales and 58,282 jobs in 1998. Moreover, Chinese and Indian immigrants started companies at an accelerating rate in the 1990s.

"The economic contributions of immigrants are not limited to their direct role as engineers and entrepreneurs. Although Silicon Valley's new immigrant entrepreneurs are more highly skilled than their counterparts in traditional industries, like those counterparts they have created a rich fabric of professional and associational activities that facilitate immigrant job search, information exchange, access to capital and managerial know-how, and the creation of shared ethnic identities. The region's most successful Chinese and Indian entrepreneurs rely heavily on such ethnic resources while simultaneously integrating into the mainstream technology economy.

"These networks are not simply local. Silicon Valley's new immigrant entrepreneurs are building far-reaching professional and business ties to regions in Asia. They are uniquely positioned because their language skills and technical and cultural know-how allow them to function effectively in the business culture of their home countries as well as in Silicon Valley. A transnational community of Chinese—primarily Taiwanese—engineers has thus fostered two-way flows of capital, skill, and information between California and the Hsinchu-Taipei region of Taiwan. In this process, Silicon Valley-based entrepreneurs benefit from the significant flows of capital that these immigrants coordinate, as well as from the privileged access that they provide to Asian markets and to Taiwan's flexible, state-of-the-art semiconductor and personal computer manufacturing capabilities. Silicon Valley's Indian-born engineers have played a similar, but more arm's-length role, linking technology businesses in Silicon Valley with India's highly skilled software programming and design talent. These long-distance social networks enhance economic opportunities for California and for emerging regions in Asia.

"[S]killed immigrants contribute to the dynamism of the Silicon Valley economy, both directly, as engineers and entrepreneurs, and indirectly, as traders and middlemen linking California to technologically advanced regions of Asia."

SOURCE: Excerpted from Saxenian, AnnaLee. 1999. *Silicon Valley's New Immigrant Entrepreneurs*, Executive Summary. San Francisco: Public Policy Institute of California. Available online at <http://www.ppic.org/publications/PPIC120/ppic120.sum.html>.

• As do domestic entrepreneurs, scientists, and engineers, so also foreign entrepreneurs, scientists, and engineers create jobs.[4] Entrepreneurs create businesses that hire others, while scientists and engineers—through the science and engineering that underlies new technologies—create jobs for other scientists and engineers working with those technologies.

At the same time, foreign workers in the United States can have negative impacts as well:

• Learning from U.S. IT sector firms, they may bring back to their home countries expertise and knowledge that they can use to compete more effectively against U.S. companies.

• The availability of foreign workers to U.S. employers raises the supply of labor for those jobs that foreign workers will fill. As with any increase in the supply of available workers, the use of foreign workers may have deleterious effects on the wages and job security of U.S. workers who might otherwise do the work entrusted to foreign workers. To the extent that foreign workers compete with native U.S. workers, economic principles suggest that (a) the foreign workers may displace the domestic workers and (b) the presence of the foreign workers may hold down wages in those jobs.[5] Wages may be depressed even if all employers paid temporary nonimmigrant workers the wages prevailing for the jobs for which these nonimmigrant workers are hired.

This remainder of this chapter discusses in more detail the use of foreign IT workers in the United States and in their native lands by U.S. firms.

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[4]For example, foreign-born individuals have been instrumental in starting major U.S. hardware, software, and semiconductor firms, including Wang, Intel, Sun, and Computer Associates.

[5]This outcome was endorsed by Federal Reserve Chairman Alan Greenspan when he argued in testimony before the House Banking Committee on February 16, 2000, that the availability of foreign workers was a critical factor in holding down wage inflation during a long period of economic growth. Specifically, he stated that ". . . imbalances in the labor markets perhaps may have even more serious implications for inflation pressures. While the pool of officially unemployed and those otherwise willing to work may continue to shrink, as it has persistently over the past 7 years, there is an effective limit to new hiring, unless immigration is uncapped. At some point in the continuous reduction in the number of available workers willing to take jobs, short of the repeal of the law of supply and demand, wage increases must rise above even impressive gains in productivity. This would intensify inflationary pressures or squeeze profit margins, with either outcome capable of bringing our growing prosperity to an end."

5.2 FOREIGN WORKERS IN THE UNITED STATES

For many foreign IT workers, the United States is more attractive than other nations as a place to work. One reason is that English is by far the dominant language of information technology, and many foreign IT workers already have some basic fluency with English. Thus, in choosing a nation in which English is the language of social and business interaction, they do not need to learn another language to function well in that (new) country. The United States has a reputation as a land of free enterprise where individuals can start new businesses and achieve great success,[6] or, perhaps more realistically, find attractive job prospects and maximize their earning potential. And, historically the United States has been much more tolerant of ethnic diversity than have many other nations.

5.2.1 Foreign Workers Overall

For purposes of this report, a foreign worker is a foreign-born individual who is either a temporary nonimmigrant worker or a permanent resident of the United States. Foreign workers enter the U.S. workforce through two different channels: direct recruitment from abroad and change or adjustment of the status of an individual already in the United States.[7] And, the sponsoring party can be a U.S. firm that employs the worker directly, a foreign company that has a branch office (unincorporated) in the United States, or an intermediary U.S.-based organization that employs the worker on behalf of a U.S. firm. In some cases, the intermediary organization has close ties to a foreign IT firm that is doing work outsourced from the U.S. firm; in other cases, the intermediary organization functions as a "temp agency" that places its workers in assignments of varying length with U.S. firms, who then use these temporary placements as a way of trying out these workers and possibly selecting them for permanent hires.

Flows of foreign workers into the United States have remained roughly constant over the last decade, though the mix of permanent immigrants and temporary nonimmigrant workers has varied. In general, foreign-born individuals constituted about 17 percent of the Category 1 IT workforce in 1998, compared to about 10 percent of the total U.S. popula-

[6]See, for example, Spaeth, Anthony, 2000, "The Golden Diaspora," *Time*, June 19; Chabria, A., "Silicon Raj," *Upside*, July 25, p. 155.

[7]A change of status refers to a change from one nonimmigrant visa status to another (e.g., from F-1 to H-1B); an adjustment of status refers to adjusting one's status from that of a nonimmigrant (e.g., an H-1B) to that of a permanent resident or immigrant by submitting an adjustment application to a local INS office.

tion.[8] In addition, they tend to cluster geographically, living in just a few states, most of which have large concentrations of other foreign-born individuals.

5.2.2 Foreign Worker Programs

Because differences between permanent residents (also known as green-card holders) and temporary nonimmigrant workers are an essential nuance of the policy debate over the use of foreign talent in the United States, the next two subsections address these programs in more detail.

Permanent Residents

A permanent resident of the United States is a noncitizen who is entitled to remain and work in the United States indefinitely.

Numbers of Permanent Residents By law, 140,000 permanent residents can be admitted to the United States each year based on their job skills. This figure is subject to numerical limits based on country of origin and categories of workers. It also includes both the principal alien and his immediate family, so the actual number of "workers" is significantly lower than 140,000. The major categories of workers are the following:

- *Priority workers*. Up to 40,040 of the employment-based visas may go to workers of "extraordinary ability,"[9] professors and researchers who are internationally recognized as outstanding in a specific academic field,[10]

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[8]See, for example, Ellis, Richard, and B. Lindsay Lowell. 1999. "Foreign-Origin Persons in the U.S. Information Technology Workforce," Report III of the IT Workforce Data Project. New York: United Engineering Foundation. Available online at <http://www.uefoundation.org>. (The term "foreign-born" as defined in this report includes foreign workers, foreign students in the United States, and naturalized U.S. citizens. Thus, the Ellis and Lowell estimate of foreign-born IT workers is higher than the percentage of H-1B workers in IT, which is estimated at 10 percent. See discussion at footnote 19.)

[9]"Extraordinary ability" in the sciences, arts, education, business, or athletics must be demonstrated by sustained national or international acclaim and achievements that have been recognized in the field through extensive documentation. INS regulations suggest that only a small percentage of aliens will have risen to the very top of their field of endeavor. Workers of "extraordinary ability" are essentially limited to Nobel Prize winners, world-renowned entertainers, and individuals of similar stature.

[10]Under this category, individuals must have a minimum of 3 years of experience in teaching and/or research in that field and enter the United States in a tenure or tenure-track teaching or comparable research position at a university or other institution of higher education, or in a comparable research position with a private employer, and have a record of outstanding teaching or research.

and executives and managers of foreign companies who are permanently transferred to the United States.[11]

- *Professionals with advanced degrees and/or exceptional ability in the sciences, arts, or business.* Up to 40,040 of the employment-based visas may go to workers who are "members of the professions holding advanced degrees or their equivalent," or workers "who because of their exceptional ability in the sciences, arts, or business will substantially benefit prospectively the national economy, cultural or educational interests, or welfare of the U.S." (8 USC 1153).
- *Skilled workers, professionals, and other workers.* Up to 40,040 of the employment-based visas may go to skilled workers with at least 2 years of experience, professionals with a baccalaureate degree, and other workers with less than 2 years of experience. (An additional 19,880 visas are reserved for so-called special immigrants and employment creation visas, neither of which is relevant here.)

Obtaining a Green Card In order to obtain permanent residency (a "green card") most workers in the above categories must first obtain a permanent labor certification (PLC) from the Department of Labor (DOL).[12] To obtain a PLC, a prospective employer must test the U.S. labor market under DOL supervision to ensure that there are no minimally qualified U.S. workers interested in and available for the position for which an alien is sought and that the employment will not adversely affect the wages and working conditions of similarly employed U.S. workers.[13]

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[11]The executive must manage the organization or a department, subdivision, function, or component of the organization; supervise and control the work of other supervisory, professional, or managerial employees or manage an essential function within the organization, or a department or subdivision of the organization; have the authority to hire and fire; and exercise discretion over the day-to-day operations of the activity or function for which the employee has authority. In concept, it is similar to the requirements imposed on individuals in the L nonimmigrant category.

[12]The primary exception is for individuals of extraordinary ability, for whom no job offer need exist and no permanent labor certification is necessary. In addition, a PLC is not required if the prospective immigrant can show that his or her employment would be in the "national interest" (although the INS has dramatically limited national interest waivers since issuing a restrictive decision in August 1998).

[13]Note a significant unintended consequence of this requirement. While the PLC application is pending, the employer cannot materially change the job duties of the applicant, even if the applicant is already working in the job (e.g., on an H-1B visa), because INS rules require the applicant to be performing the job duties described in the approved labor certification at the time he or she applies for adjustment of status. And the employer cannot change the location of the job at all (unless the new location is in the same metropolitan area as the old) because of the potential impact on wages.

A labor certification consists of two steps.[14] First, the prospective employer files an application with the local state employment office describing the position and its minimum requirements and the foreign worker's education and experience, and stating a prevailing wage for persons similarly employed in the area of intended employment. The local office supervises this recruitment phase of the labor certification, which generally requires that employers place specialty job advertisements in newspapers and trade journals and interview qualified candidates. Second, this office forwards the case to the regional DOL office, which either approves the case or issues a notice listing possible deficiencies in the job requirements or recruitment (in which case the employer must delete these contested requirements and re-advertise to avoid a denial).

After the PLC is approved, the employer files an immigrant visa petition with the Immigration and Naturalization Service (INS). The immigrant visa petition establishes that both the job in question and the sponsored worker meet the relevant definitions for experience and/or education as well as any job requirements specified in the labor certification.

Finally, the foreign national must apply for immigrant status, either at a U.S. consulate abroad or—more commonly—by submitting an application at the local INS office to adjust his or her status from that of a nonimmigrant (e.g., an H-1B) to that of an immigrant. A foreign national must satisfy many requirements to qualify for adjustment of status, a process that generally takes about 12 to 18 months (due to backlogs in security checks provided by the Central Intelligence Agency and other processing delays).

One of the most important requirements is the applicant's immediate eligibility for an immigrant visa under the numerical quota system, and an applicant's position in the queue is established by the date on which the PLC is filed (the priority date) (Box 5.2). Applicants who bump up against the per-country quotas (because their priority date is too late) must wait until additional slots are made available in subsequent fiscal years.

The time required to obtain permanent residence for professional workers is measured in years. At best, it takes about 2 to 3 years. In the worst-case scenario (which is not limited to isolated cases), it may take 8 to 10 years.[15] The steps and intervals are as follows:

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[14]In cases where the position in question appears on a list of occupations considered in short supply by DOL (including nurses, physical therapists, and certain aliens of exceptional ability), an automatic labor certification is granted.

[15]While an H-1B visa holder is in the middle of the green-card process, he or she usually retains an H-1B status for both work authorization and travel purposes. If the H-1B visa expires first, a number of complex scenarios can play out. However, a detailed description of these scenarios is not relevant to this report.

BOX 5.2
Per-Country Quotas

In general, the allocation of immigrant visas is controlled by a system of worldwide numerical limitation based upon country of origin and the chronological order of the date of filing a labor certification or immigrant visa petition, depending upon the requirements of the visa category. (This date is called the "priority date.") As noted in the main text, the maximum quota for all employment-based immigration is 140,000 per year. About 70,000 of these visas are reserved for the two categories of professional workers requiring labor certifications.

In FY1998, the Immigration and Naturalization Service admitted fewer than 50,000 immigrants in these categories, but this number was artificially low due to severe delays (1 to 2 years) in processing adjustment-of-status applications; as INS begins to approve these delayed cases, and the increased numbers of H-1B workers admitted in FY1999 to FY2001 begin to apply for permanent resident status, the 50,000 figure will skyrocket, likely resulting in visa backlogs in these two visa categories.

Additionally, persons born in certain high-demand countries (such as India and China) also must contend with per-country limitations of less than 10,000 visas per country per year. Beginning in 1996 for India and 1997 for the People's Republic of China, per-country backlogs have resulted in visa waiting periods of $1^1/_2$ to 3 years for Indian nationals and from 2 to 4 years for PRC nationals. In other words, even though there are 20,000 unused employment-based visas, a visa backlog arises in any year during which the demand for such visas from Indian or PRC nationals exceeds 10,000 per year (including the foreign worker's spouse and children). Whenever this occurs, visa applicants from these countries must wait until more visas become available in subsequent fiscal years before they can complete their quest for permanent residence.

- Labor certification, $^1/_2$ to 4 years;
- Immigrant visa petition, $^1/_2$ to 1 year;
- Adjustment of status, 1 to $1^1/_2$ years; and
- Delays due to per-country limits, 0 to 3 years.

Temporary Nonimmigrant Workers

The United States allows those on temporary visas to enter the United States for periods of limited, but varying, duration for a number of purposes, including employment, study, and tourism. These individuals are generically categorized as nonimmigrants because nonimmigrants, in contrast to immigrants, are not expected to remain in the United States permanently. Many nonimmigrant categories permit aliens to work while they are in the United States; such individuals are classified as temporary nonimmigrant workers. For purposes of this report, the most significant nonimmigrant visa category is the H-1B visa. (Box 5.3 describes other important nonimmigrant visas.)

H-1B visas are available for a maximum of 6 years to foreign persons with skills in a "specialty occupation," i.e., those that require both (a) theoretical and practical application of a body of highly specialized knowledge and (b) attainment of a bachelor's degree or higher (or its equivalent) in the specialized field as a minimum for entry into the occupation. Some of the fields included in "specialty occupation" include architecture, engineering, computer programming, accounting, medicine, teaching, and so on.

The theory underlying the H-1B program is that temporary workers play an important role in helping to meet workforce needs in times of labor market tightness. However, during slack labor markets, the presence of such workers can complicate efforts to ensure that qualified U.S. workers are able to find work. The time lines built into the H-1B program (6-year maximum, renewable once after 3 years) allow for a significant reduction in the H-1B workforce in 3 years (to 65,000 admitted per year, or a total of 390,000 H-1B visa holders in the steady state), assuming a concurrent decision to refrain from converting H-1Bs to permanent residency.[16] Thus, in principle though perhaps not in practice, the program has a degree of built-in flexibility that policymakers can use to respond to serious recessions, during which labor markets tend to slacken.

Numbers of H-1B Visas and Workers The American Competitiveness and Workforce Improvement Act of 1998 (ACWIA) temporarily raised the level of temporary nonimmigrant H-1B visas from 65,000 (the cap level established in 1990) to 115,000 in FY1999 and FY2000, dropping it to 107,500 in FY2001, and then reverting to 65,000 in FY2002. Currently, proposed legislation would raise these caps again.

While data on H-1B visa holders are scarce, in February 2000 the INS released the results of a one-time study of H-1B visa holders, based on a random sampling of approximately 4,200 H-1B holders admitted during the 15 months from May 1998 to July 1999.[17] According to this survey, approximately 56.7 percent of H-1B visa holders were employed in occu-

[16]Note that under international commitments that the United States has formalized under the General Agreement on Trade in Services, the United States is barred from lowering the H-1B limit below 65,000. This commitment is expressed in the U.S. Schedule of Commitments and List of MFN Exemptions in the Final Texts of the Uruguay Round of Multinational Trade Negotiations, signed on April 15, 1994, in Marrakech, Morocco.

[17]U.S. Immigration and Naturalization Service. 2000. *Characteristics of Specialty Occupation Workers (H-1B)*. Washington, D.C.: Immigration and Naturalization Service, February.

BOX 5.3
Major Non-H-1B Nonimmigrant Visa Categories

"E" Treaty Traders and Investors

E visa holders enter the United States under the provisions of a specific treaty of commerce and navigation (or a bilateral investment treaty) between the United States and the alien's native country. An E-1 visa holder enters to engage in trade between the foreign country and the United States. An alien may also qualify as a treaty investor to develop and direct the operations of an enterprise in which he or she has invested, or of an enterprise in which he or she is actively in the process of investing a substantial amount of capital. The E category also allows certain key employees (executives, supervisors, and persons with essential skills) to enter in treaty-trader or treaty-investor status.

"F" Foreign Students

F visa holders are primarily undergraduate and graduate students at U.S. colleges and universities. After 1 year in F visa status, a foreign student becomes eligible for on-campus work or off-campus work if he or she can prove financial hardship, primarily in nonskilled positions. F-1 foreign students are also eligible for "practical training" during which they may work for a U.S. employer in the field of their studies, either in a work/study program or internship, during annual vacations, or after completion of a course of study.

"J" Exchange Visitors and Spouses

J visa holders include a wide variety of foreign nationals whose purposes in the United States range from students to trainees to summer camp counselors to au pairs. However, they are generally prohibited from remaining in the United States

pations that are explicitly computer-related (mostly in systems analysis and programming); an additional 4.9 percent were employed in "electrical and electronics engineering" occupations, and a significant fraction of these individuals certainly work in the IT field. H-1B visa holders in systems analysis and programming received a median wage, not including bonuses or benefits, of $47,000 (Table 5.1). Nearly half of all H-1B visa holders (47.5 percent) came from India, with 9.3 percent coming from China. As for formal education, 41 percent of all H-1B visa holders had post-baccalaureate degrees; of those employed as systems analysts and programmers, about 34 percent had a master's degree or higher. Finally, beyond the period covered by their initial admission. Unlike F students, who can change status to H-1Bs and eventually to permanent residents, many J visa holders are required to return to their home countries for 2 years before they can return to the United States. In addition, the spouse and dependents of a J visa holder are permitted under certain circumstances to work in the United States, which is not true of the spouse and dependents of F visa holders.

"L" Intracompany Transferees

L visa holders have worked abroad for 1 continuous year within the preceding 3 years in an executive, managerial, or specialized knowledge capacity for a qualifying, related business entity and are transferred temporarily to the United States to work in an executive, managerial, or specialized knowledge capacity for a qualifying, related business entity. The limit on duration of stay is 5 years for the "specialized knowledge" category (i.e., employees with special knowledge of their firm's product, service, and/or research and their application in international markets) and 7 years for L-1 executives and managers. Spouses and children of L-1 visa holders are not allowed to work.

Trade-NAFTA Visas ("TN")

TN visa holders are certain Canadian and Mexican nationals who can enter the United States under the "TN" nonimmigrant category. The major benefits of TN status to Canadian citizens otherwise eligible for H-1B visa status are the streamlined application procedures at ports of entry, the lack of any limit on the number of extensions of stay or applications for readmission, and the absence of a limit on the total number of TN admissions that may be granted. Restrictions on Mexican applicants for TN visas are more stringent.

60 percent of H-1B visa holders originated outside the United States, while 22.9 percent represented conversions from F-1 student visas.[18]

The committee's best estimate of the number of H-1B workers in the Category 1 IT workforce is about 255,000, or about 10 percent of the Cat-

[18]Note, however, that the data do not allow the determination of the share of "new" H-1B applicants who had previously studied in the United States, but had returned home prior to applying for an H-1B visa.

TABLE 5.1 Characterization of H-1B Visa Holders in the United States, 1998

Field[a]	Percentage in Field	Median Wage (not including bonuses or benefits)
Systems analysis and programming	53.3	$47,000
Electrical/electronic engineering	4.9	$54,000
Computer-related occupations, not elsewhere classified	3.4	$49,400
College and university education	3.0	$35,000
Accountants, auditors, and related occupations	2.8	$36,000
Architecture, engineering, surveying, not elsewhere classified	2.3	$51,000
Other	30.3	$40,000

Note on methodology: The INS took random samples of approximately 1,100 approved petitions from each of the four INS service enters (in Vermont, Texas, Nebraska, and California). All petitions were approved during the period from May 11, 1998, to July 31, 1999, and all were potentially recorded against the H-1B cap from FY 1999.

[a]Field of H-1B worker is as indicated by the sponsoring employer on the Labor Condition Application.

SOURCE: Immigration and Naturalization Service. 2000. *Characteristics of Specialty Occupation Workers (H-1B).* Washington, D.C.: INS, February.

egory 1 IT workforce.[19] However, it cautions that this estimate is built on the assumptions of footnote 19 below as well as the premise that the fraction of recent H-1B visas that have been granted to IT workers has

[19]As indicated above, about 58 to 62 percent of H-1B visa holders work in Category 1 IT-related fields; for computational simplicity, the discussion below uses 60 percent. An estimate of the total number of H-1B visa holders in the United States is provided by the assumption that all H-1B visa holders remain in the United States for the full 6 years allowed by law, and that the cap on H-1B visa holders was exhausted in each year of the program's operation: this calculation (65,000 × 5 + 115,000 in FY 1998) yields 440,000 H-1B visa holders in the United States at this writing, a number consistent with the Lowell estimate of 425,000 (see, for example, Ellis, Richard, and B. Lindsay Lowell. 1999. "Foreign-Origin Persons in the U.S. Information Technology Workforce," Report III of the IT Workforce Data Project. New York: United Engineering Foundation. Available online at <http://www.uefoundation.org>). Using the Lowell figure of 425,000 and an estimate of approximately 60 percent, an estimate of 255,000 H-1B visa holders working in the Category 1 IT professions is obtained. This figure, combined with the assumption of a Category 1 IT workforce of 2.5 million as discussed in Chapter 2, results in an estimate of about 10 percent as the fraction of the Category 1 IT workforce occupied by H-1B visa holders.

been approximately the same throughout the life of the H-1B program. Because it is unlikely that employers of IT workers made greater use of the H-1B visa program in its earlier days than they do today, the estimate of 10 percent most likely represents an upper bound on this figure. H-1B workers may be directly employed by the firm that obtains the H-1B visa—the H-1B worker is paid by the firm for which he or she is doing the work. Or these workers may work for a third party—a personnel supply or business service firm—and perform services at a customer's work site, as described in Box 5.4.

Obtaining an H-1B Visa A U.S. employer seeking to fill a position with an H-1B worker must satisfy requirements of the Department of Labor and the Immigration and Naturalization Service. When the worker applies for a travel visa to enter or reenter the United States in H-1B status, engagement with the Department of State is necessary as well. With the DOL, all employers must file a labor condition application (LCA), on which they must attest that the H-1B worker will be paid the higher of the actual wage at the employer's work site or the prevailing wage for the particular position in the geographic area, that the working conditions of U.S. workers similarly employed will not be adversely affected, and that there is no strike or lockout. Further, the employer must post a notice of the need for an H-1B worker for other employees to review. (Box 5.5 describes other worker protections as well as additional LCA requirements targeted at employers whose workforce contains a significant fraction of H-1B workers.) Employers are required by law to offer H-1B workers benefits (health and other forms of insurance, retirement and savings plans, bonuses, and stock options) on the same basis as they are offered to U.S. workers. Once it has reviewed the LCA, DOL "certifies" it and returns it to the employer for the next step in the process.[20]

The second step is for the employer to submit the LCA (certified by DOL) along with a more detailed petition sponsoring a specific individual to the INS. The petitioner must be a U.S. employer or a U.S. branch or subsidiary of a foreign employer, and the job may be either a temporary position or a permanent position that is filled on a temporary basis. At this stage of processing, employers must submit substantial documentation regarding the potential worker's education and accomplishments. A fee of $610 is required, which must be paid by the employer, not the alien.

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[20]On one LCA an employer can obtain certification for hiring several potential H-1Bs into several potential positions. Further, at this point, the employer need not have identified a specific individual he or she would like to hire.

BOX 5.4
Different Business Models for Third-party Use of Nonimmigrant Foreign Labor

Personnel Supply Firms

Personnel supply firms (PSFs) provide temporary labor to their client firms. Though the workers that the PSF supply to a client firm formally work under the supervision of a PSF manager, the client firm provides overall direction for those workers. Billing of the client company by the PSF is almost always by the hour (i.e., for the worker's time rather than for a product or for performance). Sometimes, small, discrete projects are given to a PSF (which might then use one or more of its workers to perform the work), but such projects would typically be done on the premises of the client, and under the overall direction of the client. Firms providing temporary labor for IT are more logically classified as employment agencies and help-supply agencies (e.g., like Manpower or Kelly services) rather than as software producers. This characterization of PSFs holds true whether the firm employs domestic or foreign workers.

PSFs have strong economic incentives to pay any given worker a lower salary than s/he might otherwise receive, while charging the client firm a rate more reflective of that individual's true skills and abilities. By doing so, the firm increases its profit margin. A PSF that employs H-1B workers is required to pay them the higher of the actual wage paid to other similarly qualified employees of the PSF at the work site (typically, the customer's place of business) or the prevailing wage for the position in question.

Demand for temporary services in IT has grown because of tightness in the IT workforce. As a result, the demand for workers willing to accept the economic realities described above (perhaps in exchange for a variety of other benefits) has increased—and this category includes nonimmigrant foreign IT workers from nations in which prevailing wages are low.

Firms that supply temporary labor appear to fall into two separate market niches. One niche involves providing low-cost labor. In this niche, temporary staff firms are more likely to employ workers at below-market rates, have less favorable working conditions, and attract workers with lower skill levels as compared to those provided by firms in the second niche. Firms in the second niche provide temporary IT staffing with more highly skilled, high-quality workers who have the potential to be permanent workers or who could conduct their work at a level closely comparable to the firms' own staff. Client firms establish long-term relationships with these temporary firms because they can provide consistently good-quality and reliable workers in sufficient numbers.

At its public meetings, the committee heard substantial oral testimony about firms that allegedly violated the terms of the H-1B program by paying H-1B workers at a level that undercut the salaries of domestic workers. Without detailed information about the specific employers involved, it is not possible to determine if these charges are true or to identify with certainty the niche into which any particular firm whose compensation practices were challenged may fall, but the economic incentives suggest that it is more likely that they fall into the first niche described above. Because firms in the second niche often serve a recruiting function for U.S. clients, it seems less likely that such firms would pay workers far below market rates. In fact, a number of U.S. client firms reported that when they wanted to hire the temporary workers permanently, a nontrivial number of the temporary workers refused because they were making higher wages as temporary workers. This is not to say that U.S. clients do not take advantage of whatever lower costs the firms in the second niche can lawfully provide—but as a rule, lower costs do not appear to be the sole or primary factor in use of this temporary staff.

Business Service Firms

Business service firms (BSFs) provide IT services that clients wish to outsource (e.g., running a computer room, involving mostly hardware and operating systems maintenance, or LAN administration or PC maintenance). They also provide software maintenance and supplemental staffing for projects, although the latter would tend to be defined more by project area than by job. They might also provide consulting services, such as SAP implementation. And they may undertake the development of software products specifically customized for their clients.

A number of these firms have strong foreign ties. One rationale for the existence of firms with such ties is that they can offer their services to U.S. clients at substantially lower cost than would be charged by U.S.-only firms. These firms take advantage of lower wage structures available abroad (e.g., in Asia) to do the bulk of the necessary development work. However, because substantial interaction is required to understand client needs and requirements, it makes a great deal of sense to establish a U.S. presence through which ongoing contact, requirements analysis, testing, and liaison functions can be done in direct, physical contact with the client at the client site, while design, programming, testing, documentation, and other functions can be done abroad. Firms using this model find that a substantial amount of total project effort can be done in this manner.

To use the BSF model for H-1B workers, a U.S. employer is needed. In some cases, the U.S. employer is the parent firm, which subcontracts work to a foreign IT firm or subsidiary in, for example, India. In other cases, it is the Indian firm that is the parent, which then establishes a U.S. subsidiary to serve as the U.S. employer of record. In any event, because of the need to translate requirements into specifications that can be fed into the development process, there is a high premium on selecting for work in the United States individuals who are compatible with those abroad. Under these circumstances, it is understandable that the U.S. employer would try to use individuals from the foreign nation to perform the interface function—and these individuals are often nonimmigrant foreign workers on H-1B visas in the United States.

Payments to these U.S. employers are for practical purposes part of the fee that the U.S. client pays to the consulting or custom development firm. Because their primary goal is to provide IT products and services, these firms have less incentive to underpay workers relative to their talents compared to firms whose role is solely to provide labor. In particular, their incentives seem to be no higher or lower than those of any other IT-sector or IT-intensive firm in the United States to use nonimmigrant foreign labor.

Note that ACWIA includes several new LCA requirements designed to eliminate economic incentives for personnel supply or business service firms, and other firms that rely heavily on H-1B workers, to hire foreign born workers. These requirements are listed in the second half of Box 5.5.

SOURCE: The description of PSFs and BSFs is based largely on Salzman (Salzman, Hal, with Radha Roy Biswas, University of Massachusetts-Lowell, “The Indian IT Industry and Workforce,” commissioned paper prepared for the Committee on Workforce Needs in Information Technology, March 2000).

BOX 5.5
Additional Requirements of the H-1B Program

In addition to the requirements described in the main text, there are three other requirements levied on all employers of H-1B visa holders:

- If an H-1B nonimmigrant is dismissed before the end of the period of authorized stay, the employer is liable for the reasonable costs of the beneficiary's return transportation "abroad," i.e., to the beneficiary's last place of foreign residence. Any dismissal is covered, including one for cause. The exception is that when the beneficiary voluntarily terminates employment; the individual is then responsible for his or her own return travel costs.
- An H-1B employer cannot impose a financial penalty on an H-1B employee who chooses to leave his or her position prior to an agreed date. This provision is designed to ensure that employees are free to terminate their employment if they so choose. (Employers found guilty of imposing such a penalty are subject to a $1,000 fine.)
- However, employers are permitted to collect liquidated damages under state law provisions that permit the parties to agree by contract for the payment of liquidated damages in the event one party breaches, but only if the H-1B employer and the H-1B worker are parties to a contract authorizing same.
- Employers cannot fail to pay an H-1B worker who is in nonproductive status due to the lack of work or the lack of a permit or license for the alien. This "no-benching" provision was intended to discourage the hiring of foreign professionals for speculative employment by requiring the continued payment of wages and benefits even when the work does not materialize and the employee remains available for work.

Further, additional requirements are placed on "H-1B-dependent" employers:[1] These requirements—adopted in 1998 in the ACWIA—include:[2]

Of that fee, $500 goes primarily for education and training programs for U.S. workers and for enforcement purposes.[21]

[21]Specifically, of the $500, 56.3 percent is for DOL demonstration programs and projects described in section 414(c) of the American Competitiveness and Workforce Improvement Act of 1998; 28.2 percent is for National Science Foundation scholarships aimed at low-income students enrolled in a program of study leading to a degree in mathematics, engineering, or computer science; 4 percent is for National Science Foundation grants for programs that provide opportunities for enrollment in year-round academic enrichment courses in mathematics, engineering, or science; 4 percent is for National Science Foundation systemic reform activities; 1.5 percent is for DOJ actions to decrease the processing

- A "no-layoff" provision under which the employer must promise that in hiring H-1B workers, it is not laying off a U.S. worker from a job that is "essentially the equivalent" of the job for which the H-1B worker is being hired. U.S. firms that place an H-1B worker at a third-party work site "where there are indicia of an employment relationship" (including PSFs that fit into the second niche described in Box 5.4) also must determine that their customers have not and will not lay off any workers in equivalent positions.[3]
- A "prior recruitment" provision under which the employer must promise that it has taken good-faith steps to recruit for the position in the United States using industry-wide standard practices, and has offered the job to any U.S. worker who applies and is equally or better qualified than the H-1B worker.[4]

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[1]Under ACWIA, an H-1B-dependent employer is one who has (a) 25 or fewer full-time equivalent (FTE) employees employed in the United States and employs more than 7 H-1B nonimmigrants, (b) 26 to 50 FTEs employed in the United States and employs more than 12 H-1B nonimmigrants, or (c) 51 or more FTEs employed in the United States and employs H-1B nonimmigrants as 15 percent or more of the number of FTEs.

[2]In testimony to the committee, a number of individuals asserted personal knowledge of business practices that these provisions are intended to prevent. However, because these provisions do not go into effect until after both DOL and the INS have issued final regulations implementing ACWIA, there is not yet any indication of their effectiveness in addressing such business practices to the extent that they exist. And while INS issued final regulations on February 29, 2000 (see *Fed. Regist.* 65:10678), DOL but has yet to issue a final rule (although it issued proposed rules on January 5, 1999; see *Fed. Regist.* 64:627).

[3]In addition, ACWIA provides for strict liability on the part of the H-1B employer if the customer (i.e., the company in control of the worksite) proceeds to displace a U.S. worker or has actually displaced a worker before the date of placement.

[4]Initially, the employer determines qualifications but ACWIA allows any U.S worker who applied and was rejected to file a complaint with the attorney general to allege that he or she was rejected in favor of a less-qualified foreign worker.

After the INS approves the petition, one of two things may happen. If the alien is already in the United States (e.g., under a student visa), the INS can also approve a change of status from the former visa to an H-1B. If the alien is outside the United States, the approved H-1B petition is forwarded to an American consulate post near the alien's foreign residence, where the alien makes formal application for an H-1B visa. Upon receipt, the consulate reviews the final application for the H-1B visa and

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time for petitions made for nonimmigrants; and 6 percent is for DOL action in reducing processing times for various applications related to the use of foreign labor in the United States.

may schedule an interview with the worker.[22] And, even if the consular officer issues the applicant an H-1B visa, INS airport or land-border inspectors must then make the final determination of H-1B admission.

As a general rule, H-1B approvals are available within a few months from the date of filing the LCA.[23] DOL action on an LCA is required by statute to occur within 7 days of filing, and INS review of the H-1B petition (and change of status application when appropriate) typically takes 10 to 12 weeks. Finally, if the H-1B worker is outside the United States, it may take an additional week or two to obtain an H-1B visa from a U.S. consulate.

Once the H-1B worker is admitted to the United States, he or she must work solely for the sponsoring employer of record. H-1B workers may change employers freely as a matter of law, although the new sponsoring employer must file an amended petition with the INS, accompanied by a new LCA (certified by DOL).

5.2.3 Issues Regarding the Foreign Worker Programs[24]

The Permanent Residence Program

Although a detailed analysis of the permanent residence program is beyond the scope of this report,[25] there are at least two significant consequences to extremely slow processing times for green cards:

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[22]Unlike applicants for many other nonimmigrant categories, applicants for H-1B visas (and L visas) are not required to prove that they have strong ties that would motivate them ultimately to return to their home countries.

[23]However, if the cap has been reached, an additional delay is incurred. In the past 3 fiscal years, the H-1B cap was reached several months before the end of the fiscal year, and employers were unable to hire foreign workers under H-1B status until visa numbers became available again on October 1 (the start of the new fiscal year).

[24]Critics of programs to bring foreign workers (both temporary and permanent) often cite a DOL inspector general report issued in 1996 (Joseph Fisch, DOL Assistant Inspector General for Audit, *The Department of Labor's Foreign Labor Certification Programs: The System Is Broken and Needs to Be Fixed*, Final Report No. 06-96-002-03-321). This report concluded that the permanent labor certification (for permanent residents) and the labor condition application (for H-1B visas) programs were not meeting their legislative intent. This report itself generated some criticism, based on assertions that the DOL IG report misunderstood congressional intent for both the permanent and the temporary programs, and that it made inferences without considering certain relevant evidence (see, for example, Anderson, Stuart. 1996. "Widespread Abuse of H-1Bs and Employment-Based Immigration: The Evidence Says Otherwise," 73 *Interpreter Releases* 637 (May 13). Also, Bell, Steven. 1997. *Analysis/Rebuttal of DOL Inspector General Report*. Washington, D.C.: NAFSA, Association of International Educators. Executive Summary available online at <http://www.ailf.org/global/clearing/110499a.htm>).

[25]For a critique of labor certification, see Papademetriou, Demetrious, and Stephen Yale-

• Many employers with immediate job openings who testified to the committee reported that they are unable to use the green-card process to hire foreign workers, because a time scale of years for putting someone to work is not responsive to the demands of the IT market. As a result, they have turned to the H-1B process, which allows them to put a foreign worker on the job in as little as 10 to 12 weeks.

• H-1B visa holders whom an employer sponsors for a green card are, for the most part, unable to change employers without restarting the green-card process. Because the H-1B visa is limited to 6 years, H-1B holders who change employers run a significant risk that their visas will expire before the green-card process is completed. They are thus "indentured" to their original employer to a large extent. This point was made on several occasions to the committee during open testimony.

Partly for these reasons, employers, foreign nationals, and many advocates for domestic labor dislike the labor certification program. Employers dislike it because the labor certification processing is inefficient, inconsistent, overly bureaucratic, and in some instances fails to reflect real-world recruitment and hiring practices. More specifically, it forces some employers who have hired H-1B workers through their normal recruitment process to engage in "post-hiring" recruitment of U.S. workers for labor certification, particularly when the employer's "prehiring" recruitment does not satisfy DOL's recruitment requirements.[26] Foreign nationals dislike it because the process is so lengthy (often 3 years or longer in some areas of the country) and prevents them (on pain of having to begin the process all over again) from changing employers or even taking on significantly different assignments with the same employer until the labor certification is approved and they receive a green card. Advocates for domestic labor dislike it because they are skeptical about the aims of the program, its fairness to American workers, and the ability of DOL to administer the program given its budget and resulting lack of staff.

The H-1B Visa Program

It is uncontested that the H-1B program is popular among employers,

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Loehr, 1996, *Balancing Interests: Rethinking U.S. Selection of Skilled Immigrants*, Carnegie Endowment for International Peace, pp. 48-70 (labor certification fails to perform its intended function of protecting U.S. workers) and 101-113 (labor certification is inherently flawed and should be abolished).

[26]In recent years, DOL has promulgated a "reduction in recruitment" (RIR) process that is intended to take into account recruitment practices normal to industry today, and thus to reduce the time needed to process labor certifications.

although many IT workers are more critical. This section reviews the claims of both sides of the debate and then discusses a few key issues regarding the program.

The Employer Perspective Employers argue primarily that they need foreign labor because of difficulties recruiting qualified U.S. workers. And, as discussed above, they seek primarily H-1B visas because they cannot wait the years that it takes to obtain a green card for foreign workers. Another reported reason that employers support the H-1B program is that it allows them to obtain workers with better qualifications for the same job. For example, a common path to employment as an H-1B worker in IT is for the H-1B worker to first obtain an undergraduate degree in his or her home country and then come to the United States for a master's degree, after which the individual's visa is converted from an F student visa to an H-1B worker visa. Interviews conducted for the committee[27] with several hiring managers resulted in the observation that these managers often see foreign nationals with master's degrees from U.S. universities in applicant pools consisting primarily of domestic workers with bachelor's degrees.

Despite these advantages to hiring foreign workers through the H-1B program, employers—especially smaller employers—also argue that hiring foreign workers entails substantial costs, such as fees for lawyers, visa fees, higher relocation costs, and associated difficulties with "visa maintenance." These costs are often better managed by larger companies that are able to create procedures and expertise to minimize such overhead.[28] Further, employers argue that the H-1B application process entails delays and uncertainties that are not present when a domestic worker is hired. As a result, many employers—large and small—argue that all else being equal (equal pay, equal qualifications), they would prefer to hire domestic workers and only choose to hire foreign workers when the benefits outweigh the costs.

The Worker Perspective H-1B critics essentially deny (or at least minimize) a significant need for foreign labor, arguing that there are sufficient

[27]Salzman, Hal, with Radha Roy Biswas, University of Massachusetts-Lowell, "The Indian IT Industry and Workforce," commissioned paper prepared for the Committee on Workforce Needs in Information Technology, March 2000.

[28]Employers also highlight that those who violate the terms of the H-1B program (e.g., by failing to pay the required wages and/or benefits) face serious penalties including not only fines but also debarment from filing future employment-based immigrant or nonimmigrant visa petitions for up to 3 years, which is a strong disincentive for many employers against engaging in proscribed conduct.

domestic IT workers to meet employer needs if employers will broaden their recruiting to underrepresented groups (e.g., minorities and women), older workers, and those workers who with little retraining could obtain the necessary skills. They further assert that the use of H-1B workers undermines the status and bargaining position of U.S. workers for several reasons.

First, many critics argue that some of the requirements of the H-1B program are poorly enforced (e.g., those requiring the payment of prevailing wages to H-1B workers). In particular, critics note that by law, DOL may review the LCA only for accuracy and completeness; it may not initiate investigations unless a complaint is filed against the employer.[29] Because of DOL's limited authority, critics argue that it is relatively "easy" for employers to violate one or more of the program's requirements, creating the opportunity for significant financial incentive to employ H-1B workers.

Critics also argue that this financial incentive extends beyond the salary level. In particular, they argue that even if the foreign workers are paid the same salary as domestic workers, foreign workers may be more willing than domestic workers to work long hours, especially if they do not bring their families with them. Critics also point to impediments in the H-1B worker's mobility in the labor force—something they regard as an "indenture." As noted above, an H-1B worker seeking permanent resident status (and these individuals are numerous) is reluctant to change employers because doing so is likely to invalidate all previous efforts and waiting time spent on processing his application for permanent residency. If the worker leaves the employer and has to begin the process all over again with a second employer, the process may not be finished before the worker is forced to leave the country at the expiration of his H-1B status.[30] (Box 5.6 illustrates a hypothetical scenario.) Further, some H-1B workers are subject to the payment of liquidated damages, which may be substantial enough to provide a disincentive for leaving one's original sponsoring employer. (Unfortunately, there are no data available on the extent to which H-1B visa holders change employers.) Because of these impediments to mobility, an employer may have greater latitude in its treatment of these individuals than it would have in dealing with domestic workers, and thus may well prefer to hire such individuals when there is a choice.

[29]Section 413(e) of ACWIA gives DOL authority to investigate an employer without a complaint having been filed if DOL receives "specific, credible" information from a source who is likely to have knowledge of an employer's practices regarding employment conditions or an employer's compliance with the employer's labor condition application.

[30]In addition, the H-1B worker must find a second employer before he leaves the first employer, or else he faces the risk of deportation for violating the terms of the visa.

BOX 5.6
A Plausible Scenario for How the H-1B Visa Holder's Dilemma Arises

Assume that Company A employs K, an Indian national, as a software engineer under H-1B status. K is anxious for Company A to file his labor certification because (a) the date of filing establishes his priority date and (b) per-country limits have created severe backlogs for persons born in India, making an early priority date of the utmost importance to K if he is to complete the steps for obtaining permanent resident status before his H-1B visa status expires.

In order to employ K on a permanent basis, Company A must first obtain a labor certification of a particular job, with specific duties and skill requirements, at a prevailing wage that is appropriate for the particular time and place of employment. Company A begins the labor certification process, but K soon realizes that neither his job nor his salary nor his future prospects are satisfactory to him. If K changes jobs prior to approval of the labor certification, however, its continued validity is questionable. Although DOL permits "substitution" of a new employer on the labor certification, substitution must occur before a final determination of the labor certification and the new job must be essentially the same in its duties, requirements, and salary as the previous job with Company A. Because these conditions are rarely met, and DOL rarely approves such substitutions, K risks forfeiting his priority date and having to restart the labor certification process if he accepts an otherwise more attractive job offer from Company B.

If K has an approved labor certification, he may also be reluctant to change jobs for two reasons. First, even if Company B agrees to sponsor him for a green card, there is no guarantee that a new labor certification will be successful; second, even if it is successful, he may not complete all three steps in his new case (labor certification, immigrant visa petition processing, and adjustment of status) prior to the expiration of his H-1B status. Again, DOL rules permit K to preserve the priority date of his labor certification with Company A, but only if his new job is in the same metropolitan area (thereby ensuring that the prevailing wage for the job with Company A is still valid for the new job with Company B). Of course, if the specific job opportunity with Company A becomes unavailable (because Company A has gone out of business, moved to a new location, or withdrawn the job offer), the previously approved labor certification is rendered invalid.

These complex rules for determining the continued validity of a labor certification pose a dilemma for K: If he remains at his current job, his employer may take advantage of the fact that his mobility is very limited; if he leaves and has to begin all over again, he may not finish in time to avoid leaving the country at the expiration of his H-1B status. Even changes in his job duties with Company A may jeopardize his chances of obtaining permanent residence (because INS rules require K to be performing the job duties described in the approved labor certification at the time he applies for adjustment of status, while DOL rules generally make it difficult if not impossible to amend the job requirements in an approved labor certification).

Third, according to interviews with H-1B employers conducted for the committee,[31] some foreign workers—especially from Asia—are willing to take jobs entailing work "below their qualifications" as a means of entry into the United States because the pay in such jobs is better than that in jobs available in their home countries. Thus, to the extent that foreign applicants for a given job bring better (more advanced) credentials than do their domestic counterparts, the foreign applicant has a natural advantage.

Fourth, critics assert that without a ready supply of foreign workers, employers would be forced to make greater use of the existing domestic labor pool by increasing salaries, training opportunities, and other aspects of job compensation and "attractiveness." This argument has been especially focused on the available pool of older IT workers.[32]

Discussion As should be clear from the two perspectives on the program, a key question in the debate is whether employers have a financial incentive to employ H-1B workers rather than domestic workers. Unfortunately, the evidence on this point is mixed, and the data poor. For example, based on interviews with some H-1B employers, Salzman reported that H-1B workers in jobs requiring lower levels of IT skill received lower wages, less senior job titles, smaller signing bonuses, and smaller pay and compensation increases than would be typical for the work they actually did.[33] However, it is unclear whether these employers are representative of all IT employers. Similarly, while violations of existing law governing the employment of H-1B workers (such as payment of the prevailing wage) obviously happen to some degree, the number of documented violations is small.[34]

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[31]Salzman, 2000, "The Indian IT Industry and Workforce," commissioned paper.

[32]See, for example, Matloff, Norman. 2000. *Debunking the Myth of a Desperate Software Labor Shortage,* University of California at Davis, April 8. Available online at <http://heather.cs.ucdavis.edu/itaa.real.html>.

[33]Salzman, 2000, "The Indian IT Industry and Workforce," commissioned paper.

[34]Since FY 1992, when DOL was first assigned the responsibility for investigating alleged violations of the H-1B program, through the end of FY 1999, the agency (per its own data) handled 448 complaints, commenced 304 investigations, and closed out 159 cases. Of the 159 completed investigations, 134 of them resulted in a finding of a violation; 25 involved no violations. Since the inception of DOL's H-1B oversight, 15 employers have been statutorily debarred for at least a 1-year period from obtaining employment-based nonimmigrant work visas and sponsoring workers for permanent resident status. An additional 12 employers agreed in consent decrees to a period of voluntary debarment. During this 7-year period (FY1992 to FY1999), the agency ordered repayment of back wages in 107 cases totaling $2,667,880 (or a cumulative average of $381,125 per year or a per employee average of $3,675) and required payment of civil monetary penalties of $221,250 (a cumulative yearly average of $31,607). During this 7-year period, the INS approved 409,834 H-1B visa peti-

That said, it is the judgment of the committee that direct employers of H-1B visa holders—especially large ones—are probably less likely than others to violate the laws and regulations that govern the H-1B program. The reason is that large employers are likely to have the internal human resources expertise to directly manage H-1B workers in their companies in a manner consistent with their corporate values and with the law.

However, employers may also turn to outside personnel service firms such as those described in Box 5.4 to meet needs for temporary labor. And firms providing temporary labor have strong economic incentives to pay any given worker a lower salary than s/he might otherwise receive, while charging the client firm a rate more reflective of that individual's true skills and abilities. By doing so, the firm's profit margin increases. As demand for temporary services in IT has grown (because of tightness in the IT workforce), the demand for workers willing to accept lower wages (perhaps in exchange for a variety of other benefits) has increased—and this category includes nonimmigrant foreign IT workers from nations in which prevailing wages are low. These forces imply that these outside personnel service firms have a greater incentive to violate the law regarding the payment of prevailing wages than do firms that hire H-1B workers directly.[35]

A second key question in the debate over the H-1B program is what would happen in its absence. The committee believes that the number of H-1B workers in the Category 1 IT workforce is large enough that without these workers there would likely be a slowdown in the rate of growth in the IT sector.

A related issue is the effect of the program on the wages (or more generally, compensation, which includes benefits as well) and employment of domestic workers. In theory, even if all employers did comply with the law, the hiring of H-1B workers could have an effect on wages. To see this, assume that an employer—seeking to comply with the law—does in fact offer an H1-B worker the same wage that it pays for a domestic worker doing the same job. On the face of it, such an action both complies with the law and is regarded as "fair" treatment. (Another reason for paying comparable wages rather than higher ones—whether to

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tions. Thus, documented violations do not provide evidence that large numbers of H-1B employers have failed to maintain compliance with LCA requirements. The magnitude and the extent of undocumented violations are unknown.

[35]These incentives are greatest for such firms without a "brand" that could lose value if the schemes are uncovered. Well-established personnel firms are less likely to violate the law than are "fly-by-night" firms that can easily operate under a variety of corporate identities.

incoming domestic workers or to foreign workers—is that they may well influence the wages that must be paid to others in the firm.)

However, if the H-1B worker were not available, the employer would have to seek a domestic worker. Under tight labor market conditions, the employer might well have to offer a domestic worker wages or hours or conditions of employment that are better than those for others in the company. If so, the effect of the H1-B program is not necessarily to depress wages and working conditions but rather to keep them from rising as rapidly as they would if the program did not exist.

Unfortunately, the magnitude of such an effect is hard to estimate with confidence. In a study of the economic impact of immigrants, the National Research Council used an empirically based elasticity of demand for labor of about 0.3, suggesting that a 10 percent increase in the size of the labor force would result in the wage of competing workers being reduced by about 3 percent below what it would have been in the absence of that labor pool increase.[36] However, this estimate is based primarily on studies that have focused on all foreign-born individuals and not only "highly skilled" foreign workers, such as those with H-1B visas. As such, the committee has not found sufficient evidence on the magnitude of wage and employment effects to make a judgment about the effects of the program on domestic IT workers.

This discussion also highlights the fact that the committee has not found an analytical basis on which to determine the optimal number of H-1B visas. Without such a basis, decisions to reduce or increase the cap on H-1B visas are fundamentally political, and outcomes in such a process depend primarily on political balances of power. That said, the committee notes that an increased number of H-1B visas will likely result in future additional pressure on the already beleaguered permanent immigration program unless Congress also adjusts the various numerical limits on permanent residents.

Table 5.2 summarizes the various pros and cons of changing the level of H-1B visas.

5.3 AVAILABILITY OF FOREIGN IT WORKERS TO U.S. FIRMS

U.S. firms can use foreign IT workers in two ways: they can be brought to the United States (in which case other nations can compete for their services), or they can be used in their home nations.

[36]See National Research Council. 1997. *The New Americans: Economic, Demographic, and Fiscal Effects of Immigration*. Smith, James P., and Barry Edmonston, eds. Washington, D.C.: National Academy Press.

TABLE 5.2 Pros and Cons of Changes to H-1B Levels

	Reduced H-1B Levels	Increased H-1B Levels
Pros	• Encourages effective use of U.S. workers, raising skill levels through training • Boosts wages for employees	• Provides immediate relief for labor market tightness • Allows more rapid growth of IT sector • Dampens wage costs for employers • Increases supply of IT workers
Cons	• Opportunities lost, growth forgone • Increased wage costs for employers • Possibility that work may be exported	• Dampens wage growth for employees • Sends potentially wrong messages to workers and educational establishments • In case of recession, could lead to unemployment and repatriation problems • Increases demand for permanent visas

5.3.1 Competition for Foreign Workers

The United States is not the only nation with a strong IT sector, and demand for overseas IT workers is expected to increase as other developed countries face tightness problems in their IT labor markets. Germany has established an allocation of 10,000 "green cards" for highly qualified immigrants from outside the European Union as part of its efforts to relax restrictions on the use of nonindigenous IT talent.[37] Japan plans to hire up to 10,000 Indian software engineers to meet a shortage of qualified IT workers.[38] In the United Kingdom, the government is looking to initiate a new immigration policy to help end skill shortages in the U.K. economy, signaling a break with the "closed-door" policy on economic immigrants in place since the early 1970s.[39]

Furthermore, the IT industries of the countries from which these workers come are also growing. Particularly important in this context is

[37]See Tagliabue, John, 2000, "Sprechen Sie Technology? Europeans Try to Relax Borders for Skilled Workers," *New York Times*, May 5, Business Section, p.1 ; Bröll, Claudia, 2000, "Indonesia Technician Accepts Green Card," *Frankfurter Allgemeine*, July 31.

[38]"Japan to Hire 10,000 Indian Software Engineers," *Times of India*, May 16, 2000.

[39]Adams, Christopher, and Rosemary Bennett. 2000. "Immigrant Policy Aims to Close Skills Gap," *Financial Times*, August 11.

the Indian IT industry, given that about half of the H-1B visas for IT are held by Indian nationals. According to the initial findings of a study by the National Association of Software and Service Companies (NASSCOM), 340,000 software professionals were employed in the Indian software and services industry in March 2000, more than double the number employed 3 years before.[40] Despite expectations of strong growth in the Indian software industry, the study predicts no shortage of skilled IT workers in India until 2002-2003, when the IT labor market there will become very tight unless immediate steps are taken by the Indian government and the Indian software industry.

Growth in the IT industries abroad and the accompanying competition for talent from nations such as India may restrict the supply of foreign workers to the United States. Of course, because the trajectory of future demand for foreign IT workers here and abroad is unknown, as is that of production rates of qualified foreign IT workers, this outcome is by no means a certainty.

5.3.2 Locating IT Work Abroad

Another way for U.S. firms to use foreign IT talent is to locate work abroad. One approach is for a U.S. firm to outsource work to foreign IT companies or to give it to a foreign subsidiary. For example, a U.S. IT-intensive company may contract with a foreign IT firm to develop a needed business system. A U.S. IT-sector company may contract with a foreign IT firm to handle product testing or documentation or even program coding.

A second approach is for a U.S. firm to establish its own presence (e.g., through a subsidiary) in a foreign land. In some instances, companies establish a foreign presence in order to be closer to customers and more in touch with their needs and to develop new products for a wider audience (i.e., products that are not targeted just to U.S. customers). Often, marketing to foreign countries is more effectively undertaken with local presence. And, sales, support, and servicing are much easier through local offices. A U.S. firm might establish an R&D laboratory near foreign centers of excellence, so as to monitor technological developments occurring in the host nation and to tap into the expertise that would now be local and develop familiarity with new science and technology.[41]

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[40]"NASSCOM for Immediate Action to Increase Supply of Knowledge Workers," NASSCOM press release, New Delhi, April 17, 2000.

[41]According to the U.S. Department of Commerce, the IT industry is less likely, on average, than other R&D-intensive industries to carry out R&D abroad. When the intensity of

Or a firm that wishes to develop a new product line may locate work abroad *because* of opportunities afforded by its relative isolation—such isolation may help to insulate the unit undertaking the development from "cultural" dimensions extant in the mother firm's U.S. locations that are incompatible with developing the new product line.[42] At other times, U.S. investment in overseas locations is part of a large package that a U.S. company has negotiated with a foreign country. For example, a U.S. company might agree to locate a facility in another nation as part of a sales agreement with that nation. A foreign facility might be established to reduce costs (e.g., through the use of cheaper labor, or by taking advantage of subsidies or incentives provided by the foreign host nation, or by overcoming locally imposed tariff barriers). Finally, the public relations value of being seen as a "local" company and the intellectual opportunities to collaborate in foreign research consortia should not be underestimated.[43]

Box 5.7 provides some historical perspective on overseas investment.

For U.S. employers that wish to take advantage of lower foreign labor costs (which may be lower by factors of 3 and 4 in certain Asian countries), locating work abroad is the most effective approach to doing so. In some cases, a firm may move abroad to take advantage of a greater certainty in the rapid availability of qualified IT workers. On the other hand, locating work abroad can have many costs. When work can be cleanly partitioned from other work so as to minimize communication between parties doing each type of work, location abroad is likely to be successful. But when large amounts of communication are needed, location abroad becomes much more problematic.[44]

R&D globalization is defined as the ratio of foreign to domestic R&D spending by U.S. companies, the industry with the highest level of R&D globalization is drugs and medicines (globalization ratio = 33 percent). The computer (ratio = 4.2) and electronic/electrical equipment (ratio = 5.6) industries have the lowest levels of R&D globalization. (See Dalton, Donald H., and Manual G. Serapio. 1999. *Globalizing Industrial Research and Development*. Washington, D.C.: U.S. Department of Commerce, Technology Administration, Office of Technology Policy.) Nevertheless, a number of major U.S. IT firms have R&D labs abroad; these firms include Microsoft, Intel, IBM, and Hewlett-Packard.

[42]For example, a firm may have an engineering culture that values high performance and sophistication, with cost being a relatively secondary issue. If that firm wishes to develop products that are less expensive, it may well make sense to conduct the development of such products in an environment where that culture is not operative—which may call for geographical separation.

[43]More discussion of these rationales can be found in Dalton and Serapio, 1999, *Globalizing Industrial Research and Development*.

[44]Some of the following is discussed in greater detail in Callan, B., S. Costigan, and K. Keller. 1998. *Exporting U.S. High Tech: Facts and Fiction about the Globalization of Industrial R&D*, Study Group Report. Washington, D.C.: Council on Foreign Relations.

BOX 5.7
Investment Abroad by the IT Industry

An Early 1990s Perspective[1]

Foreign Facilities

"The globalization of the [IT] industry also is reflected by generally increasing foreign direct investment by all U.S. computer hardware manufacturers except supercomputer firms, which remain firmly placed in the United States. U.S. firms' cumulative foreign direct investment in computer-related facilities stood at $20.6 billion in 1991. By positioning facilities near foreign customers, companies improve customer service and reduce transportation costs on increasingly price-sensitive goods.

"U.S. foreign direct investment likely will continue to expand in the future because some foreign markets are growing more rapidly than the U.S. market. Between 1988 and 1991, for example, the average annual growth rates of Asian and European computer markets consistently exceeded 10 percent, compared with average annual growth rates of less than 5 percent over the same period in the United States. Customers outside the United States now account for 65 percent of global computer purchases.

"Although small by comparison, foreign firms' direct investment in the United States has been growing at a relatively steady pace as these companies pursue advanced technologies and research facilities in this country. Foreign firms' cumulative direct investment in the U.S. computer industry totaled $2.9 billion in 1991."

Strategic Alliances

"Joint ventures, collaborative research programs, and formal technological alliances involving U.S. and foreign computer hardware manufacturers have proliferated in recent years. In many instances, U.S. firms have allied themselves with foreign competitors. One of the primary reasons for establishing a cooperative alliance is to share the costs and risks associated with research and product development. Companies competing within the same product segment occasionally form alliances to conduct precompetitive research. For example, IBM has formed a joint research venture with Toshiba and Siemens-Nixdorf to develop a new generation of memory chips. In other cases, companies look beyond their immediate competitors and cooperate with firms capable of supplying complementary technology. For example, Apple Computer combined its considerable computer design skills with Sony's expertise in manufacturing and miniaturization to produce the 3-pound PowerBook notebook computer.

continued

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[1]Text extracted from U.S. International Trade Commission. 1993. *Global Competitiveness of U.S. Advanced Technology Industries: Computers*, Investigation No. 332-339, Publication 2705.

BOX 5.7 continued

"Strategic alliances are also used to increase a company's involvement in and knowledge of a foreign market. Because consumer demands and expectations may vary in different markets, many firms prefer to enter new geographic markets by forming alliances with companies having a long-standing regional presence. IBM, for instance, has entered a marketing alliance with Hitachi to distribute IBM notebook computers in Japan, a country in which long-standing distributor contacts are reportedly essential.

"Finally, the number of strategic alliances has increased in direct proportion with company cost-cutting and streamlining efforts. Some companies have narrowed their business focus to manage costs more effectively, and consequently have formed partnerships that allow them to rely on other firms to perform important production, sales, and delivery tasks. Sun Microsystems' alliance with Fujitsu in the development and production of workstation microprocessors typifies such alliances."

A Mid-1990s Perspective: Employment in U.S. Parent Companies and Their Affiliates Abroad

Comparison of employment at U.S parent companies with employment at their foreign affiliates over the period from 1994 to 1997 indicates the following for the

TABLE 5.7.1 Number Employed (thousands) in U.S. Parent Companies and Foreign Affiliates by IT Industry Sector, 1994 to 1997

	Computer and Office Equipment		
Year	At U.S. Parent	At Foreign Affiliates	At Affiliates as Percentage of Parent
1994	430.2	379.8	88
1995	395.2	373.1	94
1996	417.9	373.0	89
1997	408.7	433.4	106

industry groupings most relevant to the IT industry (data from a finer categorization are not published):[2]

- For computer and office equipment, employment at U.S. parent companies totaled around 400,000, while employment at their foreign affiliates grew to approximately the same number (Table 5.7.1).
- For electronic components and accessories, employment at U.S. parent companies grew at a rate of 3 percent per year, and employment at foreign affiliates was about three-quarters of the employment at U.S. parent companies.
- For computer and data-processing services (including software), employment at U.S. parent companies grew at a rate of 23 percent per year, while employment at foreign affiliates grew even faster. Employment at foreign affiliates as a percentage of employment at U.S. parent companies grew from 29 percent in 1994 to 39 percent in 1997.

Thus, the IT industry has invested heavily abroad, particularly in the computer and office equipment industries and the electronic components and accessories industries. The computer and data-processing services industries have invested less heavily, although employment in U.S. parent companies is growing rapidly and employment in their foreign affiliates is growing even more rapidly.

[2]These data, taken from the annual "U.S. Direct Investment Abroad: Operations of U.S. Parent Companies and Their Foreign Affiliates" produced by the Bureau of Economic Affairs at the Department of Commerce, give some appreciation of recent investments abroad by the U.S. IT industry.

Electronic Components and Accessories			Computer and Data-Processing Services (including Software)		
At U.S. Parent	At Foreign Affiliates	At Affiliates as Percentage of Parent	At U.S. Parent	At Foreign Affiliates	At Affiliates as Percentage of Parent
407.5	n/a		196.1	56.9	29
423.5	303.3	72	251.3	88.4	35
438.6	313.6	72	355.3	126.4	36
444.5	338.8	76	363.6	143.0	39

• Different time zones (and 6- to 12-hour time differences) inhibit regular communication. (At the same time, they can facilitate around-the-clock operation when the work is easily transferable from one location to another.)

• The use of different spoken languages can lead to difficulties in communication. Even if the spoken language is nominally English, American English and Indian English are not the same, and cultural references and idioms are clearly different.

• Informal communication is dramatically reduced, with the result that formal channels of communication (e-mail, phone calls, voice mail, teleconferencing) become necessary to communicate what could be communicated over lunch or in a chance hallway encounter.[45] This in turn adds to overhead. Creativity and spontaneity may also suffer, since these are often the result of chance interactions.

• Foreign nations may lack an adequate IT infrastructure to support active collaboration over large distances. Nevertheless, certain foreign nations, notably India and Ireland, have sought to nurture nascent IT industries by paying a great deal of attention to infrastructure.

• Many foreign nations operate under legal regimes that are very different from that which characterizes the United States. For example, some foreign nations have laws (or practices) that allow for the routine surveillance of business communications, the results of which are passed to indigenous businesses in an attempt to seek competitive advantage. Anticorruption laws may be weak, placing U.S. businesses operating in foreign lands at a disadvantage.

This is not to say that technological innovations could not help to mitigate some of these difficulties, but it is safe to say these innovations have not yet materialized in a form that eliminates most such difficulties.

Location of work abroad also has disadvantages for the U.S. economy. Dollars spent abroad do not contribute directly to the U.S. gross national product and do not contribute to the number of domestic jobs, and other jobs associated with the use of foreign workers here in the United States might well follow these individuals overseas.[46]

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[45]Cockburn finds that remote collaboration often entails the loss of physical proximity, multiple communication modalities (e.g., gestural or facial communication), vocal inflection, and timing that may emphasize the importance of a sentence, or interactive questions and answers that can help to reveal ambiguities in someone's explanation. See Cockburn, Alistair. 1999. "Characterizing People as Non-Linear, First-Order Components in Software Development," Humans and Technology Technical Report, TR 99.05, October. Available online at <http://members.aol.com/humansandt/papers/nonlinear/nonlinear.htm>.

[46]Although the decision to locate work abroad involves both benefits and costs and is

5.4 INTERACTION BETWEEN THE USE OF FOREIGN WORKERS AND LOCATING WORK OFFSHORE

The previous two sections describe the domestic use of foreign workers and location of work offshore as though they were alternatives to each other. In some cases, they are—if the benefits of using foreign labor outweigh its costs, a domestic absence of foreign workers will inevitably lead to location of work abroad.

On the other hand, the use of foreign workers can complement the location of work offshore. As described in Box 5.4, a U.S. firm may contract for IT work with a foreign IT company with a U.S. subsidiary that serves as a domestic interface to the U.S. firm. (The same argument could apply as well to a stand-alone U.S. corporate entity with close corporate and personal ties to the foreign work performer.) Given the requirements for close communication with the work-performing firm, the workers for the U.S. company serving as interface are likely to be foreign workers from the country in which the work performer is located—and they are most likely to be brought to the United States on H-1B or L-1 visas.[47]

This arrangement puts pressure on wages for domestic workers, but for an entirely different reason than that offered by most H-1B critics. Compared to domestic work performers who could do the same job, it can take advantage of a lower wage structure (i.e., that of certain foreign nations such as India or Taiwan) for the entire project. This is likely to provide the foreign work-performing firm with a cost advantage that domestic work performers will be hard-pressed to beat. Thus, to the extent that foreign firms are more attractive to U.S. firms with work to outsource, they take away work from domestic work performers, with all of the wage consequences that that implies (Box 5.8). Note also that the same wage considerations apply when the U.S. company establishes a foreign subsidiary, even if it has done so for reasons entirely unrelated to labor costs.

The use of foreign labor versus location of work abroad cannot always be reduced to a simple choice between the two possibilities. Employers understanding the complexity of these issues are likely to make choices

determined by many factors, an inability to hire adequate numbers of workers in a timely fashion may encourage more firms to locate work abroad. (For example, companies may be stymied in their hiring because the cap on H-1B visas is reached early in the fiscal year, necessitating a longer-than-expected delay in hiring an H-1B visa holder until the start of the next fiscal year.)

[47]Note that the use of L-1 visas is small compared to the use of H-1B visas. One important reason is that an L-1 visa requires the visa holder to be an incumbent employee of the company that wishes to transfer him or her to the United States.

BOX 5.8
Labor Cost Savings Using Foreign Labor

A simple model will quantify the difference in the cost of using domestic versus foreign labor. Assume that 10 percent of a project's personnel are needed to provide the interface, and the other 90 percent do the implementation. For simplicity, assume that all personnel are paid the same amount (X). Compare three situations.

- *Situation A:* Both the interface personnel and the implementers are domestic workers. In this case, the labor cost per person of the project is $0.1\ X + 0.9\ X$. (If the interface personnel are H-1B visa holders and are paid the prevailing wage, in accordance with the law, the use of H-1B workers is cost-neutral.)
- *Situation B:* The interface personnel are underpaid H-1B visa holders and the implementers are domestic workers. Various reports assert that H-1B workers are paid significantly less than U.S. workers for the same jobs, thus saving their employers significant amounts in labor cost; for the sake of argument, assume that they are paid 30 percent less than the wages paid domestic workers (a difference claimed by some H-1B critics). In this case, the labor cost per person of the project is $(0.1)(0.7)\ X + 0.9\ X$.
- *Situation C:* The interface personnel are domestic workers (or H-1B workers paid the prevailing wage) and the implementers are foreign workers working in their native land, and paid the prevailing wages there. Various reports place comparable salaries at a factor of 3 lower than in the United States and often even lower. Assuming a factor of 3, the labor cost per person of the project for Situation C is $0.1\ X + (0.9)\ (1/3)\ X$.

Comparing Situation B to A, it is clear that the labor cost of Situation B is 97 percent that of Situation A. But the cost of Situation C is 40 percent of the cost of Situation A. The inevitable conclusion is that all else being equal, savings in H-1B labor costs due to the alleged exploitation of U.S. employers would be overwhelmed by the savings due to the use of foreign labor working in their native lands.

that reflect the mix of work they wish to locate abroad versus that which they wish to keep within the United States, as well as their judgments of the benefits (e.g., better access to local markets or significantly reduced labor costs) and costs (e.g., reduced and inhibited communication).

5.5 RECAP

For purposes of this report, foreign workers are foreign-born individuals who are either temporary nonimmigrant workers or permanent residents of the United States. Foreign-born individuals (including both foreign workers and naturalized U.S. citizens) constituted about 17 percent of the Category 1 IT workforce in 1998, compared to about 10 percent of the total U.S. population. The committee estimates that temporary nonimmigrant workers (mostly with H-1B visas) constitute about 10 percent of the Category 1 IT workforce, although this figure likely represents an upper bound.

Because the United States does not have a monopoly on productive, knowledgeable, and motivated individuals, U.S. employers seek talent from around the world. The critical feature of the H-1B program is that it enables employers to hire qualified foreign workers in a matter of months, in contrast to the years required to attract and train additional U.S. students or to obtain green cards for prospective permanent residents.

The committee believes that foreign Category 1 and Category 2 IT workers—including the H-1B visa holders—can make positive contributions in a number of ways to the U.S. IT sector, IT-intensive firms, and the economy as a whole. For example, while H-1B visa holders are far from the dominant influence on the IT workforce, their number is large enough that without these workers there would likely be a slowdown in the rate of growth in the IT sector. At the same time, economic theory implies that an increase in the supply of IT workers, including temporary nonimmigrant workers, will cause the corresponding IT wage rates to be lower than they otherwise would have been. Theory alone does not imply any particular numerical magnitude of this effect. It is the committee's judgment that the current size of the H-1B workforce relative to the overall Category 1 IT workforce is large enough to exert a nonnegligible moderating force that keeps wages from rising as fast as might be expected in a tight labor market.

Finally, in light of the controversy over the level of the H-1B cap, the committee has found no analytical basis for determining the optimal level of such visas, and decisions to reduce or increase the cap on H-1B visas are fundamentally political. However, an increased number of H-1B visas is likely to result in future additional pressure on the permanent immigration program unless Congress also adjusts the various numerical limits on permanent residents.

6

Making More Effective Use of the Existing IT Workforce

One approach to reducing the difficulties that employers have in hiring is to make more effective use of qualified workers who can be put to work in a relatively short time with little or no additional education or training. Thus, the strategies discussed in this chapter can fairly be characterized as actions that individual employers may take to relieve their hiring difficulties to a certain extent. While many, if not most, employers may be aware of these strategies, the committee hopes that a brief discussion of them here may help increase awareness of their potential for reducing hiring difficulties. Furthermore, for these strategies to pay off, execution and follow-through are as essential as initial awareness of the strategies. According to much of the anecdotal information provided to the committee, employers who implement these strategies successfully appear to have fewer difficulties in hiring.

6.1 ATTRACTING AND USING IT WORKERS MORE EFFICIENTLY

Several options for attracting and using IT workers more efficiently are discussed with respect to their potential benefits and costs. The actual benefits and costs will, of course, depend on the circumstances of each employer.

6.1.1 Increased Use of Overtime

Historically, the increased use of overtime in preference to hiring additional workers has been one response to tightness in the labor force. Especially for exempt workers, the use of overtime may save money relative to hiring additional workers, because many fringe benefits, such as health insurance, unemployment insurance, and workers' compensation, are fixed and the firm will not experience any increase in costs for these benefits when current employees work additional hours. As importantly, workers who can work overtime are in fact already on the payroll, and so an employer does not incur the costs of recruiting additional workers.

A common stereotype of IT workers portrayed in the popular press is that of workers who work long days and as much as 80 hours per week. Furthermore, this stereotype is typically described as being caused by the culture of the IT workplace, the push to bring products to market before other firms, and the overall shortage of workers available to IT firms. However, the quantitative data available to the committee do not support this stereotype across the board.

In particular, data from the Current Population Survey (CPS) on selected Category 1 occupations indicate that, during 1997 and 1998, average weekly hours in these occupations were just under 40 hours per week.[1] By comparison, weekly hours across all workers averaged 34.6 during 1997 and 1998. Full-time managers, executives, and professional specialty workers, though, worked an average of 44.7 hours per week during 1999.

Figure 6.1 and Figure 6.2 illustrate a distribution of CPS-tabulated (Category 1) IT workers in numbers of hours worked per week. About 80 percent of computer systems analysts, computer scientists, and computer programmers worked between 36 and 50 hours per week in 1999 according to the CPS. A November 1999 survey by *Software Development* magazine, which yielded 3,928 responses to a question about hours worked per week, yielded similar results: among this self-selected group, 61 percent reported clocking 41 to 50 hours per week.[2]

Moreover, the percentage of employees who worked 40 or more hours per week was higher for each of lawyers and judges, health diagnostic occupations, and engineers than for IT jobs as tabulated by CPS. As shown in Figure 6.3, only 25 percent of computer programmers and 40 percent of computer systems analysts and scientists worked more than

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[1]U.S. Department of Labor, Bureau of Labor Statistics, Current Population Survey, March 1999, special tabulation.

[2]Morales, Alexandra Weber. 1999. "Salary and Job Satisfaction Survey," *Software Development*, November. See <http://www.sdmagazine.com/articles/1999/0011/0011a/0011a.htm>.

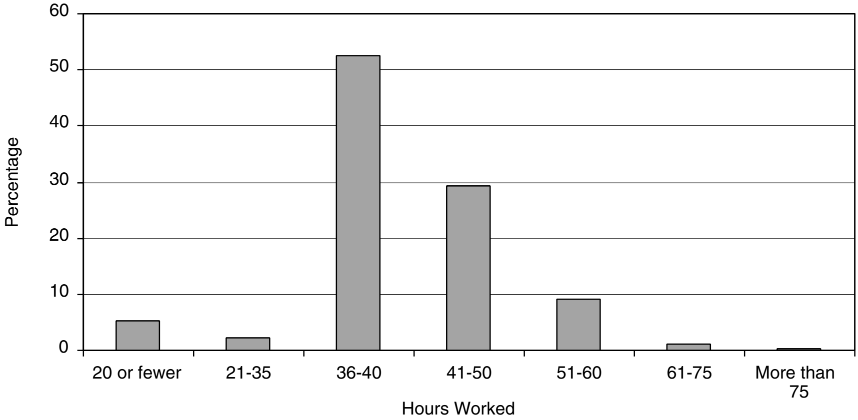

FIGURE 6.1 Computer systems analysts and scientists, by number of hours worked per week, 1999. SOURCE: U.S. Department of Labor, Bureau of Labor Statistics, Current Population Survey, 1999, special tabulations.

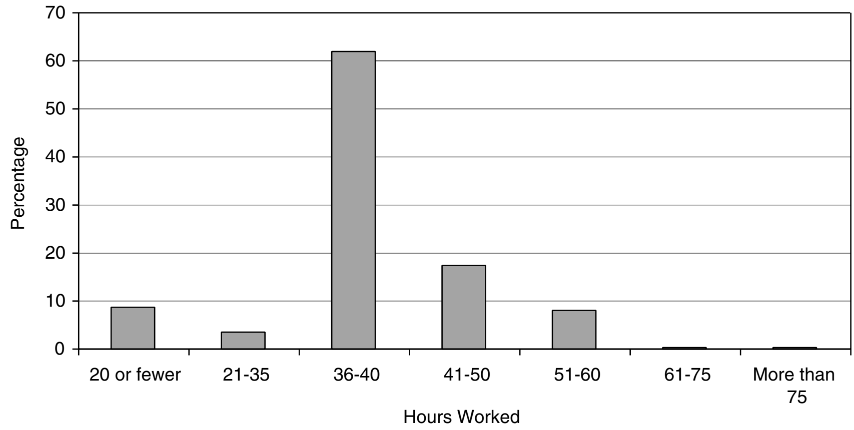

FIGURE 6.2 Computer programmers, by number of hours worked per week, 1999. SOURCE: U.S. Department of Labor, Bureau of Labor Statistics, Current Population Survey, 1999, special tabulations.

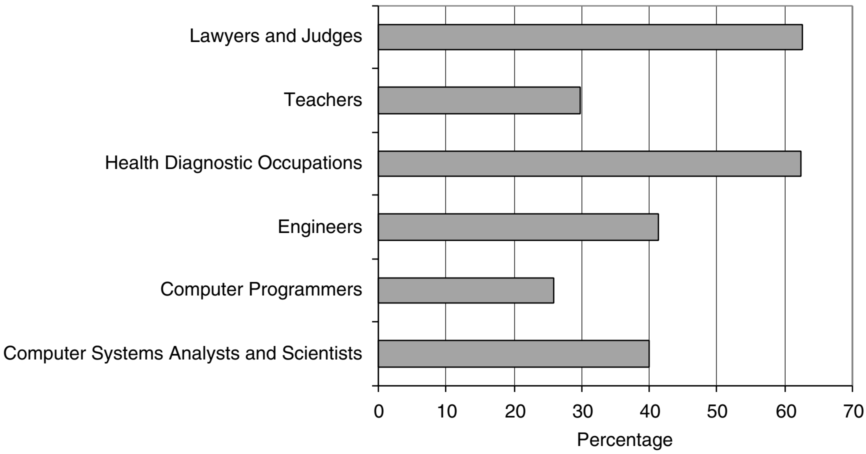

FIGURE 6.3 Percent of employed who worked more than 40 hours per week, IT and selected occupations, 1999. SOURCE: U.S. Department of Labor, Bureau of Labor Statistics, Current Population Survey, March 1999, special tabulation.

40 hours per week in 1999 according to the CPS. The vast majority of these individuals worked between 41 and 50 hours per week.

Only small numbers of CPS-tabulated IT employees work more than 50 hours per week. According to the CPS, 10.5 percent of computer systems analysts and scientists and 8.6 percent of computer programmers worked more than 50 hours per week in 1999. Similarly, the *Software Development* survey results indicated that 13 percent said they worked 51 to 60 hours per week, and 4 percent said they worked an average of 61 hours or more per week.

A related issue is the availability of vacation and the ability to use accrued vacation time. The *Software Development* magazine survey asked respondents about this. Among the 3,862 respondents, 57 percent said they were able to use their vacation each year, but another 40 percent said they could use only part of their vacation, and rolled the rest over to the following year. Only 3 percent said they were unable to use any of their vacation time.

The data also do not support the notion that longer workdays are more typical in smaller firms. Figure 6.4, for example, provides data on the percentage of computer systems analysts and scientists who work 40 or more hours per week by firm size. Data on computer programmers are very similar.

Despite the implication of the large-scale quantitative data that long work hours do not characterize the IT workforce taken as a whole, the anecdotal evidence provided to the committee in testimony, electronic

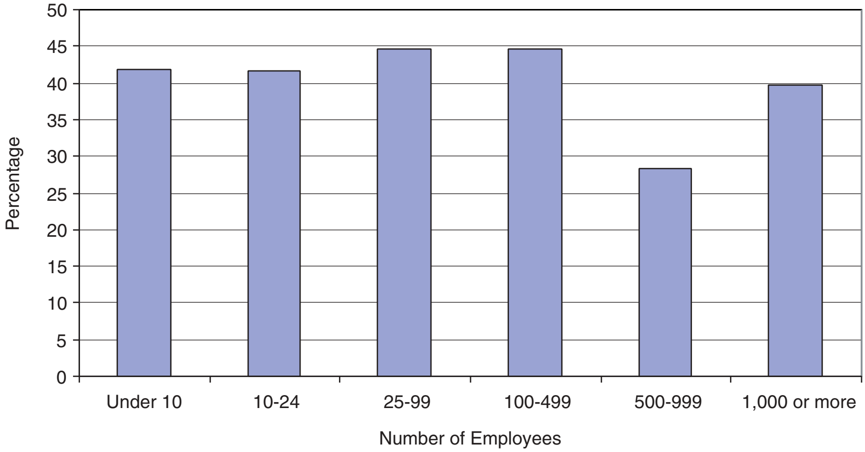

FIGURE 6.4 Percent of computer systems analysts and scientists who worked more than 40 hours per week, by size of firm, 1999. SOURCE: U.S. Department of Labor, Bureau of Labor Statistics, Current Population Survey, March 1999, special tabulation.

input, site visits, and the public press suggests that these large-scale averages may mask a wide variation in work hours characteristic of different individual employers. Employees at different firms visited by the committee described their work hours quite differently. Employees at Firm A—a moderately sized software company that has not yet gone public—actively sought "Type A" employees willing to work 18 hours a day 6 days a week, with the consequence that turnover in the firm was high. Firm B, a small growing company, provided compensatory time for the long hours that were sometimes necessary. Employees from Firm C said they "had a life." Microsoft employees report the hours of work and the pace are moderate, involving some "crash" periods with night and/or weekend work at other times during the 2- to 3-year cycle of software development.[3]

Why might some firms feel pressure to expect long hours from their IT workers? In some cases, market windows for certain IT firms are small, and these firms must beat competitors to market with acceptable levels of functionality. Under such time pressure, the approach of partitioning the work to be done by more workers entails considerable over-

[3]Fallows, James. 2000. "Inside the Leviathan," *The Atlantic Monthly* 285(2):34-38.

head in terms of communicating what the additional people are doing, resulting in significant inefficiencies.[4] As a result, employees may have to work long hours in order to meet deadlines. This point is most significant when the work involved requires knowledge of the entire system being developed and how the different portions of it interact with each other. Good system design minimizes the number of such interactions needed, but perfect isolation of components is never possible—indeed, a completely isolated component cannot contribute at all to the functionality of the system.

A second reason is that the individual culture of some firms—not only in the IT sector—involves very long hours. People who work reduced hours are often seen as uncommitted to project success and/or to their employer.[5] And, in competitive environments that reward differential effort, private incentives lead people to work too much.[6]

When they exist, long hours are controversial for many of the same reasons that they are unpopular in other businesses. Long hours are often viewed negatively by workers who wish to live lives more balanced between work and nonwork. Long hours also tend to lead to inefficient behavior in any case as workers make more mistakes, especially when these hours are sustained for extended periods of time. And many IT workers are "exempt" from overtime,[7] and thus employers need not pay

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[4]See, for example, Brooks, Frederick. 1995. *The Mythical Man-Month: Essays on Software Engineering*, Anniversary Edition. Reading, Mass.: Addison-Wesley.

[5]See, for example, Landers, Renee M., James B. Rebitzer, and Lowell J. Taylor. 1996. "Rat Race Redux: Adverse Selection in the Determination of Work Hours in Law Firms," *The American Economic Review* 86(3):329-348. This study noted that in law firms, long hours were regarded by senior decision makers as a symbol of commitment and ambition. (The study also found that long hours became a symbol because these decision makers had few objective measures of an individual's work quality, a difficulty that is probably less operative—but not entirely absent—in the context of a software development firm.)

[6]Robert, Frank, and Philip J. Cook. 1995. *The Winner-Take-All Society*. New York: Free Press. See also Schor, Juliet. 1993. *The Overworked American: The American Decline in Leisure*. New York: Basic Books.

[7]Workers in certain jobs are exempt from the overtime provisions of the Fair Labor Standards Act and do not receive a premium for hours in excess of 40 hours per week. "Exempt" jobs are defined by law, not by the employer. As a general rule, a job entailing intellectual work requiring the consistent exercise of discretion and judgment in its performance is exempt. Job titles are not necessarily associated with "exempt" status. In addition, Public Law 104-188 (29 USC 213, paragraph 17) mandates exempt status for "any employee who is a computer systems analyst, computer programmer, software engineer, or other similarly skilled worker," and who is compensated on an hourly basis at more than $27.63 an hour. The primary duties of these employees must be "(A) the application of systems analysis techniques and procedures, including consulting with users, to determine hardware, software, or system functional specifications; (B) the design, development, documentation, analysis, creation, testing, or modification of computer systems or programs,

them for overtime work—a practice that is interpreted as employer exploitation by some commentators. At the same time and as noted in Chapter 1, the committee also heard from a number of individuals who asserted that many IT workers spend much longer at work than necessary, because they work inefficiently and do not cleanly separate work and play—in this view, excessively long hours are the result of poor personal time-management strategies.

6.1.2 Improved Recruitment and Retention

Improving Job Attractiveness

Upgrading the attractiveness of a job can increase the number of qualified applicants, make it more attractive for incumbents holding that job to stay (thus reducing turnover), and provide incentives for students, as well as workers in other industries, to obtain the education and training necessary to qualify for these more attractive jobs.

As noted earlier, increasing financial compensation is the time-honored way of making a job more attractive. Financial compensation can take many forms: base salary; bonuses for recruitment, retention, and performance; and stock options and/or equity stakes.[8] And IT workers have seen wages rise in real terms in recent years, though not uniformly through all categories of IT employment (as discussed in Chapter 3). (Of course, when *other* firms are able to raise compensation, turnover at any given employer may well increase, all else being equal.)

At the same time, even though workers may temporarily set aside their concerns about quality of life in a quest for riches, they are also equally concerned with quality-of-life factors, including telecommuting, less stressful commuting, and hours providing a better balance between work and family. In addition, mentoring, plum work assignments, a

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including prototypes, based on and related to user or system design specifications; (C) the design, documentation, testing, creation, or modification of computer programs related to machine operating systems; or (D) a combination of duties described in subparagraphs (A), (B), and (C) the performance of which requires the same level of skills."

[8]Stock options and equity stakes in small start-up companies can also act to drive employees away on a time scale of a few years. In particular, talented IT workers can build their own stock portfolio of pre-initial public offerings shares in order to improve their chances of winning the high-tech lottery and striking it rich. They may well be tempted to leave for another start-up company after a relatively short period of time (e.g., 2 years), with only a fraction (but a significant fraction) of their options vested in order to exploit the opportunity offered by another employer to receive additional options in a different company.

congenial work culture, good management, and opportunities for retraining can all make a job more attractive.[9]

Most importantly, the opportunity to work on challenging projects with new and interesting technology is a great motivator for many employees. Indeed, many surveys report that employees commonly rank compensation lower on their priority lists than technical challenges and the opportunity to learn new technical skills.[10] Many IT workers, especially those doing large amounts of Category 1 work, are sustained by a love of technology and the intellectual challenges of working on cutting-edge problems with others of comparable technical skill and intelligence. This is not to say that money is unimportant—but rather that they are also motivated strongly by their intellectual environment. These points suggest that employers that have a choice about projects to which to assign workers may be able to attract workers in individual cases with nonfinancial incentives as well as with higher levels of compensation.[11]

One study[12] has found that long-term employment relationships in large firms stem from the greater capacity of large employers to provide job opportunities within the enterprise and the lower probability of business failure facing large producers. In addition to directly lowering turnover, these factors act to raise the expected returns from on-the-job training as the expected duration of the employment relationship increases. As a result, large firms invest in higher levels of on-the-job training that in turn inhibits turnover. Mobility is further reduced by large firms hiring employees who prefer stability and permanence and paying mobility-inhibiting wage premiums and fringe benefits in order to protect their training investments.

An example of an employer program to increase retention is the Intel

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[9]In the case of foreign workers brought to the United States, it is not unreasonable to consider the opportunity to live and work in the United States as an additional nonmonetary compensation, which is one reason that the United States is attractive to foreign workers.

[10]Additional evidence on this point can be found in the fact that many programmers volunteer time beyond their paid jobs to participate in Open Source software development, an example of which is the development of Linux. For a discussion of this phenomenon, see Eric Raymond, *The Cathedral and the Bazaar*. Available online at <http://yuma.tdyc.com/bazaar.html/bazaar.html>.

[11]For example, a large employer may have multiple projects and be faced with the choice of assigning a worker to a project in which he or she will be maximally productive because of high familiarity with the project, or to a different project that presents new technical challenges and a learning opportunity for the worker. While the first choice may be better from the standpoint of immediate efficiency, the second choice may motivate the worker more effectively.

[12]Idson, Todd L. 1995. *Employer Size and Labor Turnover.* New York: Columbia University, February. Available online at <http://www.columbia.edu/dlc/wp/econ/econ673.html>.

Corporation's practice of redeployment. All employees who face potential job loss due to a project ending or an obsolescence of skills are permitted to join a redeployment pool for an assigned period of time, depending on a number of factors including skill type, retraining potential, etc., but generally around 4 months. During this time they receive job search support and retraining for other jobs and are utilized as a pool for temporary positions that arise within the company. As a result, an overwhelming majority of employees find internal positions within the company. This program was recognized by the Equal Employment Opportunity Commission as a Best Practice in 1997.

Former employees are another source of labor. For example, to deal with the current labor force tightness of middle and senior managers in the IT sector, certain farsighted employers are reaching out to previously unutilized former employees to fill those gaps.[13]

Finally, taking steps that combat negative stereotypes of IT work may have positive effects. For example, stereotypes of the entire IT field as being a field for young and generally single workers with Friday night beer parties, very long hours and/or extensive business travel in a fast-paced and highly unstructured environment, and risky compensation practices (e.g., stock options and equity stakes in lieu of higher wages) may well discourage a broad segment of the population from seriously considering such work, and/or encourage negative feelings and perceptions of IT work on the part of some of those already working in the field. Perceptions resulting from such stereotypes may lead potential workers to self-select away from the IT field, and employer actions to emphasize a company's appeal to a wider population may help to broaden its appeal.

Increasing Awareness of Jobs Among Potential Workers (Including Those Working for Competitors)

In order to attract potential workers, many employers advertise publicly. IT employers in particular (as well as biotechnology firms to a somewhat lesser extent) tend to emphasize job advertising on the Internet; print advertising is used as well but less often (and is required by law as an element of a permanent labor certification for an alien).

Many IT employers also recruit at colleges and universities for recent graduates for entry-level positions. At the same time, they openly acknowledge a strong preference for recruiting primarily at colleges and universities known to have strong computer science programs, and not at

[13]Reingold, Jennifer, and Diane Brady. 1999. "Brain Drain," *Business Week*, September 20. Available online at <http://www.businessweek.com/1999/99_38/b3647001.htm>.

other institutions. In many instances, IT employers have developed extensive relationships with the IT programs at these universities (which may include contributions of money, equipment, software, faculty, and advice). Employers are thus drawn to recruit from strong programs whose curricula they know well.

Finally, a substantial amount of recruiting for IT positions is undertaken by "head-hunters," word of mouth, and personal connections (e.g., a firm goes to a university computer science department head to ask for top students, a current employee personally recruits another employee). In some cases, personal connections may simply be the most efficient way to find new employees. Employees doing referrals are likely to be hesitant to recommend individuals who are unqualified, and the candidates they recommend are likely to know more about the work and working conditions than other job candidates. Many IT employers report that open advertisements are far less useful than personal referrals in attracting appropriate candidates, and an increasing number of employers pay recruiting bonuses to employees who bring in new workers.

In principle, all of these channels to promote awareness could be used more. More aggressive advertising could be done, both in print and on the Internet. Such advertising might, for example, target groups underrepresented in the IT workforce. Recruiting efforts at colleges could be stepped up, e.g., by recruiting at more colleges and universities. And greater efforts could be made to bring in personal referrals.

Each of these strategies has associated costs as well as benefits. For example, open advertising is costly, and often results in a flood of unqualified candidates who must then be screened out. Advertising targeted at underrepresented groups may fail because the proportion of individuals with the relevant skills is too small. And broader advertising is likely to be successful only when the unemployment rate for IT workers and/or the number of IT-work-capable people working in other professions is high. Many IT employers report that only a fraction of their new hires result from open advertising, as opposed to other channels.

Expanding the number of universities at which a firm can do meaningful recruiting is a longer-term affair that requires substantial effort in engaging the relevant departments intellectually. Recruiting without such engagement is possible but is likely to have a relatively low yield, because the employer will have relatively little idea of the curricula imparted to the student. (And some IT employers question the value of recruiting at large numbers of universities beyond the top tier, because they believe the work they do requires students of top caliber.)

Reliance upon word-of-mouth recruiting potentially exposes employers to legal challenges, though there is no affirmative legal requirement that firms hire competitively. Case law addresses word-of-mouth hiring, which is often challenged when it systematically leads to disparities (e.g., a Korean-owned janitorial business that operates in a black neighborhood in Chicago but hires no blacks, saying all its hiring is word of mouth and that just happens to produce all Koreans); however, the circuit courts are divided on the legality of word-of-mouth hiring that produces such results.[14] Such challenges to employer practices may present risk to employers and in any event are costly for employers to handle. A further downside is the fact that word-of-mouth recruiting may limit the population from which an employer draws. For example, to the extent that social relationships are most common among age peers, qualified older individuals would more rarely come to the attention of those responsible for hiring in companies that have large numbers of younger workers.

For some employers, a particularly effective approach in seeking out new workers is to target employees working for other firms. Compared to recent college graduates or those who might read an employment ad by chance, workers from other firms are more experienced, better understand the business environment, and infuse the new employer with knowledge of and a perspective on another company's practices. Furthermore, a resume that does not indicate experience with multiple employers can be regarded as an indicator of an employee's lack of quality in a tight job market (i.e., this person has not been desirable to many employers).

Improving Internal Human Resource Policies

Employment practices and policies at a given firm may not be well-connected to its needs for IT workers. For example, amidst corporate concerns about internal equity and morale, salary scales may well be determined on a corporation-wide basis, based on experience and educational background. But such scales may not be well-suited to IT workers, who may be able to command significantly higher salaries on the market for the same experience and educational background. Accustomed to a more sedate employment market for other specializations, company policy may forbid "special treatment" for IT workers that may include rapidly growing wages, bonuses for hiring and "hot skills," and team perfor-

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[14]In *EEOC vs. Consolidated Services Systems*, the Seventh Circuit Court held that a firm using word-of-mouth as its primary mode of recruitment was not in violation of Title VII of the Civil Rights Act, even though that practice resulted in disproportionate representation of certain protected groups (*EEOC vs. Consolidated Services Systems*, 989 F.2d 233, 7th Cir., 1993). In *Domingo vs. New England Fish Company*, the Ninth Circuit Court held that a firm using word-of-mouth recruitment that results in disproportionate representation of certain protected groups may, under some circumstances, violate Title VII (*Domingo vs. New England Fish Company*, 727 F.2d 1429, 9th Cir., 1984).

mance and retention bonuses. Further, because the human resources (HR) department is often the intermediary between job applicants and line managers that actually need workers, mismatches between company policy and the realities of hiring IT workers are often perceived by line managers as problems caused by HR departments.

"Cultural" issues arise as well. The highly informal culture of work in IT may differ significantly from that of the parent company, which may be highly formal, and insistence that IT workers conform to the cultural practices of the parent company is likely to be a significant disincentive for many of them.

Finally, to the extent that HR departments (especially in companies that do not focus on IT as their principal business) are staffed by generalists who are not able to keep track of rapidly changing trends in IT or in the marketplace for IT workers, the detailed requirements set for hiring IT workers may not reflect the current state of the IT workforce. For example, an IT department may be seeking workers with substantial Java experience. On the basis of their work with other departments in the company, someone unfamiliar with technology trends in IT may well translate this need into an advertisement running in 1998 specifying "5 years of experience with Java"—an impossibility since Java was formally announced in 1995.

Increasing the coupling between HR and IT would improve the matching process, and indeed, some IT-sector companies have begun to develop internal structures that address recruitment, training, and retention of the company's skilled workforce. In some cases, these internal structures are mini-HR departments that work exclusively with the IT department; in other cases, IT departments and corporate HR departments have established closer connections.

6.1.3 Making Clearer Distinctions Between Essential and Optional Attributes

An employer's desire for a new employee to be a perfect fit to the requirements of a job for both skills and experience is understandable and has many motivations.[15]

- Employers believe that new employees should be able to "hit the ground running."

[15]Some of these motivations are described by York (York, Thomas. 1999. "Why Are Employers So Picky?" *Infoworld*, November 22, available online at <http://www.infoworld.com/articles/ca/xml/99/11/22/991122cajob.xml>).

- Employers are often risk-averse, and workers who fit job requirements perfectly pose less of a risk, all else being equal, than workers who don't.
- The IT environment today is complex, with many technologies interacting with each other, thus creating a requirement for skills in many areas.
- With employee turnover at high levels, employers are reluctant to hire someone who needs training or retraining because they fear losing their investment. This premise puts a premium on individuals with no need for training (i.e., individuals with many skills rather than few).
- Hiring managers are loath to spend time interviewing individuals who are not at least well-matched to the jobs in question.

In addition to skills, IT employers may place a high value on actual experience, in some cases higher than the value accorded education or training. In interviews conducted for the committee, hiring managers often stressed that demonstrated ability and experience were the most important factors for hiring—degrees and ranking of the college were secondary factors.[16] The most attractive candidates are those who can show they have applied the latest programming languages or other technological skills on the job. Individuals other than recent college graduates who can demonstrate only that they have taken formal training in the current language or other "hot" technology may not even obtain an interview.

While understandably motivated, employer behavior in searching for the perfect candidate is puzzling. Insistence on a long list of qualifications will inevitably make it harder to find a qualified worker, and yet much of the time that an employer is waiting to hire could be invested in training a worker with nearly the right skill set. However, making a commitment to training someone entails the certain loss of productivity while that individual is training, whereas it is indeed possible that an applicant requiring no training could show up tomorrow. Given this fact, it is not surprising that many individuals (including hiring managers) end up waiting longer than they expected to hire someone, simply because they believe that an appropriate applicant could be "the next one in the door." (And training an individual, say for 6 months, would not result in an individual with 3 years of experience, whereas waiting "just a little longer" might result in someone with such experience.) On the other

[16]Salzman, Hal, "Information Technology Labor Markets," commissioned paper prepared for the Committee on Workforce Needs in Information Technology, 2000.

hand, if such a person is not forthcoming, it may take months or even a year to recruit and hire the "dream date," with the common result that the project schedule is not met.

The fact that this behavior is understandable does not make it entirely rational, and a relaxation of the requirements needed to fill any job opening will result in a larger number of now-qualified applicants. And some companies are indeed taking the route of hiring applicants who possess many of the required skills and training the employee in the remaining job requirements. For these companies, it often takes less time to provide this training and upgrade a new employee's skills than it would take to continue searching for the ideal job candidate. For the companies that testified to the committee, the "break-even" point was typically 4 to 6 months for the "retrain versus hire-from-outside" decision because college grads only become available on that time scale (i.e., every semester).

6.2 EXPANDING THE POOL OF IMMEDIATELY AVAILABLE WORKERS

One approach to coping with tight labor markets is finding better ways to identify talent within the labor pool. A natural consequence is for employers to search from the broadest possible pools of talent. On the assumption that the distribution of human talent does not respect ethnic, racial, or national boundaries, this is fundamentally the "enlightened self-interest" rationale for employers seeking out workers from under-represented groups as well as from the traditional pools, and it is also a major rationale for seeking talent abroad.

6.2.1 The Role of Assessment

To find ways of utilizing a broader pool of talent, it is necessary to use assessment techniques that can identify qualified individuals in that broader pool. (For purposes of this report, assessment is the process by which employers evaluate applicants for the purpose of making hiring decisions.) For the IT employer, assessment is particularly difficult because of rapid change in technologies and in the business. Such change makes it difficult to analyze the requirements of today's jobs and even more difficult to identify the skills, knowledge, and ability that might be required in the future.

Assessment techniques are never perfectly accurate. There will always be false positives (applicants who are hired but cannot perform the job) and false negatives (applicants who are rejected but can perform the job). Preselection screens using hiring standards that are too high cause many false negatives, and many applicants will be rejected even though they would be highly productive on the job. The cost of this approach also would be to artificially inflate demand by artificially increasing sector-wide vacancy rates. The primary goal of assessment is to minimize false positives and false negatives to the greatest extent possible.

On the whole, IT-sector employers have been generally successful in minimizing false positives (i.e., screening out unqualified applicants)—this success is not an unreasonable inference from the IT sector's broad success and growth throughout the economy. On the other hand, given existing tightness in the IT workforce, a question arises as to whether IT-sector employers could do a better job in reducing false negatives (i.e., finding additional qualified and productive applicants from under-represented groups that they currently overlook).

Because of the heterogeneity of IT-sector firms, it is difficult to make broad generalizations about assessment practices across the IT sector. Nevertheless, Murphy reports that many IT firms do not make use of structured assessment methods.[17] Structured assessment methods are procedures that are used to evaluate a job applicant and that are administered in a standardized and uniform manner, scored in a consistent manner, and validated against indicators of job success. However, Murphy finds that IT employers seem to prefer assessment methods that require minimal time (e.g., resume screening) or function as two-way communication (e.g., unstructured interviews) rather than more formal "structured" assessment methods.[18]

For example, many IT employers obtain a significant number of their new employees from the pool of relatively recent college graduates. Often, they prefer to focus their recruiting on recent college graduates with high grades from the top computer science departments, on the theory that good academic performance at top-tier universities is suggestive of highly productive workers and because this approach makes efficient use of recruiter efforts. At the same time, there is no data or evidence to suggest that those who do not attend top schools are less qualified or less productive.

In other cases, companies seek to identify entry-level prospects through proactive means, such as asking the professors of university computer science departments for recommendations and/or hiring undergraduates for summer internships. In such cases, employment decisions are not

[17]Murphy, Kevin, and Zinta Byrne, "Applications of Structured Assessment in the IT Workforce," commissioned paper prepared for the Committee on Workforce Needs in Information Technology, 2000.

[18]Murphy and Byrne, 2000, "Applications of Structured Assessment in the IT Workforce," commissioned paper.

made on a competitive basis, in the sense that the individual prospective new hire does not compete against his or her peers for a given job.

Another approach to seeking talent is to advertise and wait for resumes to arrive. Under these circumstances, an initial screening of resumes winnows initial applicants to those who are "promising." The committee heard a number of hiring managers report that they used "years of experience" as a first-order filter. As discussed in Chapter 2, some experience clearly improves programmer productivity. But other studies indicate no clear relationship between the programmer's level of experience and the quality of the programs he or she writes or the time required to implement those programs.[19] In practice, research shows a rather low level of correlation between years of experience or education and actual measures of job performance.[20]

Among IT employers seeking to fill senior jobs requiring high levels of experience and sophistication, initial screening is almost always undertaken with a human being reading submitted resumes.[21] But for entry-level jobs and jobs requiring relatively low levels of experience, automated resume screening appears to be quite common. This practice is made possible because many IT employers emphasize their Web presence as their primary employment point of entry. Applicants can submit resumes electronically with a single mouse click. As a result, a company may receive hundreds of resumes for a single job vacancy. To sort through the many resumes received, both individual employers and online services use search engines that hit on keywords selected by hiring managers and recruiters.[22]

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[19]Prechelt, Lutz. 1999. "Comparing Java vs. C/C++ Efficiency Differences to Interpersonal Differences," *Communications of the ACM* 42(10). Prechelt also reports (personal communication, October 1999) that the relationship between programmer experience and time to code the program is very weak, and that the correlation between time to code the program and the program's performance is also small. (He does note also that there is some tendency for Java programs to run faster after longer programming times, while programs in other languages were slower.) For data on the first point, see <http://wwwipd.ira.uka.de/~prechelt/documents/experience_years.gif>. and <http://wwwipd.ira.uka.de/~prechelt/documents/experience_KLOC.gif>. For data on the second point, see <http://wwwipd.ira.uka.de/~prechelt/documents/worktime_efficiency.gif>.

[20]The average correlation between years of education and years of job experience and measures of job performance is 0.10 and 0.18, respectively. See Schmidt, F.L., and J.E. Hunter. 1998. "The Validity and Utility of Selection Methods in Personnel Psychology: Practical and Theoretical Implications of 85 Years of Research Findings," *Psychological Bulletin* 124:262-274.

[21]Murphy and Byrne, 2000, "Applications of Structured Assessment in the IT Workforce," commissioned paper.

[22]To test online keyword searches of resumes, an NRC staff member on this study submitted the following paragraph. "Ph.D. in physics, received in 1979 from MIT. Extensive

For jobs involving such open competition, the second screening usually entails an interview involving multiple persons (perhaps in a group, perhaps a series of one-on-one encounters).[23] But what is asked of the applicant during the interview varies. In many cases, the interview is unstructured. Unstructured interviews are easy to conduct, but by definition they do not ask the same questions of an applicant and do not use a common scoring system. In other cases, the applicant is asked to provide a work sample in real time. For example, candidates for software engineering positions might be required to take a series of software design and coding tests, the results of which are evaluated by other, experienced, technical personnel. The advantage of such an approach is that it can examine the overall approach that the candidate uses, as well as the specific skills the candidate applies.

Accounting for Unintended Bias

Even among the most well-intentioned of individuals, the possibility of unintended bias is present. That is, without knowing that he or she is doing so, those responsible for hiring may favor someone that "looks like us" (for whatever definition of "us" is relevant). The hiring managers may select a superbly qualified person who looks different in contrast to an adequately qualified person who looks the same, but the bias is most likely to come out in a choice between two nearly equally qualified individuals.

Steps can be taken to reduce the likelihood of unintended bias—as a general rule, these steps involve separating the dimensions on which an individual is evaluated from personally identifying (and irrelevant) characteristics. Of course, such a separation is not always possible (e.g., when an individual's ability to work in a team is being evaluated), but it is possible more than it is practiced.

The impact of such steps can be quite significant. For example, in hiring musicians, symphony orchestras require applicants to audition. All auditions are "live," but some orchestras conduct them with the appli-

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but old background in systems programming and development, but without current technical skills. Seeking position doing design and requirements specification on interesting project, subject irrelevant. Demonstrated problem-solving skills and ability to ask the right question. Currently employed doing policy work—and bored with it. Want to return to technical work." A few hits were received in a 1-week period. He then added the following line: "I don't know C++ or Java or Oracle databases, but I'm a very quick study on technical matters." The hit rate tripled in the next week.

[23]This phenomenon was widely reported to the committee in site visits and regional open testimony in Santa Clara, California.

cant behind a screen that prevents the judges from seeing the musician. In doing so, the music that the applicant plays—the relevant part of the audition—is separated from the irrelevant characteristics of the applicant's sex, race, and age. Goldin and Rouse find that the use of screen increases—by 50 percent—the probability that a female musician will be advanced from certain preliminary rounds and increases by severalfold the likelihood that a female musician will be selected in the final round.[24]

Effectiveness of Assessment Techniques and the Role of Job Analysis

How effective are current methods for identifying highly productive workers among applicants from underrepresented groups? As noted above, IT employers commonly use unstructured assessment methods and fail to evaluate applicants against the same criteria. One primary reason may be that many hiring managers are simply unaware that there are alternatives. Another reason may be that the alternatives are more expensive. On the other hand, the appropriate cost comparison must consider not only the immediate cost of unstructured informal methods versus the alternatives, but also the likelihood that one may find a larger number of productive workers from within a given applicant pool.

A variety of structured assessment methods are described in Box 6.1. Several of the methods have a solid empirical basis, a long and consistent record of validity,[25] and demonstrated cost-effectiveness.[26] Furthermore,

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[24]Goldin, Claudia, and Cecilia Rouse. 2000. "Orchestrating Impartiality: The Impact of "Blind" Auditions on Female Musicians," *American Economic Review* 90(September):715-742.

[25]A 1999 review of 85 years of research into alternative methods of assessment found the following average correlation with measures of job performance: cognitive ability tests (0.51), work samples (0.54), structured interviews (0.51), and assessment centers (0.37). See Schmidt, F.L., and J.E. Hunter. 1998. "The Validity and Utility of Selection Methods in Personnel Psychology: Practical and Theoretical Implications of 85 Years of Research Findings," *Psychological Bulletin* 124:262-274. However, note that these correlation figures are based on a number of statistical and psychometric corrections that are controversial (Hartigan and Wigdor, 1989; Murphy and DeShon, in press) and that probably lead to inflated estimates. Nevertheless, there does seem to be clear and compelling evidence that selection tests can show substantial validity as predictors of performance, and conclusions about the relative validity of these tests (i.e., rank-ordering these tests by validity) appear reasonable.

[26]Numerous studies have shown that structured assessment methods can be highly cost-effective. For example, Campion et al. conclude that structured interviews have substantially greater validity than unstructured interviews. See Campion, M., D. Palmer, and S. Campion. 1997. "A Review of Structure in the Selection Interview," *Personnel Psychology* 50(3):655-703.

Three factors contribute to the cost-effectiveness of certain structured assessment methods. First, these methods are good at predicting job performance. Second, the quality and

BOX 6.1
Structured Assessment Methods

Structured assessment methods are procedures used to evaluate the skills, abilities, competencies, personal characteristics, or experience of a job applicant or job incumbent. There are many types of structured assessment, ranging from interviews to pencil-and-paper cognitive ability tests, but all have three features in common: standardized administration, consistent scoring rules, and empirical evidence that scores are job-related.

Structured assessment methods are more likely to be used for lower-level jobs than for managerial, executive, or professional jobs. The reason is that lower- and mid-level jobs generally involve a small set of clearly defined tasks, while the responsibilities and duties of managers and professionals are broader and more variable. As a result, it is easier to analyze lower- and mid-level jobs and to develop assessment methods that can accurately predict future performance in these jobs. Nevertheless, some structured assessment methods, including work samples and simulations and assessment centers (discussed further below) have been developed and tested on managerial and professional jobs.

Among employers who do use structured assessment methods, the following types of structured assessments are most widely used in hiring and evaluating employees. These methods, when used individually or in combination, provide good opportunities for IT employers to find qualified workers from groups that heretofore may have been overlooked.

- *Assessments of experience, background, and biographical information*. To assess prior experience and other biographical information, many employers rely on applicant-written resumes. However, research suggests that underperformers tend to overrate their abilities, while overachievers tend to underrate their abilities,

structured assessment methods have been shown to facilitate the selection of highly productive workers,[27] though the utility of these methods

productivity of IT workers vary tremendously, so that good selection methods have a huge potential payoff. Finally, the costs of most assessment methods are minuscule in comparison to the benefits of making good hiring decisions (i.e., minimizing false positives and false negatives).

If structured assessment can result in the identification of the most productive IT workers, the benefits are potentially huge. Because the productivity of individual systems analysts and programmers varies tremendously, companies that can identify the top-performing candidates are likely to have greater revenues and profits than will companies that do not use structured assessments.

[27]Murphy and Byrne, 2000, "Applications of Structured Assessment in the IT Workforce," commissioned paper.

and in fact many applicants "tune" their resumes to match the skills required by the opening. An alternative is to construct empirically validated systems that can evaluate and score biographical data obtained from resumes, job applications, or other sources. These systems hold great promise as assessment tools and are among the most valid and cost-effective methods of assessment for hiring.

- *Structured interviews*. Recent research comparing measures of actual job performance with responses to interviews suggests that interviews can be a useful and valid method of selecting employees, as long as a uniform structure is imposed. All methods of adding structure (standardizing questions, tying questions to job analysis, rating each answer on a fixed scale) improve the reliability and validity of interviews. In addition, the reliability and the validity of interviews as assessment tools are improved by focusing interview questions on behaviors, rather than attitudes or skills. Interviews are especially useful for assessing "soft skills," including social skills that increase job performance in a wide variety of jobs.
- *Work samples and simulations*. Assessments based on work samples or simulations are most likely to be successful if the tasks comprised by the job are well understood and can be done by a person working alone. Work samples are most often used in selecting managers. In particular, a simulation test known as the "in-basket" test is commonly used and has been found reliable. Another technique known as the "leaderless discussion" has been used to assess persuasiveness, self-confidence, resistance to stress, and oral communications ability.
- *Assessment center*. The assessment center is not, as its name might imply, a place, nor is it a single, unified method of predicting job performance. Rather, an assessment center is a structured combination of assessment techniques that is used to provide a wide-ranging, holistic assessment of each participant. This technique is most likely to be used in making decisions about the selection and promotion of managers, although assessment centers are also employed for decision making about many other jobs.

depends on the quality of the information available about the content and requirements of the job. Several of these structured assessment methods have also been shown to expand the selection process to include larger numbers of persons from traditionally underrepresented groups such as women and minorities.[28]

Identifying the appropriate assessment method for a given IT job or

[28]A 1994 review of the validity and adverse impact of structured assessment methods found that certain methods, such as assessment centers, work samples, and trainability tests, are equal to traditional cognitive ability tests in terms of validity but are far more inclusive in terms of identifying qualified applicants from underrepresented groups. See Reilly, R., and G. Chao. 1994. "The Validity and Fairness of Alternatives to Cognitive Ability Tests," pp. 131-224 in *Policy Issues in Employment Testing*. L.C. Wing and B.R. Gifford (eds.). Boston: Kluwer.

classification of jobs requires that the duties and responsibilities of the job(s) be identified. Systematic efforts to determine the duties, responsibilities, and requirements of a job are often referred to as "job analysis."[29] In principle, job analysis is based on concrete and specific information about the tasks, duties, and demands of the job. Traditional methods of job analysis have proved most successful in jobs that are relatively stable and well-defined. But, because the IT industry is changing so rapidly, it is very difficult to apply these traditional methods to many IT jobs, especially those in Category 1.

A recently completed NRC study[30] notes that current job analysis techniques are not sufficiently detailed to describe work attributes such as abstract analytical work, skill in the use of information technology, teamwork competencies, and skill in performing effective work. Further, they are not sufficiently flexible to address unpredictable combinations of job requirements. In general, a more contingent approach to describing Category 1 IT jobs may be needed if the most effective structured assessment methods are to be identified for this category of jobs (one that can take account of different systems for organizing work and of work systems that are undergoing continuous improvement or more rapid change).

Job analysis tends to be most appropriate for IT jobs in Category 2. For example, the Northwest Center for Emerging Technologies' *Skill Standards for Information Technology* provides information about skills, tasks, curricula, etc. for eight major career clusters in the IT industry. For higher-level jobs in the "core" IT occupations, the U.S. Department of Labor's *Dictionary of Occupational Titles* and its successor *O*NET* provide some information about the tasks, duties, and skills involved in many IT jobs, but they are insufficiently fine-grained to capture the specifics of what many IT employers seek.

While some structured assessments are often resource-intensive to administer and thus more suitable to assessments of a relatively small number of individuals, other structured assessment methods can have applicability even for initial screening purposes. For example, rather than automatic keyword searches on applicant-submitted resumes, an approach

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[29]However, there is variability in the definition of a good job analysis and in the methods that might be used to analyze work. See, for example, Harvey, R.J., 1991, "Job Analysis," pp. 71-164 in *Handbook of Industrial and Organizational Psychology*, 2nd Edition, M.D. Cunnette and L.M. Hough, eds., Vol. 2, Palo Alto, Calif.: Consulting Psychologists Press; Fine, S., and S. Cronshaw, 1999, *Functional Job Analysis: A Foundation for Human Resources Management*, Mahway, N.J.: Lawrence Erlbaum Associates; and Whetzel, D.L., and G.R. Wheaton, 1997, *Applied Measurement Methods in Industrial Psychology*, Palo Alto, Calif.: Davies Black Publishing.

[30]National Research Council. 1999. *Changing Nature of Work: Implications for Occupational Analysis*. Chapter 7. Washington, D.C.: National Academy Press.

based on an "accomplishment record" can be used to perform initial screening.[31] Accomplishment records require organizations to identify the key dimensions of performance for each job and to develop specific behavioral examples of performance at the level required in that job (e.g., the behavioral examples that describe adequate performance on the dimension of "oral communication" would be different for a university professor than for members of a team involved in assembling automobile engines). Applicants then rate themselves in reference to these dimensions and exemplars.

Legal Dimensions of Assessment

Apart from the value of assisting employers to identify and hire the most productive and talented IT workers, assessment is important to employers for legal reasons as well: some methods of assessment run afoul of antidiscrimination statutes—and others may raise suspicions of discrimination even if they are legally defensible. Employers who do not exercise care in the way in which they conduct assessments leave themselves vulnerable to legal challenge.

These concerns arise from a fundamental conflict between the protection of individual rights and the rights of employers to make assessments of potential employees for legitimate business reasons. The essential reality of assessment is that any assessment method will result in false positives (an individual will be hired who in fact is unable to perform adequately) and false negatives (an individual will not be hired who in fact is able to perform adequately). Thus, any employer making hiring decisions will reject some qualified people in hiring decisions. On the whole, this outcome is not surprising—and is in fact the cost that a society must pay for the overall good. But for understandable reasons, individuals who feel that they were improperly rejected are loath to accept this outcome.

For these reasons, *any* system used for making decisions about hiring, placement, firing, compensation, or conditions of employment is potentially vulnerable to legal challenge. Employers that discriminate or are perceived to discriminate against members of legally protected groups

[31] Accomplishment records have proven reasonably accurate in predicting success in professional jobs and are also cheap enough to administer on a large scale. See Hough, L., 1984, "Development and Evaluation of the 'Accomplishment Record' Method of Selecting and Promoting Professionals," *Journal of Applied Psychology* 69(1):135-146; Smith, M., and I.T. Robertson, 1989, *Advances in Selection and Assessment*, New York: John Wiley & Sons; and Von Bergen, C.W., and B. Soper, 1995, "The Accomplishment Record for Selecting Human Resources Professionals," *Advanced Management Journal* 60:41-46.

(e.g., applicants over 40, women, or members of minority groups) will find it difficult to offer an effective defense if they cannot demonstrate the appropriateness of their assessment methodology. The choice of assessment strategy can have a substantial impact on the perceived (and actual) fairness of assessments and decisions based on those assessments.

The assessment problem is further complicated by the fact that there is often a tradeoff between the time and effort needed to conduct an assessment and its validity in predicting job performance. For example, work sample or simulation assessment methods are known to be very good predictors of job performance. They also do a good job of increasing diversity within the pool of applicants identified as best qualified. However, they are labor-intensive to develop and administer, and they require much of the applicant's time. Employers may have difficulty applying such methods on a large scale (making them less practical for initial screening). However, such methods may be cost-effective when the employer is seeking employees for senior management positions.

Note also that perceptions play an important role—even if a particular assessment methodology is valid (i.e., can be shown on average to predict job performance at a reasonable rate) and legally defensible, the perception that its use constitutes discriminatory behavior on the employer's part may lead to legal action being taken against the employer. If the methodology is valid and legally defensible, the employer will prevail—but at a nontrivial cost in legal expenditures and bad publicity. For this reason, employers should use assessment methodologies that have "face validity," that is, are perceived as valid and fair by applicants.

Job candidates seem to view some structured assessments (e.g., multiple interviewers using uniform questions with concrete feedback to the applicant on his or her performance) as more fair than unstructured assessments (e.g., an unstructured interview conducted by a single hiring manager).[32] If an employer who uses certain structured assessment methods does face a lawsuit, he or she may be more able to successfully defend the selection procedure than an employer who uses unstructured methods. Thus, companies using certain structured assessments may be less likely to encounter rejected job candidates claiming illegal discrimination.

The employer's defense against charges of discrimination can be strengthened if it can provide a clear definition of what the jobs in question entail with respect to duties, skills, and required abilities, of what constitutes good performance or success on the job, and of how the information that was used to make decisions about applicants is related to

[32] Murphy and Byrne, 2000, "Applications of Structured Assessment in the IT Workforce," commissioned paper.

successful job performance. However, as noted earlier, the IT sector (as well as work in many IT-intensive industries) is characterized by rapidly changing jobs in a rapidly changing business environment amidst rapidly changing technology. Under these circumstances, it is understandable that IT employers may not have as formal a set of standards for employee selection as they might have in a more slowly changing sector. Nonetheless, IT employers are expected as a matter of law to have standards that are job-related and nondiscriminatory. Moreover, less formal employment standards are precisely the circumstances that lead unsuccessful applicants to fear that they are the victims of adverse actions that are based on something other than their qualifications.

Future Trends in Assessment of IT Workers

Because of the difficulty of assessing future job performance in a fast-changing industry, and because job postings often draw very large responses, some IT employers are turning to outside vendors to assist with recruitment and hiring. As noted above, a large number of online job-matching services are now available to both employers and jobseekers.

In addition, online assessment and certification of several different types of computer hardware and software skills are growing rapidly. These certification systems are particularly well developed for skills and knowledge related to support and maintenance of computer hardware and networks. For example, the Tek.Xam assessment examination measures technology and problem-solving skills within the technology environment. The Tek.Xam is Internet-based, vendor-independent, and delivered online in a proctored computer lab. According to its creators, individuals certified by the Tek.Xam can "synthesize and analyze data, draw conclusions, and present those conclusions using a variety of common computer applications. They can create websites and can effectively use the Internet for information gathering and analysis. In addition, they understand a wide range of computer concepts related to networking, hardware and software as well as the key legal and ethical issues associated with the use of this technology."[33] Primarily a test for mastery of computer applications, the test is useful chiefly to certify individuals who are "management trainees in production, finance, marketing, customer service and human resources; webmasters and help desk personnel in IT; research assistants, project managers, analysts, and consultants." In general, the test seems directed at individuals applying for positions that "do not require candidates to have a specialized degree in engineering or

[33]From the Tek.Xam Web site at <http://www.tekxam.com>.

computer science but are strengthened by those with problem-solving skills."

Finally, one of the most recent developments is assessment and certification of a broader range of skills. In theory, employers might use such certificates as an important part of (or even in place of a large part of) their own assessment of job candidates. For example, a commercial testing group is now offering skills assessment and certification based on the Northwest Center for Emerging Technologies skill standards. The Chauncey Group International, a for-profit testing firm, will certify an individual as an "Associate Technology Specialist" if he or she is successful on three assessments. Two of the examinations relate directly to one of the eight career clusters identified by NWCET, while the third measures the skills common to all eight clusters. This third, "core skills" assessment is now being offered in the marketplace, via computer-based delivery or paper-and-pencil administration. Over the next 3 months, the Chauncey Group will be pilot-testing assessments designed to measure skills in all eight IT skill clusters.

It is possible that new types of online assessments, similar to those described above, will be developed for use in assessing the potential future performance of workers in higher-level IT jobs. One central issue that remains to be addressed in assessing IT workers is the fact that many of them work in teams. Most of the structured assessment techniques described in Box 6.1 (with the exception of the assessment center and the leaderless discussion) focus on predicting the ability of an individual to apply his or her skills alone. New methods are needed to assess the potential future ability of an individual to contribute productively to a software development team.

6.2.2 Targeting Underrepresented Groups for IT Careers

Talent is equally distributed among all demographic groups, without regard for race, ethnicity, nationality, gender, or age. What is not equally distributed is the opportunity and the encouragement to develop and use one's talents.[34]

[34] In addition to the sources cited later in this section, useful data on women in IT can be found in Camp (Camp, Tracy. 1997. "The Incredible Shrinking Pipeline," *Communications of the ACM* 40(10):103-110) and in Carver (Carver, Doris L. 1999. "Research Foundations for Improving the Representation of Women in the Information Technology Workforce," Virtual Workshop Report, pp. 8-9. Available online at <http://www.cise.nsf.gov/itwomen/itwomen_final_report.pdf>). Data on minorities can be found in Garcia, Oscar N., and Roscoe Giles, "Research Foundations on Successful Participation of Underrepresented Minorities in Information Technology," available online at <http://www.cise.nsf.gov/itminorities/itminorities_final_report.pdf>.

As noted in Chapter 2, IT workers are predominantly white and male. In 1997, 27 percent of all U.S. computer and mathematical scientists were women, 4 percent were black, and 3 percent were Hispanic.[35] In the same year, 73 percent were men, 81 percent were white, and 12 percent were Asian American. In 1986, 36 percent of all earned bachelor's degrees in computer science went to women; a decade later, the proportion had declined to 28 percent.[36] At the master's level, the numbers are also down, although less dramatically: from 30 percent in 1986 to 27 percent in 1996.[37] In 1997, research showed that elementary and middle school boys and girls were using computer games and the Internet in roughly equal proportions; male and female high school students are also roughly equal in their rate of computer use. High school women have substantially increased their participation in science courses, although only 17 percent of students taking Advanced Placement courses in computer science in 1997 were female.

In 1998, the percentage of college freshmen planning science or engineering majors was slightly higher among black and Hispanic students (33 percent for both groups) than among white students (30 percent). The gap between males and females planning to study S&E was largest among white and Hispanic students (10- and 9-point gaps, respectively) and smallest among black students (32 percent of females versus 34 percent of males).[38] However, a substantial fall-off occurs between freshmen's declaration of intent to study S&E fields and actual completion of degrees in those fields. A survey of students at enrollment in 1989-1990, with follow-up in 1995,[39] indicated that less than one-half of all students who had declared an intent to do so completed an S&E degree within 5 years. Within this overall trend, however, females were more likely than males to complete an S&E degree within 5 years. Furthermore, the survey found that, compared with the white and Asian/Pacific Islander groups, fewer underrepresented minority students completed an S&E degree within 5 years, and a higher percentage of underrepresented minority students switched to non-S&E fields.

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[35]National Science Board. 2000. *Science and Engineering Indicators—2000*. Arlington, Va.: National Science Foundation, Appendix Table 3-10.

[36]National Science Board, 2000, *Science and Engineering Indicators—2000*, Appendix Table 4-17.

[37]National Science Board, 2000, *Science and Engineering Indicators—2000*, Appendix Table 4-23.

[38]National Science Board, 2000, *Science and Engineering Indicators–2000*, Appendix Table 4-8.

[39]National Center for Education Statistics (NCES). 1996. *Beginning Postsecondary Student (BPS) Longitudinal Study*. Washington, D.C.: U.S. Department of Education, Office of Educational Research and Improvement.

Among underrepresented racial and ethnic minority groups in the United States, the percentages receiving both bachelor's and master's degrees increased during the 1980s and 1990s but still remain at low levels. In 1996, among U.S. citizens and permanent residents awarded bachelor's degrees in mathematics and computer science, 10 percent were black, 5 percent Hispanic, and less than one-half of 1 percent American Indian or Alaskan Native.[40] At the master's level, proportions were even lower: fewer than 6 percent were black, 3 percent were Hispanic, and 0.3 percent were American Indian or Alaskan Native.[41] The wage gap is also evident between white and Asian U.S. scientists and engineers and black and Hispanic scientists and engineers. In 1997, the median annual salary for computer and mathematical scientists and engineers was $56,000. Whites earned 101.4 percent of the median and Asians 100 percent, while blacks earned 85.7 percent and Hispanics 94.6 percent.[42]

The argument has been made that the use of foreign workers should be curtailed so that employers and industry groups will be motivated to work harder to attract, recruit, promote, and retain U.S. IT workers who are members of underrepresented groups.[43] Whether in fact this strategy would be effective is an empirical question, about which the committee has seen no evidence one way or another.

Whether temporary immigration and outreach to the underrepresented should be linked explicitly in a policy sense is essentially a political question on which the committee is explicitly silent. Nevertheless, encouraging members of underrepresented groups to develop their talents in areas relevant to IT makes sense for reasons of economics and social policy. Economically, a tight labor market should imply the development of all sources of talent. Socially, such encouragement strengthens the commitment to fairness and equity in a democratic society.

Many commentators have observed the underrepresentation of certain demographic groups in IT, and some have sought to develop explanations for it. One reason may be a lack of awareness among those in underrepresented groups about IT careers. For example, a survey taken in Silicon Valley indicated that African American and Hispanic students were less aware of such IT careers as engineer, network manager, and

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[40]National Science Board, 2000, *Science and Engineering Indicators–2000*, Appendix Table 4-35.

[41]National Science Board, 2000, *Science and Engineering Indicators–2000*, Appendix Table 4-38.

[42]National Science Board, 2000, *Science and Engineering Indicators–2000*, Appendix Table 3-17.

[43]See, for example, Hugh B. Price, statement of the National Urban League, "National Urban League Calls upon Congress to Hold Off on Another Expansion of the H-1B Special Visas Program," June 20, 2000.

computer programmer than were their Caucasian and Asian American counterparts.[44] Female students were consistently less aware of career opportunities than were males. Another recent survey found that, in middle and early high school, girls and young women "deselect" technology careers.[45] These female students lacked or had wrong information about the nature of IT work, the preparation required, the degree to which technology careers might interfere with having children, and opportunities for women in technology fields.

A second reason may be what is often termed the "digital divide."[46] Even within similar socioeconomic classes, whites are disproportionately more likely than blacks and Hispanics to own a computer and have access to the Internet. The divide continues at school, where suburban schools and more affluent schools report a better ratio of student to computer use than that seen in urban, rural, and poor schools. Likewise, teacher facility in using technology in the classroom differs markedly, with teachers of "higher achieving" students reporting using the Internet more, and boys and "better students" found dominating classroom computer use. Conversely, reports claim that African American students are tasked to use computers simply for practice and drill sessions rather than for the computer-facilitated development of higher-order skills that are emphasized in majority, suburban, affluent classrooms.[47]

A third possible reason may be perception of IT work as highly stressful, competitive, demanding, and overwhelming. Furthermore, the field may have a "majority male" model stereotype that places under-represented members in a position as outsider upon entering the field.[48] For example, as female participation in college-level computer science majors has declined overall, one study showed that, of students transferring out of computer science majors, nearly twice as many women as men cited worries about career demands and lifestyle as factors.[49]

A fourth possible reason is that whether or not justified by their actual educational background, certain groups may feel inadequately prepared

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[44]Joint Venture: Silicon Valley Network. 1999. *Joint Venture's Workforce Study: An Analysis of the Workforce Gap in Silicon Valley.* Palo Alto: Joint Venture: Silicon Valley Network. Available online at <http://www.jointventure.org/initiatives/edt/work_gap/home.html>.

[45]Northwest Center for Emerging Technologies (NWCET). 1999. "CyberCareers for the Net Generation," Bellevue, Wash.: NWCET.

[46]Fisher, Allan. 1999. *Report of the Carnegie Mellon Symposium on Minorities in Computing,* a white paper. Available online at <http://www.nsf.gov/sbe/tcw/events_991114w/start.htm>.

[47]Fountain, Jane E. 2000. "Constructing the Information Society: Women, Information Technology, and Design," *Technology in Society* 22:45-62.

[48]These possibilities were also discussed at the CMU symposium.

[49]Fountain, 2000, "Constructing the Information Society: Women, Information Technology, and Design."

to major in IT-related fields. For example, a 1995 survey conducted in the Massachusetts Institute of Technology's Electrical Engineering and Computer Science Department commented on the extent to which women MIT undergraduates feel that they are less prepared than their peers to major in computer science. The report noted that "although it is probably true that women, on the average, come to MIT with less experience in EE and CS than do men, it also seems true that such a difference in responses must be due partly to perception rather than reality."

As this report went into review, the report by the Commission on the Advancement of Women and Minorities in Science, Engineering, and Technology Development was released (July 2000).[50] Because of the release's timing, the committee was unable to consider the report of the commission fully. The report concluded that "the nation needs to cultivate the scientific and technical talents of *all* its citizens, not just those from groups that have traditionally worked in science, engineering, and technology fields," and made recommendations to address a number of problems that the commission found in this area (Box 6.2).

6.3 RECAP

Because efforts undertaken to promote education and training will bear fruit only in the relatively long run (and these are discussed in Chapter 7), it is worth paying some attention to ways that employers can make more effective use of qualified workers who can be put to work in a relatively short time without additional education or training.

For example, employers can ask workers to work very long hours. While this can be a practical strategy during certain limited periods, over the long run it is unsustainable if workers wish to achieve a good integration of work and life. The data available to the committee indicate that taken across the universe of employers of IT workers, excessively long hours week in and week out do not characterize the lives of IT workers.

Seeking to reduce turnover and to attract more qualified applicants, employers can make jobs more attractive. Additional compensation is one element, of course, but many studies have indicated that IT workers are also highly motivated by the opportunity to work on technically interesting problems. Corporate personnel policies that take into account a tight labor market for IT workers to allow, for example, higher salaries for

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[50]Commission on the Advancement of Women and Minorities in Science, Engineering, and Technology Development. 2000. *Land of Plenty: Diversity as America's Competitive Edge in Science, Engineering, and Technology*. Available online at <http://www.nsf.gov/od/cawmset/report/cawmset_report.pdf>.

BOX 6.2
Recommendations from the Report of the Commission on the Advancement of Women and Minorities in Science, Engineering, and Technology Development

Problem	Recommendation
For underrepresented minority students, inadequacies in the precollege environment that prevent access to high-quality science and mathematics education For women, active discouragement and the dearth of out-of-school science, engineering, and technology experiences and role models For students with disabilities, poor access to well-prepared teachers, assistive technologies, and personal assistance	Adopt comprehensive, high-quality standards in mathematics and science by all states. Enact state legislation requiring school districts to collect student achievement data disaggregated by socioeconomic status, English proficiency, disability status, race/ethnicity, and sex; hold districts, school boards, and school administrators accountable for the success of all subgroups in meeting state achievement standards.
For members of underrepresented groups, departure in large numbers at different transition points in the mathematics and science pipeline	Undertake aggressive, focused intervention efforts targeting women, minority, and disabled students at all levels of pre-baccalaureate education.
For women, negative social pressures resulting from the negative social image of scientists and engineers, lack of encouragement (coupled with active discouragement) For persons with disabilities, an absence of positive media images of scientists and engineers, lack of assistive technologies For all, rising costs of college tuition and the deficiency of scholarships and grants	Significantly expand investment in the financial support of underrepresented groups in SET [science, engineering, and technology] higher education, including, but not limited to, those attending minority-serving institutions and two-year colleges.

continued

BOX 6.2 continued

Pervasive racial prejudice and ethnic and gender stereotypes in professional life	Hold all employers in science, engineering, and technology accountable for the career development and advancement of their employees who are women, minorities, and persons with disabilities.
Inaccurate and derogatory public image of scientists, engineers, and technology workers; lack of media portrayal of women, underrepresented minorities, and people with disabilities in science, engineering, and technology careers	Identify or establish a body, representing public, nonprofit, and private sectors, to coordinate efforts to transform the image of the SET professions and their practitioners so that it is positive and inclusive for women, underrepresented minorities, and persons with disabilities.
Lack of accountability for promoting diversity	Establish or identify a collaborative body to continue the efforts of the Commission through the development, coordination, and oversight of strong, feasible action plans.

SOURCE: Excerpted from Commission on the Advancement of Women and Minorities in Science, Engineering, and Technology Development. 2000. *Land of Plenty: Diversity as America's Competitive Edge in Science, Engineering, and Technology*. Available online at <http://www.nsf.gov/od/cawmset/report/cawmset_report.pdf>.

IT workers with a given level of experience would position many employers to compete more effectively in the IT labor market for talent.

Employers who make a clearer distinction between essential and optional attributes in the workers they hire will find it easier to hire workers in a tight labor market.

In a tight labor market, the expansion of the pool from which employers draw their workers is one of the most rapid ways in which employers can address their hiring difficulties. And, contrary to popular belief, an expansion of the hiring pool need not necessarily lead to a reduction in the quality of the individuals being hired. In particular, some techniques of structured assessment—including but not limited to paper-and-pencil tests—have been shown to expand the pool of qualified workers in fields that share many attributes with IT work. Formal assessment techniques also reduce the likelihood of unconscious bias on the part of those making employment selection decisions. And, while structured assessment techniques are likely to be more useful for jobs involving Category 2 work, they can be used to identify certain attributes that are necessary for Category 1 work as well.

Whether temporary immigration and outreach to the underrepresented should be linked explicitly in a policy sense is essentially a political question on which the committee is explicitly silent. Nevertheless, encouraging members of underrepresented groups to develop their talents in areas relevant to IT makes sense for reasons of economics and social policy. Economically, a tight labor market should imply the development of all sources of talent. Socially, such encouragement strengthens the commitment to fairness and equity in a democratic society.

Finally, it is important to note that while some of these approaches to making more effective use of the existing workforce are well-known, execution and follow-through are as essential as awareness of the strategies.

7

Longer-Term Strategies for Increasing the Supply of Qualified Labor: Training and Education

This chapter examines two groups of strategies for increasing the supply of IT workers in the United States (A third class of strategy, the use of more foreign workers domestically and abroad, is discussed in Chapter 5.) More precisely, these are *strategies for facilitating an expansion in supply*.[1] The first group includes various forms of "formal" education, ranging from K-12 through higher education. Most of these are long-term strategies, which take anywhere from 2 to 20 years to be effective. However, some educational programs in community colleges, proprietary schools, and vendor-oriented courses can produce results in a few months or less. The second group, which overlaps to some extent with the first, comprises worker training.

7.1 THE ROLE OF FORMAL EDUCATION

Any systemic approach to relieving tightness in IT labor markets must include education and training for a variety of IT occupations. As noted in Chapter 2, IT career pathways are highly variable. A few individuals enter the IT workforce directly from high school, or with minimal additional training such as preparation for vendor certification. More com-

[1]As noted in Chapter 5, any increase in the number of qualified workers has the effect of dampening wage growth. But from an overall national perspective, it is less controversial politically for a U.S. worker who loses a job (for example) to lose it to another U.S. worker than for him or her to lose it to a foreign worker.

monly, individuals acquire both technical and foundation skills by completing an associate's degree at a community or technical college. The majority of Category 1 workers complete at least a bachelor's degree before beginning their IT careers. Other routes include the military, government-funded worker training or "upskilling" programs, targeted programs for special populations, corporate education, and local initiatives (e.g., industry-educational consortia).

Career paths in the IT field can be highly fluid. Individuals can start out as programmers and subsequently become systems analysts or integrators, database developers, or even Web site designers. Some enter IT from seemingly unrelated occupations or professions. Creativity and innovation, two skills often found in people trained in the arts, are highly transferable to software development. Artistic design and spatial abilities can often transfer from architecture or commercial art or drafting to Web page design. Theatre majors can be found leading software development teams. Nevertheless, certain transition paths within IT are highly unlikely because the "before" work is too different from the "after" work (a point discussed in Section 7.2, "Training IT Workers").

7.1.1 Secondary Education

As noted in Chapter 3, large increases in demand are forecast for Category 1 IT workers, who generally require high levels of formal education. It is axiomatic that preparation for such occupations involves adequate education, the first step of which is K-12 education that prepares students for college-level study of computer science, electrical engineering, and other IT-related fields. In addition to providing specific preparation for college-level study, the process of studying science and mathematics may help young people to develop foundational or core IT skills and abilities (discussed in Chapter 2) that they can take directly into certain Category 2 jobs or build upon in the course of additional study of IT-related topics.

In the discussion below, the committee focuses on secondary mathematics and science education, rather than primary or middle school education. The reason is that it appears to be at this level that the "average" mathematics and science education in the United States is particularly weak (Box 7.1), although reform efforts have been under way at every level for at least a decade.[2]

[2]For example, in 1989 the National Council of Teachers of Mathematics published the first mathematics standards, *Curriculum and Evaluation Standards for School Mathematics* (Reston, Va.: NCTM), and the National Research Council released *Everybody Counts: A Report to the Nation on the Future of Mathematics Education* (Washington, D.C.: National Academy

BOX 7.1
Educational Achievement of U.S. K-12 Students

One indicator of the science and mathematics achievement of K-12 students in the United States is found in the results of the Third International Mathematics and Science Study (TIMSS), conducted in 1995 and 1996.[1] Overall, on this international assessment, U.S. students scored slightly above the international average in science and slightly below the average in mathematics. However, the results for 17-year-olds—those closest to entering the IT workforce—were worse than those of the younger students.[2] In both mathematics and science, the U.S. 17-year-olds scored below the international average, and among the lowest, of the 21 countries participating. Overall, the performance of U.S. high school seniors in mathematics has been near the bottom in international comparisons over the past 30 years. Within the smaller group of 16 countries that participated in assessments of physics and advanced mathematics, the scores of U.S. 17-year-olds were among the lowest.

Other measures of the science and mathematics knowledge of U.S. students come from the National Assessment of Educational Progress, or NAEP, a nationally representative testing program involving students in grades 4, 8, and 12. The most recent NAEP results, from 1999, indicated that only a small fraction of students at each grade level were "proficient" in mathematics and science.[3]

Like the TIMSS results, the NAEP results suggested that the performance of 12th graders in science and mathematics was lower than that of younger students. It is noteworthy, however, that a National Research Council committee found problems with the procedures used for standard setting and defining the cutoff between

[1]The TIMSS assessed students at ages 9, 13, and 17 using a combination of multiple-choice questions and open-ended exercises. The study was designed to overcome a problem of previous international comparisons, in which test scores from a broad general population of U.S. high school students were compared with scores of the few students enrolled in elite, college preparatory schools in other countries. Each country participating in the TIMSS was required to administer the test to a broad sample of school classes chosen to reflect the characteristics of the country's overall population. Forty-one countries participated in the assessment of 13-year-olds, 26 in the assessment of 9-year-olds, and 21 countries assessed their 17-year-olds. As reflected in its name, the TIMSS is the third in a series of such international assessments.

[2]U.S. Department of Education. National Center for Education Statistics. 1998. *Pursuing Excellence: A Study of U.S. Twelfth-Grade Mathematics and Science Achievement in International Context*. Washington, D.C.: U.S. Government Printing Office.

[3]For example, in 1999, 97 percent of U.S. 12th graders had an initial understanding of the four basic operations of arithmetic and 61 percent could perform moderately complex procedures and reasoning (such as a basic understanding of number systems). However, only 8 percent had the reasoning skills to solve multistep problems such as those that involve algebra (U.S. Department of Education, National Center for Education Statistics. 2000. *National Assessment of Educational Progress, 1999: Trends in Academic Progress.* Washington, D.C.: U.S. Government Printing Office).

BOX 7.1 continued

NAEP scores deemed "basic" and those that represent "proficient" performance.[4] This committee's report suggested that the cutoff had been set too high, yielding results "that do not appear to be reasonable relative to numerous other external comparisons."[5] Although weak as an absolute measure of the science and mathematics achievement of U.S. students at any one point in time, NAEP scores can usefully reveal trends. Used in this way, NAEP results from 1990, 1992, 1996, and 1999 indicate that student achievement in mathematics increased significantly over that time period.

The science and mathematics achievement of younger U.S. students appears greater than that of older students. In contrast to the weak performance of high school seniors in the TIMSS, U.S. fourth graders scored above the international average in both mathematics and science, and their science performance was second highest among the 26 countries participating.[6] However, U.S. eighth graders' performance in both mathematics and science was squarely in the middle among the 25 countries participating.

What are the implications for the future IT workforce when younger U.S. students perform better on science and mathematics assessments than older students? One interpretation is that today's fourth graders will be tomorrow's IT workers, with a strong mathematics and science base to draw on. On the other hand, if the current pattern of declining test scores with age persists, these youngsters may perform more poorly in mathematics and science as they near high school graduation—just at the time when they might prepare for college-level IT study and/or for IT work.

[4]Pellegrino, James W., Lee R. Jones, and Karen J. Mitchell, eds. 1999. *Grading the Nation's Report Card: Evaluating NAEP and Transforming the Assessment of Educational Progress.* Washington, D.C.: National Academy Press.

[5]Pellegrino et al., 1999, *Grading the Nation's Report Card.*

[6]U.S. Department of Education. National Center for Education Statistics. 1997. *Pursuing Excellence: A Study of U.S. Fourth-Grade Mathematics and Science Achievement in International Context.* Washington, D.C.: U.S. Government Printing Office.

The State of Secondary Education

As noted above, it is important to the future of the IT workforce that the curriculum of secondary school mathematics and science provide a strong foundation for later study and training in IT and IT-related sub-

Press). In response to a request from the National Science Teachers Association, the National Research Council convened a committee of experts, leading to the publication in 1996 of *National Science Education Standards* (Washington, D.C.: National Academy Press).

jects. And yet, secondary mathematics and science education common in most U.S. secondary schools today may discourage some students from pursuing further IT education or training, because it does not provide the cognitive and intellectual base for learning about IT and IT-related subjects.[3] For example, only a small fraction of U.S. secondary school students demonstrated an ability to integrate mathematical concepts and procedures to solve complex problems (see Box 7.1). Such skills are essential for any advanced study of IT.

A second example is the fact that the traditional high school mathematics curriculum, especially for college-bound students, is directed toward the study of calculus. But calculus, oriented toward continuous representations, does not generally speak to discrete mathematical representations or their manipulation. From the point of view of specific content, discrete mathematics is generally more useful than continuous mathematics as a foundation for most software-oriented IT work (graphics is a notable counterexample).[4]

Much of the science in secondary education is similarly disconnected from IT career paths. For example, the Northwest Center for Emerging Technologies found that the work involved in several groups of IT careers did not require the discipline-specific knowledge associated with the biology, chemistry, earth science, or physics courses that characterize the typical high school science sequence.[5] Rather, individuals in these careers made extensive use of modeling, logical thinking, problem solving, and intellectual discipline—abilities developed in the course of studying science.[6]

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[3]Joint Venture: Silicon Valley Network. 1999. *Joint Venture's Workforce Study: An Analysis of the Workforce Gap in Silicon Valley.* Palo Alto: Joint Venture: Silicon Valley Network. Available online at <http://www.jointventure.org/initiatives/edt/work_gap/home.html>.

[4]At the same time, study of advanced high school mathematics may help some young people develop logical thinking and quantitative reasoning skills that are essential to many types of IT work. See, for example, Adelman, Clifford. 1997. *Leading, Concurrent, or Lagging: The Knowledge Content of Computer Science in Higher Education and the Labor Market.* Washington, D.C.: U.S. Department of Education.

[5]Northwest Center for Emerging Technologies (NWCET). 1999. *Building a Foundation for Tomorrow: Skill Standards for Information Technology.* Bellevue, Wash.: NWCET, pp. 23-24.

[6]A major exception to these comments is IT career paths that involve hardware. For such careers, continuous mathematics and physics are highly relevant, because these subjects are the basis for future work in design topics such as circuit theory and chip design. In light of the growing demand for IT hardware workers, it is perhaps worrisome that in 1996, 14 percent of high school graduates took precalculus or third-year algebra but only 7 percent took calculus. (See National Assessment of Educational Progress. 1996. *Student Work and Teacher Practice.* U.S. Department of Education, National Center for Education Statistics.) Nevertheless, a grounding in discrete mathematics is relevant as well for much hardware-oriented work.

Accordingly, the contribution of secondary science and mathematics education to addressing tightness in the IT workforce is likely to be measured by the extent to which that education can promote the exercise and development of cognitive abilities such as logical thinking, problem solving, analysis, careful observation, and data management. These abilities are highly valued in the workplace, and they are vital to successfully performing both Category 1 and Category 2 IT work.[7]

Finally, in addition to providing the foundational skills and abilities for those entering postsecondary education in IT disciplines, secondary education can also prepare some students to enter certain Category 2 IT jobs directly. Some properly prepared high school students are hired into occupations such as network technician, Web page author, and help desk technician. As part of that preparation, some high schools offer courses leading to vendor certifications (see discussion in Section 7.1.5). However, high school preparation alone can rarely provide an adequate foundation for movement directly into Category 1 IT jobs.

Access to IT in the Classroom

The committee believes that early exposure to computers may help spark long-term interest in IT careers and encourage students to seek the education necessary to prepare for them.[8] Over the past decade, U.S. public schools have made great progress in obtaining access to information technology, though as noted in Chapter 6, the progress is not uniform among various socioeconomic classes and ethnic categories. According to the U.S. Department of Education, the proportion of schools with Internet access has increased rapidly from 35 percent in 1994 to 89 percent in 1998, and 51 percent of instructional rooms had access to the Internet in 1998. Furthermore, the fraction of students using computers at school increased from 59 percent in 1993 to 69 percent in 1997.[9]

In addition, the IT sector has made major contributions to strengthening the IT dimension of K-12 education. For example, the Intel Corporation's Teach to the Future program brings together IT companies including Microsoft, Hewlett-Packard, Premio Computer, and Intel in an effort to train 400,000 teachers in 1,000 days. In the next 3 years, Intel will

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[7]Northwest Center for Emerging Technologies, 1999, *Building a Foundation for Tomorrow: Skill Standards for Information Technology.*

[8]The committee recognizes some controversy about this point, as some have argued that greater access to information technology in schools is not likely to produce larger numbers of people interested in IT careers.

[9]U.S. Department of Education. 1999. *Digest of Educational Statistics*. Available online at <http://nces.ed.gov/pubs2000/digest99/chapter7.html>.

contribute $100 million in cash, equipment, curriculum development, and program management while Microsoft will add $344 million in software and program support.

Nevertheless, much more remains to be done. Most teachers lack the professional development and support (e.g., training and release time) needed to incorporate information technology into daily instruction, and as a result, significant numbers of such teachers either ignore the pedagogical uses of technology or use technology ineffectively.[10] Further, continual technological change, combined with public education's limited financial resources, results in deployed educational technology that is often obsolete—making it difficult to use currently available resources to teach students about technology.

Young People's Views of Education and IT Careers

Young people's views and attitudes are related to both their academic achievement and their career choices, and these factors, in turn, influence the size of the future IT workforce. For example, one reason that most young people today do not consider IT careers may be a simple lack of information. Even in Silicon Valley, most students know little about IT careers and how to prepare for work in the industry. A 1999 survey of over 1,000 Silicon Valley eighth graders and high school juniors revealed that a higher proportion of students understood the careers of lawyer, doctor/nurse, farmer, administrative assistant, and sales and marketing than understood the careers of engineer or computer programmer.[11] When asked what kinds of courses they thought were required for IT jobs, a large majority of the students indicated that computer courses would be useful, only about 15 per cent indicated that mathematics courses were important, and less than 3 percent responded that science courses would be useful.

The attitudes of young people toward mathematics are related both to their success in the subject and to their age, and these affective issues (including beliefs, attitudes, and emotions) influence both teaching practice and student learning in mathematics.[12] Surveys and analysis of test

[10]See, for example, U.S. Congress, Office of Technology Assessment. 1995. *Teachers and Technology: Making the Connection,* Washington, D.C.: U.S. Government Printing Office, p. 2; and Seymour, Liz, 2000, "Teachers Online but Disconnected," *The Washington Post*, March 18.

[11]Joint Venture: Silicon Valley Network. 1999. *Joint Venture's Workforce Study: An Analysis of the Workforce Gap in Silicon Valley*. San Jose, Calif.: Joint Venture: Silicon Valley Network.

[12]McLeod, Douglas B. 1992. "Research on Affect in Mathematics Education: A Reconceptualization," in *Handbook of Research on Mathematics Teaching and Learning*, Douglas A. Grouws, ed. New York: Macmillan.

scores of U.S. school children suggest that students who perform well in mathematics have a positive attitude toward the subject.[13] Recognizing the potential importance of affect, the goals of the national mathematics standards include helping students understand the value of mathematics and increasing student confidence.[14] Surveys conducted in the 1980s and 1990s indicated that U.S. students' attitudes toward mathematics and their confidence about the subject declined with age.[15] In 1996, the fraction of students who agreed with the statement, "I like mathematics" declined from 69 percent at grade 4 to 56 percent in grade 8 and further still to 50 percent at grade 12.[16]

Student attitudes regarding mathematics may decline with age for several reasons. In elementary school, mathematics is a major component of the curriculum, and the curriculum is relatively easy. However, in middle school and high school, mathematics becomes increasingly difficult. At the same time, students are given a broader array of courses and subjects to choose from. Given this wider array of choices and the increasing difficulty of science and mathematics courses, many older students prefer other subjects. For example, in the small sample surveyed in Silicon Valley, students indicated that they most enjoyed art, drama, and speech courses. A much smaller fraction (about 16 percent) of students indicated that they most enjoyed mathematics courses, computer science courses, or physical education courses, and less than 10 percent indicated that science classes were their favorites. When asked why art, drama, and speech were their favorite classes, the most frequent response was that the class was "fun," followed closely by "have strong interest."

Beliefs as well as attitudes may affect motivation to study, to work hard, and to achieve in mathematics (and computer science). Many Americans believe that learning mathematics results primarily from ability rather than individual effort and freely admit ignorance of the sub-

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[13]The relationship between attitude and achievement is complex, and current research suggests that there is not a direct causal relationship between the two. For example, Japanese students surveyed in the 1980s indicated that they disliked mathematics more than students in other countries, yet these students had very high mathematics achievement (McLeod, 1992, "Research on Affect in Mathematics in Education").

[14]National Council of Teachers of Mathematics. 1989. *Curriculum and Evaluation Standards for School Mathematics: Executive Summary.* Reston, Va.: National Council of Teachers of Mathematics.

[15]McKnight, C.C., F.J. Crosswhite, J.A.J. Dossey, E. Kifer, J.O. Swafford, K.J. Travers, and T.J. Cooney. 1987. *The Underachieving Curriculum: Assessing U.S. School Mathematics from an International Perspective.* Champaign, Ill.: Stipes Publishing Company.

[16]Mitchell, Julia H., et al. 1999. "Student Work and Teacher Practices in Mathematics." Washington, D.C.: U.S. Department of Education, Office of Educational Research and Improvement, March.

ject.[17] Several surveys conducted in the late 1980s indicated that U.S. students viewed mathematics as important, but difficult and based largely on memorization and on following rules. More recently, in 1996, the fraction of U.S. students who agreed that "everyone can do well in mathematics if they try," declined from 89 percent at grade 4 to only 50 percent by grade 12.[18] Such beliefs are not surprising in light of analyses that suggest traditional mathematics instruction has emphasized "low-level cognitive activity, such as memorizing and recalling, rather than high-level thinking, such as reasoning and problem-solving."[19] However, if students believe that most mathematical problems can be quickly and easily solved by following rules, they may be unwilling to persist in solving more challenging and unique problems.[20] Furthermore, cognitive studies have shown that negative student beliefs about mathematics are correlated positively with an inability to solve unusual problems.[21] Thus, current student beliefs—as well as the instructional and curricular approaches that reinforce such beliefs—may pose a barrier to developing the problem-solving, analytical, and reasoning skills that are essential to many types of IT work.

7.1.2 Higher Education—Baccalaureate

The discussion below focuses primarily on computer science in higher education. Such a focus is not intended to exclude discussion of other fields, such as information systems or computer engineering; however, in light of this report's focus on software-related fields (discussed in Chapters 1 and 2), it is the computer science discipline (which is broadly defined

[17]In 1989, the National Research Council called for changing the public's beliefs about mathematics, in *Everybody Counts: A Report to the Nation on the Future of Mathematics Education* (Washington, D.C.: National Academy Press).

[18]Mitchell, Julia H., et al. 1999. "Student Work and Teacher Practices in Mathematics." Washington, D.C.: U.S. Department of Education, Office of Educational Research and Improvement, March.

[19]Silver, Edward A. 1998. "Improving Mathematics in Middle School: Lessons from TIMSS and Related Research." Washington, D.C.: U.S. Department of Education, Office of Educational Research and Improvement.

[20]Schoenfield and Silver, cited in McLeod, Douglas B. 1992. "Research on Affect in Mathematics Education: A Reconceptualization," in *Handbook of Research on Mathematics Teaching and Learning*, Douglas A. Grouws, ed. New York: Macmillan.

[21]McLeod, 1992, "Research on Affect in Mathematics Education: A Reconceptualization." However, as always, correlation does not necessarily imply causation. Thus, correlations cannot establish whether students who feel positively about mathematics are able to solve unusual problems or whether an inability to solve unusual problems causes students to feel negatively about mathematics.

in a way that is intended to encompass associated fields such as software engineering) that speaks most directly to such workforce needs.

Content

As noted in Chapter 2, IT workers have many different types of backgrounds and many types of undergraduate education. However, formal education in computer science is often one important element of a good preparation for Category 1 IT work. Thus, before examining the supply of graduates with computer science degrees, it is important to look at the additional value that formal computer science education provides to IT workers.

The value of formal computer science education depends in part on the nature of the IT work in question. Category 2 work generally does not require the knowledge and skills provided by 4 years of college study in IT-related fields; however, those doing Category 1 work often require such knowledge for two distinct reasons.

One reason deals with short-term value, the second with long-term value. Formal computer science education provides knowledge and conceptual understanding that are relevant over a very wide range of applications. A person without formal computer science education may be able to undertake relatively small, but still useful, IT projects. And, because solving business problems often requires only basic solutions, these individuals can work in domains in which Category 1 IT professionals work. Indeed, in the early days of computing and information technology, an individual could go a long way inventing an entire system from scratch.[22] However, the power and utility of formal computer science education are seen—and needed—only in the context of much larger projects.

- Developers of programs to deal with "small" problems (e.g., with few variables) need not address issues of algorithmic complexity and how the run time of a program varies with the number of variables being addressed. But it is in the nature of some problems that the same algorithm applied to a larger number of variables will simply take too long, and changing from a slower processor to a faster processor will make essentially no difference at all. Someone with an understanding of algorithmic complexity will arrive at this conclusion much more rapidly, and is more likely to seek an alternative algorithm.

[22]These comments are echoed in Roberts, Eric, "Computing Education and the Information Technology Workforce," a white paper provided to the Committee on Workforce Needs in Information Technology, March 2000.

• Developers of programs that manipulate small amounts of data are not generally concerned with efficiency of memory use. For example, for many problems involving small amounts of data, the use of simple arrays is quite convenient and entails little overhead. But the use of arrays may well not scale to problems using large amounts of data, and linked lists or other methods of arranging data may be much more effective despite the overhead they entail. Techniques for using linked lists are more likely to be encountered in the course of a formal computer science education than in the course of reading language reference manuals.

• Developers of programs that are small or are intended for personal use are notorious for writing code that is undocumented and difficult to understand. Techniques for documenting programs and enhancing maintainability become essential for large programs and systems, and these techniques are likely to be encountered in the course of an individual's first team-based or project-based effort, whether in school or on the job.

It is possible for individuals lacking formal computer science background to do "small" or "basic" projects in or with information technology. But, as the above examples illustrate, when business requirements and problems involve more complex or larger solutions, individuals with formal computer science education become more valuable. Moreover, successful software projects now require much greater attention to project management and software engineering skills. These skills are taught and developed in formal IT undergraduate programs, and few individuals are likely to discover them on their own.[23]

The long-term value of formal computer science education is encapsulated in the old saying about giving a man a fish versus teaching him to fish. Although young relative to other disciplines, computer science has matured over the past 25 years, and today it is not simply a collection of isolated bits of knowledge. Over time, computer science course offerings have reflected a growing emphasis on theory, expansion of advanced topics, and differentiation of subfields. There is less emphasis on particular current technology and more on fundamentals.[24] As a result of this evolution, current computer science education provides the core knowledge and abilities needed for IT work to a much greater extent than the computer science education of 25 years ago. Thus, recognizing that current IT graduates can handle a wide variety of challenges, some current IT

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[23]Roberts, 2000, "Computing Education and the Information Technology Workforce," white paper.

[24]Adelman, Clifford. 1997. *Leading, Concurrent, or Lagging: The Knowledge Content of Computer Science in Higher Education and the Labor Market*. Washington, D.C.: U.S. Department of Education.

managers report that they would probably not hire themselves today, because they themselves lack the levels of education and/or experience now required.[25] Today, a computer science degree imparts to students a deeper, more robust understanding of these fundamentals than would be generally possible without the benefit of formal education.

With this understanding, today's computer science graduates can approach product development in a more systematic manner. Often, when students receive undergraduate degrees from institutions with graduate research programs in computer science, they are exposed to promising technologies that will appear on the market in a relatively short time. And knowledge of fundamentals facilitates the learning of new technical skills—for example, understanding the concepts underlying object-oriented programming is an enabler for learning any new object-oriented programming language.

Just as today's IT graduates have skills needed by current labor markets, so also, according to one study, was that the case in the early 1990s. A survey of computer science graduates who entered IT occupations during the first half of the 1990s found that they spent much of their working time doing online computing and developing software.[26] An analysis of the actual course transcripts of these workers while they were enrolled in computer science majors indicated that the subjects they studied had prepared them well for these activities.

Although one recent study has suggested that most employers do not view a 4-year degree as an important factor when hiring,[27] employers appear to place a high value on formal IT credentials in many instances. For example, software companies often recruit quite intensively at computer science departments in top colleges and universities.[28]

Computing professional societies have helped to enhance the quality of formal computer science education. They have developed "model

[25]Salzman, Hal, "Information Technology Labor Markets," commissioned paper prepared for the Committee on Workforce Needs in Information Technology, 2000. Note also that U.S. employers generally are requiring more extensive educational credentials, although the skill requirements of jobs have increased only slightly (Barton, Paul. 2000. "What Jobs Require: Literacy, Education, and Training, 1940-2006." Princeton, N.J.: Eductional Testing Service, Policy Information Center).

[26]Barton, 2000, "What Jobs Require."

[27]For example, when the ITAA conducted hundreds of interviews with hiring managers, it found that less than 20 percent mentioned college degrees as important qualifications (Information Technology Association of America. 2000. *Bridging the Gap: Information Technology Skills for a New Millennium.* Arlington, Va.: ITAA, April).

[28]Roberts, 2000, "Computing Education and the Information Technology Workforce," white paper.

curricula" and established criteria for accreditation of educational institutions. The Computer Science Accreditation Board (CSAB), cosponsored by the Association for Computing Machinery and the Computer Society of the Institute of Electrical and Electronics Engineers, has a solid track record in this area. Although some of the most well-established and highly regarded computer science programs are not accredited,[29] many institutions with newer programs have become accredited. As these newer programs have followed the CSAB curriculum guidelines and met other criteria for accreditation, their quality is believed to have improved. Thus, model curricula and accreditation are tools for improving institutional programs and raising the standards of formal computer science education.

At the same time, the fact that their graduates are in high demand does not mean that academic programs in computing are doing everything right.[30] Academic departments in computer science and related disciplines are often criticized for a variety of perceived weaknesses, such as the following:

- Devoting too much attention to theoretical topics with little practical application;
- Allowing curricula to become out of date with respect to technological advancements in the field;
- Providing students with far too little experience in the practical techniques of building large systems;
- Offering poorly designed introductory courses that do not attract good students into the discipline; and
- Failing to place sufficient emphasis on the nontechnical abilities that students need to work effectively in the field, including communication skills, management strategies, and the dynamics of working in a group.

As a rule, these criticisms point to a remaining gap between the academic curriculum and business practice, a point discussed at greater length in Section 7.3.

Finally, it is worth noting that college-level mathematics study almost inevitably begins with the study of calculus. While opportunities for

[29]Colleges and universities do not always seek accreditation of educational programs such as computer science that do not require a license to practice. They generally weigh the costs of accreditation against the benefits in terms of the perceived value accreditation will add to the degrees they award (Adelman, 1997, *Leading, Concurrent, or Lagging? The Knowledge Content of Computer Science in Higher Education and the Labor Market*).

[30]Roberts, 2000, "Computing Education and the Information Technology Workforce," white paper.

studying the mathematics most related to IT work are much more plentiful at the college level than at the high school level, students who take only a year of college mathematics are much more likely to have studied calculus than discrete mathematics. First-year mathematics courses that emphasize the mathematical topics needed for IT work may facilitate further study in IT more effectively than would courses in calculus.

Supply

Specialized baccalaureate education in IT plays a large role in preparing individuals for Category 1 IT occupations, such as systems analysts and computer scientists. Today, two tracks are common: a 4-year undergraduate degree in an IT-related field such as computer science, management information systems, or computer engineering and a 4-year degree in a technical field (e.g., electrical engineering, physics, mathematics) with substantial IT preparation. Less common are concentrated programs in IT for individuals already possessing bachelor's degrees. For example, George Mason University in Northern Virginia is just one of a few 4-year institutions that have begun to offer short "Transition to IT" curricula aimed at students who will have (or already have) a bachelor's degree in a non-IT field. Further, formal computer science education need not be limited to degree programs in computer science at all. Colleges and universities can also infuse IT throughout many different departments and courses, with the effect of helping those not receiving IT degrees to work in IT.

Among these tracks and alternative approaches, 4-year programs in IT fields provide the most focused preparation for future Category 1 IT workers. Over the past three decades, the overall educational qualifications of the IT workforce have increased as a growing proportion of positions have been filled with graduates who hold specialized IT degrees. For example, the supply of computer science graduates[31] grew dramatically between 1976, when fewer than 6,000 degrees were awarded, and 1986, when nearly 40,000 students graduated.[32] In the late 1980s, the number of new graduates fell and then held constant for the early 1990s, a time coinciding with a relative downturn in the IT sector. New undergraduate enrollments in U.S. and Canadian computer science and computing engineering programs grew rapidly from 1995 through 1997, but

[31]Civil engineering and electrical engineering programs have also grown rapidly and provide another important source of graduates with specialized IT skills.

[32]Adelman, 1997, *Leading, Concurrent, or Lagging? The Knowledge Content of Computer Science in Higher Education and the Labor Market.*

then fell and increased only slightly during the 1999-2000 academic year.[33] In 2000, an estimated 42,000 bachelor's degrees in computer science will be awarded by U.S. and Canadian institutions.[34]

As graduation rates for computer science majors have fluctuated, employers have used college graduates from a variety of disciplines to do Category 1 work. For example, in the early 1990s, only one-third of Category 1 IT workers (tabulated by Current Population Survey/Occupational Employment Survey) with bachelor's degrees had received those degrees in computer science or information science. The most common other majors were business management (28 percent) and engineering (12 percent). The majority of new graduates entering IT obtained degrees in other areas. Even as employers filled IT positions with nonspecialized college graduates, many graduates who did have IT degrees entered other fields.[35] More recently (in the late 1990s), and likely in response to the same strong demand, more computer science degree holders (around 90 percent) appear to be entering IT jobs. The availability of more workers with specialized degrees is likely to support employers' preference for formal IT education when they are hiring individuals to perform Category 1 work.

Given that U.S. demand for workers capable of performing Category 1 work is projected to grow on the order of 8 percent per year through 2008, it will be important for institutions to develop ways of increasing the number of students with some formal education in computer science, such as through baccalaureate programs, minors, and areas of concen-

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[33]Irwin, Mary Jane, and Frank Friedman. 2000. "Ph.D. Enrollment Levels Off: M.S. and Undergrad Continue to Rise," *Computing Research News*, March. Although undergraduate CS enrollments grew 10 percent in 1999-2000 compared to the previous year, this average growth was almost entirely due to the dramatic 99 percent increase in CS enrollments at Canadian institutions.

[34]Irwin and Friedman, 2000, "Ph.D. Enrollment Levels Off: M.S. and Undergrad Continue to Rise." These data are based on an annual survey of Ph.D.-granting departments, which projects 13,883 bachelor's degrees in both computer science (CS) and computer engineering (CE) during academic year 2000. Although both CS and CE departments were surveyed, the response rate from CE departments has been low in recent years, making the 13,883 number a more accurate measure for CS than for CE graduates. Historically, bachelor's degrees awarded by Ph.D.-granting departments have made up about one-third of all such degrees awarded nationally, yielding the estimate above of 42,000 CS graduates in the year 2000. Another data source—the National Center for Education Statistics' "Digest of Education Statistics 1999"—indicates that there were 219,000 computer science majors in academic year 1995-1996. If one-fourth of these were freshmen, and half of the freshmen successfully completed their degrees, the result would lead to a smaller estimate of 27,000 graduates in 2000.

[35]As noted in Chapter 2, 29 percent of those graduating with an IT-related bachelor's degree in 1993 took jobs outside the Category 1 IT workforce. By 1997, this fraction had diminished to 25.5 percent.

tration. Such an increase depends on two factors—the availability of resources for educational institutions to teach additional students, and adequate preparation and interest in IT in a sufficient number of additional students.

The first factor involves resources. Today, resources (e.g., faculty, space, and possibly research funding) to support additional student enrollment in IT-related fields is likely more of a limitation than student interest in obtaining such degrees.[36] Though the resources flowing to IT-related departments are increasing, university administrators are often hesitant to agree to a significant growth of regular IT-related faculty. Rapid growth in any one department upsets traditional balances among departments, and institutions may be reluctant to rapidly increase the number of tenured IT professors, who might not be needed if a downturn in demand were to occur. Because of these factors, it is unlikely that IT-related departments will be able to grow by as much as a factor of 2 over the next decade. Thus, even if qualified faculty were available, inadequate space and computing facilities would be a bottleneck to rapid growth. A second reason is that universities are having difficulty in attracting and retaining qualified computer science faculty; Box 7.2 describes some ways to find additional faculty to teach in IT-related fields.

The second factor involves the availability of additional qualified and interested students. As noted above, many young people lack information about IT careers and about education needed to prepare for such careers. Although public and private groups are attempting to fill this void,[37] more could be done to provide guidance about IT careers. Attracting more students from underrepresented populations by providing them with the financial resources needed to attend college and graduate school is another approach.[38] The approaches used to attract students to IT

[36]An informal survey of the Forsythe list, consisting of all of the Ph.D.-granting institutions in computer science and computer engineering (most of which have undergraduate programs), suggests that lack of resources is the primary constraint on rapid increases in the production of new computer science majors. The committee inquired about "the rate-limiting factor on [the] department's ability to produce recipients of bachelor's degrees in computer science or computer engineering." The answers to this survey indicate overwhelmingly that resources, including instructors, professors, computers, and classroom facilities, are the rate-limiting factor, rather than the supply of interested and qualified students. The list includes some 200 institutions, and 80 or so answers were received.

[37]For example, the ACM's Committee on Women in Computing works with Girl Scout troops to spark interest in IT among young women, and the U.S. Department of Commerce has announced plans for a major advertising campaign to encourage teenagers to choose IT careers.

[38]For example, the Gates Foundation has donated $1 billion to support scholarships for minority students pursuing undergraduate and graduate degrees in science, math, engineering, education, or library science. See <www.gmsp.org>.

BOX 7.2
Complements to Regular Tenure-Track Faculty

- The use of adjunct faculty can supplement regular faculty. Though space (especially laboratory space) remains an issue, adjunct faculty can be engaged without long-term commitments, about which university administrators are nervous. Adjunct faculty drawn from industry have the additional advantage that they bring to the classroom substantial real-world business experience that provides valuable context for what students learn. And, by engaging IT professionals from industry, universities can begin to build stronger connections to potential employers of their students.[1]
- Contract teaching faculty can be employed on a full-time but nontenurable basis. These individuals have no formal research duties and devote their entire university time to teaching. The fact that they operate on long-term contracts provides some stability for them, and also allows some accountability to students and administration as well.
- Other, non-IT departments can hire faculty with IT backgrounds combined with other backgrounds. In a sense, computer science may become similar to mathematics in the 21st century, with departments in science and engineering (and elsewhere) using and teaching computer science applications. This is beginning to happen in some institutions. For example, the MIT aeronautics department is expanding into a "systems" department with an IT track. Cornell University is considering the creation of a school built around the computer science department with up to 10 joint appointments. Institutions that take such approaches can use faculty based in non-IT departments to do some of the teaching. Students graduating from these programs will be able to bring to their employment strong IT skills as well as substantive knowledge about important areas of application.

[1]The use of adjunct faculty can have downsides as well. For example, many believe that because the primary commitments of adjunct faculty do not lie with the educational institution, their students may well receive short shrift compared to the attention they might receive from regular faculty. To the extent that adjunct faculty rotate rapidly through the institution, students in later years do not receive the benefits of greater classroom seasoning in their teachers—adjunct faculty have less incentive to be responsive to student needs. Another serious issue is that adjunct faculty themselves may well be hard to find. If they come from the IT sector, the demand for them in the higher-education setting is likely to be greatest just at the time when they are busiest in their "day" jobs. Moreover, the pay offered such teachers is usually rather low, and many adjunct professors teach primarily for the intellectual stimulation and change of pace that the pedagogical setting offers. Finally, heavy reliance on adjunct faculty can have a significant effect on the administration of a program because there are fewer staff to do advising, searches for new faculty, plans for the future, and so on.

majors by historically black colleges and universities may provide useful lessons for other colleges and universities. Between 1989 and 1996, the fraction of graduates from majority U.S. colleges and universities majoring in computer science has been about half of the comparable rate from the historically black colleges and universities (Box 7.3). This fact suggests that higher rates of production are possible, not just for minority students, but for all students.

Of course, the issue is not only attracting more students, but also ensuring that interested students have the background necessary to study computer science. While many computer science educators believe that today's computer science students are, on average, adequately qualified for the departments' undergraduate programs,[39] it is likely that these students have better mathematics and science backgrounds than the average college student. Thus, although colleges and universities can likely generate a moderate increase in the number of computer science students through increased information and awareness about a career in IT, it will likely be difficult for them to generate a large increase without a simultaneous effort to improve the students' preparation for such studies. Such an effort would preferably be made at the high school level, as discussed above, but the models offered by the historically black colleges and universities also offer promising examples for other institutions.

Assuming an adequate supply of students qualified for and interested in studying IT-related fields, another way to increase the numbers of students who study IT is to increase the number of colleges and universities that offer computer science majors. Throughout the first half of the 1990s, just over 1,000 institutions offered degrees in computer or information science (out of a total of about 4,000 institutions in the United States).[40] However, because the total number of U.S. colleges and universities that offer a general program is limited, it is unlikely that the total number of institutions offering computer science degrees could be increased by more than 20 per cent.[41]

For the foreseeable future, demand for individuals with CS degrees is likely to outstrip supplies of such graduates. However, because an individual's exposure to formal CS education is more important than a degree per se, relying on the number of domestic computer science degree recipients as the sole predictor of new entrants to the IT field is unwise as

[39]Based on results from a survey of the Forsythe list, which consists of all of the Ph.D.-granting institutions in computer science and computer engineering (most of which have undergraduate programs).

[40]Korb, Roslyn A., and Austin F. Lin. 1999. "Education Statistics Quarterly: Postsecondary Institutions in the United States: 1997-98." National Center for Education Statistics, Integrated Postsecondary Education Data System, Fall. This source identifies 4,096 institutions as eligible for Title IV programs and that grant degrees.

[41]For example, in 1994-1995, 1,248 schools granted B.A.s in English and 1,383 offered degrees in business management out of a total of 1,855 4-year institutions in the United States. See Computing Research Association. 1999. "The Supply of Information Technology Workers in the United States." Washington, D.C.: CRA, Chapter 5.

BOX 7.3
Lessons in Promoting IT-Related Study from Historically Black Colleges and Universities

What might account for the differences in the fraction of science, engineering, and IT-related graduates between historically black colleges and universities (HBCUs) and their majority counterparts?

Note that the interesting question suggested by Table 7.3.1 does *not* compare minority students at HBCUs to minority students at majority institutions; rather, it suggests a possible difference between the ways in which HBCUs and majority institutions approach the subject of attracting and retaining *all* students to science, engineering, and IT-related degree programs.

It may be true that the student population attracted to HBCUs is generally more professionally oriented than those drawn to majority educational institutions. Such an orientation would naturally lead to a preference for majors in the scientific and engineering disciplines, including computer science and other IT-related fields. At the same time, a substantial fraction of students attending majority institutions who express an interest in science or engineering majors do not complete their degrees in such fields.[1]

To understand what HBCUs might be doing differently than majority institutions to attract and retain students in computer science majors, it is useful to understand the traditional "pipeline" model on which much of science education is based. In this model, students pass through a series of barriers, designed to filter out individuals who are incapable of studying science at the next level of sophistication or advancement. At the end of the process, those who remain are those who are "fit" to enter the profession.[2]

The model employed by HBCUs (and a number of other institutions as well) is quite different. Rather than emphasizing the filtering process, the HBCU model stresses inclusion. Thus, the model calls for extensive outreach, mentoring, and

[1]National Science Foundation. 1998. *Science and Engineering Indicators*. Arlington, Va.: National Science Foundation, p. 2-16.

[2]See, for example, Tobias, Sheila. 1990. *They're Not Dumb, They're Different: Stalking the Second Tier*. Tucson, Ariz.: Research Corporation.

TABLE 7.3.1 Differences in the Number of Science, Engineering, and IT-related Graduates at Historically Black Colleges and Universities and Majority Institutions

	1989	1990
Majority-only institutions: Bachelor's degrees in all disciplines	1,010,423	1,042,214
CS bachelor's degrees	29,756	26,652
CS degrees as a percentage of all degrees	2.9%	2.6%
HBCUs: Bachelor's degrees in all disciplines	19,748	19,937
CS bachelor's degrees	1,207	1,043
CS degrees as a percentage of all degrees	6.1%	5.2%
Ratio of HBCU percentage to majority percentage	2.08	2.05

SOURCE: Data from National Science Foundation (see <http://www.nsf.gov/sbe/srs/srs99410/>).

continuing support from the institution as a whole as well as mechanisms for students to obtain support from their peers. Students are not left to fend for themselves, as might be implied by a pipeline model; instead, students who may be in academic difficulty are sought out and intellectual, academic, and emotional support offered.

(It is useful to note that mentoring has been shown to help the recruiting and retention rates of women in computer science.[3] And, studies indicate that mentoring women is best done by other women.[4] Mentors can take the form of senior computer scientists, junior computer scientists, or peers. For example, a successful mentoring program[5] matched female faculty with female graduate students, graduate students with undergraduate female students who were considering graduate studies, and local alumnae with the female undergraduate students who were not planning on continuing their academic careers. The goal of the mentoring relationships was to retain the women students as CS majors. Establishing mentoring relationships in this way allowed women at each level to be in contact with women at higher levels. In addition, graduate and undergraduate students reap the rewards of being mentors themselves, e.g., increased self-confidence.)

The essential elements of this inclusive approach have been documented in a number of reports. But the HBCU experience provides at least an indication that a systematic application of this more inclusive approach may have far-reaching effects on the production of computer science graduates across the board.

[3]Sturm, D., and M. Moroh. 1994. "Encouraging Enrollment and Retention of Women in Computer Science Classes," *Proceedings of the National Education Computing Conference,* pp. 267-271.

[4]Sturm and Moroh, 1994, "Encouraging Enrollment and Retention of Women in Computer Science Classes"; Pearl, A., M. Pollock, E. Riskin, B. Thomas, E. Wolf, and A. Wu, 1990, "Becoming a Computer Scientist," *Communications of the ACM* 33(11):47-57.

[5]Walker, E., and S. Rodger. 1996. "PipeLINK: Connecting Women and Girls in the Computer Science Pipeline," *Proceedings of the National Education Computing Conference*, pp. 378-384.

SOURCE: This description of the HBCU approach is based on discussions with Samuel Meyers, Sr., Minority Access Inc., in April 2000.

1991	1992	1993	1994	1995	1996
1,086,334	1,126,471	1,153,105	1,155,673	1,146,064	1,150,044
24,521	23,931	23,401	23,413	23,522	23,257
2.3%	2.1%	2.0%	2.0%	2.1%	2.0%
21,663	23,601	26,173	27,468	28,372	29,771
889	923	1,076	1,045	1,140	1,148
4.1%	3.9%	4.1%	3.8%	4.0%	3.9%
1.82	1.84	2.03	1.88	1.96	1.91

a matter of policy. Indeed, it is likely that employers will continue to fill many IT jobs with individuals lacking IT degrees as they have in the past, though they may well expect or require more formal CS education in these individuals than they did previously.

Finally, because of concerns raised in the United States about the influx of temporary nonimmigrant foreign workers holding H-1B visas originating from India, it is helpful to draw a comparison to the system that has developed in India to produce graduates trained in IT-related fields (Box 7.4).

7.1.3 Higher Education—Postbaccalaureate

Students can reach the master's level through multiple tracks. In particular, individuals with bachelor's degrees in other areas (usually technical) can earn master's degrees in IT-related fields. Enrollment patterns during the 1980s led to an increased number of master's degrees from U.S. and Canadian institutions that became constant at about 10,000 for master's degrees. However, more new master's degrees have been awarded each year since 1997,[42] and an estimated 12,500 such degrees were awarded in 2000. New enrollments in master's programs have increased dramatically over the past 2 years (24 percent in 1998-1999 and 26 percent in 1999-2000), so that more graduates can be expected.

In contrast to continuing growth in the production of master's degrees, the rate of Ph.D. production for U.S. and Canadian institutions has been essentially constant (approximately 1,100 per year) throughout most of the 1990s; the number of new Ph.D. graduates is expected to be 1,167 in 2000. Further, available data do not indicate that there will be significant increases in the number of Ph.D.'s awarded, as the enrollment in doctoral programs has leveled off.

The academic research enterprise in IT continues to be strong, but industry and academia are competing for the same small pool of highly productive, creative individuals.[43] Ph.D. production and faculty recruitment and retention are both threatened by the lure of the commercial sector. Some faculty and graduate students are leaving academia for better-compensated positions in industry; others leave because only industry (especially start-ups supported by venture capital) offers them the oppor-

[42]Irwin and Friedman, 2000, "Ph.D. Enrollment Levels Off: M.S. and Undergrad Continue to Rise." As noted above, the low response rate from CE departments suggests that 12,500 is more accurate as an indicator of the number of CS master's degrees than as an indicator of both CS and CE master's degrees awarded.

[43]Roberts, 2000, "Computing Education and the Information Technology Workforce," white paper.

tunity to pursue their intellectual and research interests. (All levels of higher education are threatened, but since Ph.D. students are so much smaller in number than others, the problem is most obvious at this level.) One recent survey found that, during 1997-1998, only about half of the open tenure-track positions were filled.[44] And, compared to the benefits to be found in industry and start-ups, academic life—with the attendant burdens of low salaries, teaching, and the need to obtain grant support—is increasingly seen as unattractive to many graduate students. The long-term significance of these perceptions is at present unclear, but they do not bode well for the long-term health of the IT field. This is sometimes referred to as a "seed corn" problem, because the commercial sector is taking away the young talent (the "seed corn") that would otherwise be used to train or "grow" a new generation of IT workers.

To some limited extent, Ph.D. degrees in computer science are not necessary to teach all courses in computer science at the undergraduate level. Just as faculty with backgrounds in psychology and engineering teach (applied) statistics courses, faculty in other departments can teach, for example, certain types of programming, or can help to team teach courses requiring cross-disciplinary work. And, of course, many existing faculties of computer science have senior individuals whose academic work predated formal computer science degrees. Nevertheless, the intellectual structure of computer science tends to be best taught by those who do have a formal background in the field.

A potential complicating factor is the increasing presence of foreign nonresidents enrolled in master's degree and doctoral programs in computer science in the United States. Compared to U.S. students, foreign students have particular incentives to enroll in U.S. graduate programs in IT-related fields. A student F visa is relatively easy to obtain and often provides a route to employment in the United States on an H-1B visa. Thus, U.S. graduate education can be an easy way for a foreign student to obtain a position in the United States that can pay much more than jobs in his or her home country. In addition, foreign students may be able to obtain support from their home countries for a master's program. And, because professorial positions tend to be more highly respected in many foreign countries than in the United States, foreign students may be more inclined to pursue Ph.D.s that are an essential prerequisite to such positions.

NSF data indicate that foreign students accounted for about 26 percent of all master's degrees awarded in 1985 in math, computer science,

[44]Roberts, 2000, "Computing Education and the Information Technology Workforce," white paper.

BOX 7.4
IT Education Policy in India

In India there has been a strong educational tradition for many centuries. Since independence from the British, India has invested heavily in education at all levels. Enrollment at the college level has reached about 6 million, comprising about 5 percent of the 17 to 23 age group.

IT Education at the College Level

The educational system in technical subjects (and generally) in India is highly stratified:

- At the top are the five elite Indian Institutes of Technology (IITs), providing about 3,000 places per year. Entrance is extremely competitive. In IT fields nearly all graduates go to the United States for further education or employment.
- At the next level down, there are 17 Regional Engineering Colleges (RECs). Again, entrance is extremely competitive. REC graduates who did not major in computer science and who wish to switch to computer science must pursue post-graduate degrees abroad or enroll in private schools.
- Private engineering colleges where the fees could be as high as $10,000 for 4 years (note: a dollar buys in India many more times what a dollar buys in the United States). The quality of student is not as good as those in the RECs; moreover, admission is based on ability to pay rather then just academic performance. The quality of student in the first-tier colleges is still good, however.
- State engineering colleges offering 4-year courses. Here there are problems of quality even for those who graduate in computer science.
- Private training institutes such as NIIT (National Institute of Information Technology) and Aptech. These for-profit institutes offer 6-month courses (and longer) in IT. The quality of the graduates is very diverse. In the main, Indian IT companies do not generally hire graduates from these institutes or from the second- and third-tier state and private engineering colleges.

The number of places at the IITs and the RECs is set by the national government. The numbers have not been very responsive to the marketplace—the number of computer science slots has not been expanding much in recent years.

Since the late 1980s, India has graduated annually about 155,000 English-speaking engineering and science graduates; in addition, 200,000 diplomas are awarded each year.[1] About 60,000 of this total pool are degree and diploma holders in IT, of which 16,000 come from premier institutions.[2]

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[1]Estimates from Arora, A., V.S. Arunchalam, J. Asundi, and R. Fernandes, Carnegie Mellon University, "The Indian Software Industry," unpublished paper.

[2]Roy, Atanu. 1998. "Which Course '98: Tingle in the Training Mall," *Computers Today*, May 1.

It is not clear whether the abundance of IT workers in India can be attributed to government policy. Indeed, Arora et al. believe it is somewhat serendipitous. They write, "The Indian success story has, for the most part, been a combination of resource endowments (created in part by a policy of substantial investment in higher education), a mixture of benign neglect and active encouragement from a normally intrusive government, and good timing."[3] The lack of opportunity for science and engineering graduates outside the IT sector and IT-intensive industries has encouraged a migration of non-IT graduates toward the growing Indian IT industry and the IT opportunities in the United States. There has also been considerable private sector investment in education through private engineering colleges, private training, institutes and Authorized Training Centers (see below).

Recent Developments

There have been several recent developments whose impact on IT education in India is probably too early to assess:

- The Indian government has carried out a major study on the Indian IT industry (<http://it-taskforce.inc.in>) and has made recommendations in a wide range of areas including education.
- The government has established Indian Institutes of Information Technology, similar to the IITs.
- Some engineering colleges (e.g., in Bangalore; *The Hindu*, April 28, 2000) have increased their emphasis on information technology.
- A number of major IT companies (e.g., IBM, Microsoft, Oracle) have set up Authorized Training Centers. Some of these are located close to the new Indian Institutes of Information Technology.

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[3]Arora et al., Carnegie Mellon University, "The Indian Software Industry," unpublished paper.

SOURCES: Arora, A., V.S. Arunchalam, J. Asundi, and R. Fernandes, Carnegie Mellon University, "The Indian Software Industry," unpublished paper. Salzman, Hal, with Radha Roy Biswas, University of Massachusetts-Lowell, "The Indian IT Industry and Workforce," commissioned paper prepared for the Committee on Workforce Needs in Information Technology, March 2000.

and engineering, 30.1 percent in 1991, and 33 percent in 1993 and thereafter (through 1996). The comparable figures in all science and engineering categories (including social sciences) are 19.3 percent, 23.4 percent, and 24.7 percent.[45] Data from the 1998 Taulbee survey (covering a more restricted but also more elite group of educational institutions) indicate that 40 percent of CS and CE Ph.D.s and 49 percent of CS and CE master's degree recipients were awarded to nonresident aliens.[46] If these individuals return to their home nations, their expertise becomes unavailable to the U.S. workforce; if they do not, they count against various quotas for nonresident workers.

The large proportion of foreign students at the postbaccalaureate level has sometimes raised concerns that foreign graduate students are keeping qualified U.S. students out of graduate programs. Systematic data related to this issue are unavailable, but anecdotal evidence suggests that the relatively low fraction of U.S. students in graduate programs is due largely to their lack of willingness to go to graduate school immediately after graduation instead of accepting a position in industry.[47]

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[45]By contrast, the fraction of bachelor's degrees awarded to foreign students has been about 7 percent of all the bachelor's degrees awarded in math, computer science, and engineering, compared to about 3.7 percent of all bachelor's degrees awarded in all science and engineering categories (including social sciences). At the doctoral level, foreign students have accounted for between 45 percent and 51 percent of all doctoral degrees in math, computer science, and engineering. The corresponding range for all science and engineering categories (including social sciences) is 25.7 percent to 34.9 percent, but in neither case is there a clear trend in the data (which for doctoral degree recipients ends in 1997). See National Science Board. 2000. *Science and Engineering Indicators—2000*. Arlington, Va.: National Science Foundation, Appendix Tables 4-35 (bachelor's), 4-38 (master's), and 4-39 (Ph.D.).

[46]These figures may understate the fraction in the nonresident alien category. Freeman and Aspray, commenting on the 1994 Taulbee survey, point out that this category is supposed to include only domestic students with these backgrounds, but that in 1994 the numbers (around 17 percent) looked "unusually large to the computer scientists responsible for managing the survey" and that some of these students may be Asian-Pacific Island foreign nationals on visas. See Freeman, Peter, and William Aspray. 1999. *The Supply of Information Technology Workers in the United States*. Washington, D.C.: Computing Research Association. Available online at <www.cra.org./reports/wits/>, p. 91, n. 70.

[47]For example, a spot check at MIT indicated that foreign applications for computer science graduate programs in 1999 accounted for 46 percent of all applications to these programs but only 30 percent of the admissions. At the University of Washington, foreign applications for computer science accounted for 71 percent of applications, but only 37 percent of admissions. While the exact figures at MIT and the University of Washington might not be characteristic of other institutions, the relationship of applications to admissions is likely to be similar at other comparable schools. Assuming that foreign students and U.S. students are of comparable average quality, the pattern provides some evidence that foreign students are not displacing U.S. students from graduate programs.

Indeed, there are nontrivial disincentives, at least in the short term, for U.S. students pursuing postbaccalaureate study in IT. Support for postsecondary education is much more available at the bachelor's level (e.g., Pell grants, school-sponsored loans) and at the doctoral level (e.g., fellowships, graduate assistantships) than at the master's level, for which little support is available. Families may budget for 4 years of undergraduate work, but as a rule, they do not do so for the extra year or so that it takes to obtain a master's degree. Thus, master's level graduate work may not be within the immediate financial means of many students. Furthermore, individuals wishing for their work to have an immediate impact have a much better opportunity to realize these wishes by working in the private sector (where ideas can be turned into products and services and applications rapidly) rather than by attending graduate school.

A comparison of cumulative earnings also sheds some light on these disincentives, at least from a financial point of view. Data from the National Association of Colleges and Employers indicate that in 1999, the average starting salary offer for individuals with bachelor's, master's, and doctoral degrees in computer science was $44,469, $51,438, and $58,688, respectively. Assuming that tuition and fees for a 1-year master's program total $20,000 and that annual salary growth for both bachelor's and master's degree holders is 5 percent, the total earnings for holders of these degrees equalizes in about 10 years. Assuming a fully supported 5-year doctoral degree (effectively tuition and fees totaling zero), the total earnings equalize in about 50 years.

This model suggests that under some plausible assumptions, the financial benefits to advanced study are realized only in the long run if at all. However, it is important to emphasize that this rough calculation is based on many assumptions that may not be true in practice (e.g., identical wage growth profiles for all degree holders, no discount being applied to earnings that appear farther in the future, compensation identical to base salary).

7.1.4 Higher Education—Community Colleges

The 1,700+ community colleges of the United States are important in American higher education and play a key role in preparing many students for the workplace.[48] About 40 percent (5.6 million) of all individuals enrolled in higher education in the fall of 1997 (a total of 14.5 million)

[48] U.S. Department of Education, National Center for Education Statistics. 2000. *Digest of Education Statistics, 1999, NCES 2000-031,* Thomas D. Snyder and Charlene M. Hoffman. Washington, D.C.: U.S. Government Printing Office. Note that the terms "2-year" and "community college" are used interchangeably in this report.

were attending degree-granting 2-year colleges. Because students attend community colleges for a variety of reasons, the majority of 2-year students (about 75 percent) never complete an associate's degree.[49] About 30 percent transfer to 4-year institutions, some fail and/or drop out, and still others take only a few job-related classes.

Community colleges play a large role in educating adults, as well as full-time younger students. For example, during the 1995-1996 school year, 71 percent of 4-year students were under 25, only 17 percent were 25 to 34, and just 12 percent were over 35 years old. In contrast, slightly less than half of students enrolled in 2-year (and less than 2-year) colleges were under 25, 27 percent were 25 to 34, and about one-quarter were over 35.[50] Reflecting the need of older students to work, the majority of community college students (63 percent in the fall of 1997) enroll part-time.

Community colleges play a large and growing role in preparing their students for Category 2 IT work, and for some types of Category 1 work as well.[51] In addition to enrolling growing numbers of younger, full-time students in computer science and related fields, community colleges are training working adults for IT careers. For example, in a recent survey, more than 100,000 2-year college students enrolled in both credit and noncredit classes were asked about their background and their goals.[52] About 18 percent of all respondents enrolled in for-credit courses (leading to an associate's degree) said that gaining computer or technological skills was a major reason for enrolling. Compared to the average age of all 2-year students, the survey respondents who were seeking IT skills were quite a bit older: 24 percent were 26 to 39 years old, 32 percent were 40 to 59, and 35 percent of students were 60 or older. The survey results also suggest that community colleges are playing a growing role in retooling college graduates for IT careers: Twenty-eight percent of students in noncredit courses had already earned bachelor's, master's, or doctoral degrees. (Many IT certification programs are offered on a noncredit basis, as discussed further below.)

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[49]Halperin, Sam, ed. 1998. *The Forgotten Half Revisited: American Youth and Young Families, 1988-2008.* Washington, D.C.: American Youth Policy Forum.

[50]Halperin, 1998, *The Forgotten Half Revisited.*

[51]For example, CPS data indicate that, in 1996, 10 percent of computer programmers had a 2-year degree. United Engineering Foundation, "IT Workforce Data Project," available online at <http://www.uefoundation.org/itworkfp.html>.

[52]Lords, Erik. 2000. "Many Students Are Returning to 2-Year Colleges for Technical Training, a Survey Finds," *Chronicle of Higher Education,* April 5.

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Between roughly 1970 and 1990, community colleges increasingly focused their computer science majors on computer programming and applications. Adelman[53] compared courses taken by two different cohorts of high school graduates who went on to earn associate's degrees in computer science. Those who studied at community colleges earlier (graduating from high school in 1972 and in 1984) took a broader course of study in community colleges than those who graduated from high school a decade later. The more recent cohort of students spent more of their time on computer science, mathematics, and business subjects, with especially large increases in time spent on computer programming and applications. These courses were well-matched to the graduates' activities in the jobs they found after graduating.

However, this emphasis on business knowledge and applications did not follow the Association for Computing Machinery's 1993 guidelines, which called for spending more time on algorithms, data structures, software methods, and engineering/architecture. Adelman noted that, if community college students took more such courses, the graduates "would have greater flexibility in adapting to new programming languages and computer environments."[54] More recently and contemporaneously with the rise in importance of the Internet, community college curricula are placing more emphasis on network installation and support and Web development.

The Northwest Center for Emerging Technologies (NWCET) at Bellevue Community College in Washington State has developed comprehensive skill standards designed in part to ensure that current 2-year IT education matches the requirements of the labor market. The NWCET IT skill standards are based on clusters of IT occupations, using a general definition of IT work similar to that used in this report (Box 7.5).[55] The skill standards can be used to build curriculum modules, allowing community colleges to quickly expand their course offerings in IT disciplines. In addition, the modules allow state education agencies to align and articulate IT curricula from the high school level to community college, 4-year college, and university-level education (Box 7.6).

In recent years, the boundaries between 2-year and 4-year institutions, and between public and private training providers, have blurred

[53]Adelman, 1997, *Leading, Concurrent, or Lagging? The Knowledge Content of Computer Science in Higher Education and the Labor Market.*

[54]Adelman, 1997, *Leading, Concurrent, or Lagging? The Knowledge Content of Computer Science in Higher Education and the Labor Market,* p. 21.

[55]Northwest Center for Emerging Technologies, 1999, *Building a Foundation for Tomorrow: Skill Standards for Information Technology.*

BOX 7.5
IT Skills Standards from the Northwest Center for Emerging Technologies

The Northwest Center for Emerging Technologies (NWCET) at Bellevue Community College in Washington State led a recent effort to identify the broad skills, ability, and knowledge required for work in a broad range of IT occupations. With funding from the National Science Foundation and the State of Washington, NWCET developed initial skill standards in 1997. Information on the skills and abilities required in nine different "career clusters" (groups of occupations) was obtained through interviews, focus groups, and surveys of both workers and employers. Over the next 2 years, NWCET worked with national trade associations, educators, publishers, and others to validate and refine the initial skill standards. Panels of IT workers and managers in northern Virginia, in Springfield, Massachusetts, and in Silicon Valley provided feedback on the draft standards and identified new and changing skill requirements. Their input led to new draft standards, which were reviewed and validated through a survey of over 2,000 employers of IT workers. Finally, in 1999, NWCET released updated skill standards for eight career clusters.[1]

Following a job analysis system developed by the National Skill Standards Board, NWCET staff identified the broad job functions, or "critical work functions," required in many different jobs within each career cluster. To define skills more specifically, each critical work function was broken down further into "key activities." Based on managers' and workers' definitions of successful performance in each key activity, NWCET identified "performance indicators" for each. Next, job analysts identified the technical knowledge and the broader "employability skills" required for successful performance of the key activities and critical work functions. Examples are shown in Table 2.7 in Chapter 2, pp. 88 and 89..

[1]Northwest Center for Emerging Technologies (NWCET). 1999. *Building a Foundation for Tomorrow: Skill Standards for Information Technology.* Bellevue, Wash.: NWCET.

(see Section 7.1.5 below). For example, Carnegie Technology Education (CTE; a nonprofit subsidiary of Carnegie Mellon University) is a new educational institution that provides course content on the Internet, and partners with community colleges to deliver instruction. CTE's Software Systems Development curriculum seeks to incorporate not only the detailed skills and knowledge needed to work with today's technology, but also the fundamental underlying concepts.[56] All courses involve extensive hands-on assignments, a combination of principle and practice derived from the parent Carnegie Mellon School of Computer Science. To date, CTE's partner institutions include the Art Institute of Pittsburgh and the Community College of Allegheny County.

[56]For more information, see CTE's Web site at <http://www.carnegietech.org>.

BOX 7.6
Uses of NWCET IT Skill Standards in Secondary Schools and Community Colleges

Washington State policymakers supported the NWCET IT skill standards effort because they recognized that developing and delivering curriculum based on the modularized skill standards could significantly reduce the time required to get emerging technology trends into the classroom. This potential may be realized in several locations around the nation. For example, Maryland has developed a comprehensive technology education plan based in part on the NWCET skill standards and associated curriculum. The Maryland plan calls for a broad, integrated approach to IT education, with components in secondary school, community college, and university education, as well as internships. Wisconsin has developed a model youth apprenticeship program in IT, based on the NWCET modular curriculum. Because it includes broad, transferable skills and knowledge identified in the skill standards, this youth apprenticeship program provides the knowledge young people need if they decide to pursue further study in the state technical colleges.

The Oregon Software Association has worked with the state department of education to develop skill standards-based IT curricula for certificates of initial and advanced mastery for IT, using the NWCET curriculum, efficiently articulating programs from the high school to community college level. In addition, large secondary school and community college districts in California, Texas, Massachusetts, and Florida, with state support, have developed comprehensive systems of IT education based on the NWCET skill standards. These educational models include curricula and assessments designed to provide flexible, quality IT education at the high school and college level.

Supply

During the mid-1990s, about 10,000 associate's degrees in computing or information science were awarded each year, accounting for about 2 percent of all associate's degrees awarded nationally. Currently, the Computing Research Association estimates that about one-third of all U.S. community colleges award IT associate's degrees. This suggests that if demand for IT workers continues to grow rapidly, 2-year institutions might be able to increase the supply of formally educated workers in two ways. First, existing institutions might expand their IT course offerings, increasing enrollments and associate's degrees awarded. Second, more 2-year institutions might develop programs of study leading to associate's degrees in IT fields. In addition, as discussed in Section 7.1.5 below, community colleges could continue their rapid expansion of short-term courses leading to IT certification.

During the 1990s, the number of 2-year colleges awarding associate's degrees in computer science or information systems grew by about 15 percent.[57] Although more recent data are not available, it appears that, in response to both market forces and public policies, 2-year institutions are now in the process of quickly expanding their information technology programs. Many states have worked with their state software associations, technology committees, chambers of commerce, consortia of community colleges, and industry to initiate or augment IT programs. In addition, large IT vendors have partnered with 2-year colleges to develop industry certification programs for Category 2 workers, as discussed in Section 7.1.5 below.

One major constraint to the growth of IT programs in community colleges is a lack of qualified faculty. Community colleges cannot compete on the open market against industry for IT professionals to teach. Top starting salaries for community college instructors are often equal to what community college *graduates* are offered as starting salaries in private industry. Tenured community college faculty earn higher salaries, but might be able to earn twice as much for the same skills if they went to private firms. Furthermore, community college faculty are often unionized, with labor contracts specifying salary progressions, faculty rank, and tenure requirements. These contracts reduce the ability of community colleges to reduce, reassign, or add faculty in response to changing labor market demands.

Because 2-year colleges focus more on preparing people for employment than do 4-year institutions, they are generally more responsive to changing labor market demands. Nevertheless, community college administrators, like their counterparts in 4-year colleges and universities, tend to oppose very rapid increases in any one discipline. A typical community college may offer courses or programs in health occupations, skilled trades, arts and humanities, business, and science as well as technology. The technology program might include electronics, drafting, surveying, TV production, and media as well as information technology. With the exception of locally collected tuition and fees, community college funding is limited by funding formulas reflecting FTEs of students enrolled in a wide variety of programs.[58] Using more of this formula-

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[57]Computing Research Association. 1999. "The Supply of Information Technology Workers in the United States." Available online at <http://www.cra.org/reports/wits/chapter-5.html>.

[58]In general, a combination of state appropriations and local or regional assessments, together with the tuition and fees collected from students, provides the funding for most 2-year colleges. State and regional funding is typically based on the FTE (full-time-equivalent) student. One student attending four or five classes per quarter (with each class

based funding to increase course offerings in any one area, including IT, means cutting capacity in other areas. And, as in the case of 4-year institutions, community colleges are reluctant to add tenured faculty in any one field, including IT fields, because such positions are difficult to eliminate if demand falls.

A second problem is a lack of up-to-date computing and network infrastructure in certain community college environments, especially in rural areas. Without high-speed connectivity and up-to-date equipment, both the content and supply of IT education will lag in these areas. These deficits affect development of both basic computer literacy and the more advanced occupational skills provided by community colleges.

7.1.5 Industry Certification

Education aimed at certification is a large and rapidly growing source of skills for IT workers, particularly those who perform mostly Category 2 work. By January 2000, an estimated 2.4 million certificates had been awarded worldwide to about 1.6 million individuals.[59] In general, certification is based on successful completion of a number of examinations (as many as eight or nine for any given certificate); in some cases, a certificate requires certain levels of experience as well.

Certifying organizations specify the content of these exams and award the actual certificates. Large U.S. IT vendors, including Microsoft, Oracle, Novell, and Cisco, award the most widely recognized certificates and also provide training to those seeking certification.[60] U.S.-based associations, including the Computer Technology Industry Association (CompTIA), the Institute for Certification of Computing Professionals, and the International Webmasters' Association, offer "vendor-neutral" certificates that are less well known.

Almost all certifying organizations offer a series of certificates reflecting attainment of progressively more advanced skills and abilities.

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meeting about 3 hours per week for 10 weeks) is roughly equivalent to one FTE. This formula allows for variability in actual student schedules. One person taking three classes per quarter and another person taking two classes per quarter would still generate one FTE. Because so many community college students only attend classes part time, the FTE is a more predictable and accurate measure of instructional effort than is a head count. The FTE is used to make staffing decisions and to calculate faculty workload.

[59]Adelman, Clifford. 2000. "A Parallel Universe Expanded: Certification in the Information Technology Guild." Available online at <http://www.aahe.org/change/paralleluniverse.htm>.

[60]Approximately 50 private vendors and nonprofits offer some type of certificate. These include non-U.S. firms such as Baan and SAP (Christianson, J.S., and A. Fajen. 1999. *Computer and Network Professional's Certification Guide.* San Francisco: Network Press).

Reflecting this hierarchy, the examinations range in difficulty. Some are simple 45-minute multiple-choice tests, but individuals seeking the high-level Cisco Certified Internetwork Expert (CCIE) certificate must do well in an extended simulation (2 days) dealing with network problems, as well as completing a 2-hour written test.

Many individuals prepare for certification exams by reading technical manuals and exam-preparation books on their own. Others take advantage of training offered by a rapidly growing number of public and private providers. Private providers create their own courses, and/or reconfigure existing curricula for online or CD-based instruction. Public educational institutions at all levels, including high school, community colleges, and universities, often partner with vendors to offer training for certification. As an illustration, industry certification training for Novell, Microsoft, and Cisco products is available in Austin from private vendors, at Austin Community College, and at the University of Texas.

A common mode of cooperation between the vendor and the educational institution is an exchange of hardware and software in return for customized training: A vendor provides the educational institution (e.g., a community college) with computing hardware and software, as well as its good name (which helps to attract students). In return, the educational institution agrees to provide customized training, using the company's equipment and following the company's curriculum. For example, Cisco Networking Academy is a four-semester program leading toward the Cisco Certified Network Associate credential. Public and private educational institutions at 3,200 sites worldwide offer this program.[61]

The most widely awarded certificates are those recognizing systems administration and other computer support skills. A recent survey[62] indicates that the two most common certificates today are the Microsoft Certified Professional, awarded to nearly 460,000 people by February 2000, and the Certified Novell Administrator, with 370,000 certificate holders in late 1999. There are also certificates recognizing higher-level skills in programming, database management, and technical training. For example, Microsoft had awarded about 24,000 Microsoft Certified Solution Developer (MCSD) certificates by February 2000, and by May 1999, an estimated 50,000 individuals had been certified by the Institute for Certification of Computing Professionals (ICCP).

The most commonly awarded certificates are based on a rather narrow set of "perishable" vendor-specific skills. Certifying organizations recognize this and retire out-of-date certification tests based on old technology.

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[61] Adelman, 2000, "A Parallel Universe Expanded."
[62] Adelman, 2000, "A Parallel Universe Expanded."

Some require certificate holders to successfully complete the new exam in their field if they wish to maintain their certification.

Despite their narrow focus, most IT certificates reflect attainment of at least some generic skills as well. Recognizing this, many training providers and certifying organizations grant "credit" toward attainment of one certificate, based on attainment of another organization's certificate. Vendors have recently begun to work together to develop more generic certificates. For example, IBM, Novell, Oracle, Sun Microsystems, and Netscape have cooperatively developed a new program of Java training and certification.

Reflecting the narrow focus of most IT certificates, most schools and colleges that offer training leading to certification offer such training on a noncredit basis. However, Pima Community College District in California has developed an extensive system of challenge examinations to independently measure attainment of skills developed in certification preparation courses. Students enrolled in IT certificate preparation courses at 170 locations who successfully complete these exams can turn their knowledge into college credit. And Regents College in New York has created a B.S. in computer information science, based on credits attained by completion of certification exams.[63]

Vendors benefit from certification programs because their products often require skilled support personnel to operate those products effectively. Employers hiring certified individuals have some assurance of minimal competency, at least in "book" learning. But as a rule, they want experience as well. For example, David Hunn of the Northern Virginia Regional Partnership reports that individuals with the Microsoft Certified Systems Engineer certificate but not job experience have great difficulty finding employment in IT jobs. Like other types of educational credentials, IT skill certificates can help an individual's career but cannot substitute for actual workplace experience.

7.1.6 Distance Learning

An issue common to almost all institutions of postsecondary education—community colleges, undergraduate colleges, master's-granting institutions, and for-profit institutions—involves the use of information technology to deliver education (and training) at a distance. Many such institutions believe that through the use of information technology to

[63]This program is only open to those with either an associate's degree or at least 60 college credits.

deliver content, they will be able to expand their student body beyond the community of those who are geographically proximate to their campuses.

Whether the promise of such education is realized remains to be seen. While it is clear that information technology can help to replicate the number of sites at which content can be delivered to students, personal interactions between teacher and student, and among students—for coaching, answering specific questions, and so on—are an important element of most educational experiences. Many providers of distance education appear to recognize this fact and have developed mechanisms to promote such interactions (e.g., tutors local to the point of delivery), but it is not yet clear that these mechanisms are sufficient to provide the necessary personalized dimensions of education.[64]

7.2 TRAINING IT WORKERS

For purposes of the discussion below, training refers to activity for the purpose of improving an IT worker's job performance. For new hires, training often includes orientation to the culture of the company. In other cases, training is oriented toward the acquisition of new skills, whether technical or nontechnical. Unless otherwise specified, the term "training" includes "formal" training as well as more "informal" training, such as learning by doing.

It is generally accepted that all users of computer systems, and especially IT workers, must continually learn and update their skills to keep pace with rapidly changing technology. The discussion below addresses various dimension of training.

7.2.1 The Need for Lifelong Learning

As discussed in the previous section, successfully performing many kinds of IT work, including both Category 1 and Category 2 work, requires formal education. In addition, however, following their initial education, IT workers require ongoing training. Knowledgeable observers suggest that, to maintain technology skills in a rapidly changing technological environment, IT workers must spend 1.5 to 2 hours per day (or 7.5 to 10 hours per week) in continuing education and/or training. For example, a representative of a large IT professional association told the committee that IT workers spend 9 to 10 hours per week reading on their own time

[64]U.S. Department of Education, National Center for Education Statistics. 1999. *Distance Learning at Postsecondary Education Institutions: 1997-98*, Lewis, Laurie, Kyle Snow, Elizabeth Farris, Douglas Levin, and Bernie Greene. Washington, D.C.: U.S. Government Printing Office, December.

"to keep up technically and professionally."[65] An IT job placement specialist[66] recommends that IT workers who want to remain employable spend "a couple of hours a day" reading, attending conferences, and learning informally from other IT professionals. A representative of another job placement and training company who recommends that IT workers continually "relearn everything you've learned" follows his own advice by spending his 1.5-hour daily commute studying technical manuals.[67]

Although it may be unrealistic to expect that an employed IT worker would be willing and able to spend 20 percent of his or her time in educational activities, these estimates do provide an indication of the magnitude of the training required.

On the other hand, workers have high incentives to seek training in an environment of rapid technological change, because keeping "current" is likely—provisionally—to increase one's marketability (but see discussion at Section 7.3). Recognizing the need for ongoing training, some workers do train on their own time and at their own expense. In order to help workers to keep their skills current, a growing number of providers—including consultants, state and local governments, vendors, technical institutions, and community colleges—offer formal IT training outside of normal working hours. In addition, many IT workers join professional associations to help keep their skills current. These associations provide technical publications, conferences, and opportunities to network with other professionals.

7.2.2 Disincentives for Employer-provided Formal Training

In a rapidly changing technological environment, employers have strong incentives to have workers with skills that are well-matched to that environment. An employer can obtain such workers in one of two ways —by hiring individuals who already have the necessary skills, or by training individuals who do not already have those skills.

According to human capital theory, firms are unwilling to finance the training of workers in "general" education or skills, because the workers might leave after obtaining the new skills. However, firms are willing to

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[65]John Keaton, Manager, Research and Planning, IEEE Computer Society (made up of 104,000 IT professionals, the society is a division of the Institute of Electrical and Electronics Engineering) testimony to the Committee on IT Workforce Needs, February 29, 2000.

[66]Steve Gallison, Professional Outplacement Assistance Center, testimony to the Committee on IT Workforce Needs, February 29, 2000.

[67]Jim Holder, Program Manager, Alternative Resources Corp. (a staffing company that retrains older, disabled veterans, and welfare recipients for IT jobs), cited in Vaas, Lisa. 1999. "Recycling Wisdom," *PC Week Online*, November 1.

make some investment in training workers in company-specific skills.[68] More recently, economists have questioned these predictions of human capital theory. One reason is that they follow from the assumption that labor markets operate in perfect competition, with each worker's salary reflecting his or her true productivity. However, perfect competition does not describe all labor markets.[69] For example, in some situations, such as those in temporary help firms,[70] an employer who trains a worker may know much more about that worker's increased skills and productivity than any potential new employer might know. As a result, the current employer can keep the employee without raising his or her salary to levels reflecting the actual increase in productivity. In such cases, employer investments in training are beneficial for the firm as well as for the worker, and thus, under some conditions, firms do finance the costs of general training.[71]

Further, even in perfectly competitive labor markets firms may find it profitable to invest in general training if it can help to reduce turnover. For example, one study found that scientists and engineers whose firms paid for their graduate education were less likely to quit than other scientists and engineers who paid for their own education.[72] The authors of this analysis suggested that company investments in broad transferable training can provide "insurance" against the loss of investments in firm-specific training by reducing turnover.

That said, high turnover (as in IT today), reduces employers' incentive to train, even in labor markets that are not perfectly competitive. Conversely, a lack of on-the-job training opportunities may encourage the turnover that, in turn, discourages employer-provided training. In theory, employers could reduce the risk of losing their training investments by requiring employees to sign contracts specifying that they will stay with the firm for a certain length of time or else repay the training expense. However, such contracts appear to be rare, in part because younger workers, who do not expect to have long-term careers with a single firm,

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[68]Becker, Gary. 1975. *Human Capital: A Theoretical and Empirical Analysis with Special Reference to Education*. New York: National Bureau of Economic Research.

[69]Acemoglu, Daron, and Joern-Steffen Pischke. 1999. "The Structure of Wages and Investment in General Training," *Journal of Political Economy* 107(3):539-572.

[70]Autor, David. 2000. "Why Do Temporary Help Firms Provide Free General Skills Training?" Revised April 2000. Massachusetts Institute of Technology and National Bureau of Economic Research.

[71]Autor, 2000, "Why Do Temporary Help Firms Provide Free General Skills Training?"

[72]Feuer, Michael J., Henry Glick, and Anand Desai. 1991. "Firm Financed Education and Specific Human Capital: A Test of the Insurance Hypothesis," pp. 41-60 in *Market Failure in Training? New Economic Analysis and Evidence on Training in Employed Adults,* D. Stern and J.M.M. Ritzen, eds. Berlin: Springer-Verlag.

are reluctant to sign them.[73] In addition, "pay or stay" training contracts appear to be legally unenforceable, at least in Silicon Valley. Columbia University law professor Alan Hyde suggests that the economic success of Silicon Valley's computer industry rests on "high velocity" labor markets, which encourage workers to produce and diffuse information, with no legal constraints on employee mobility.[74] Examining contracts designed to protect trade secrets that are very similar to "pay or stay" training contracts, Hyde found that judges and juries were unlikely to uphold such contracts and that firms that tried to enforce them suffered from lower morale and difficulty in recruiting new employees.

Intense competitive pressure may either encourage or discourage employers from providing opportunities for training on the job, as well as from providing formal training. On the one hand, providing training may help employers to attract sought-after employees in this tight labor market as part of the overall compensation package. On the other hand, in the race to bring products to market, employers have a strong incentive to keep workers where they are most productive. A worker who is highly adept and productive using "old" technology may be kept on jobs using just that technology.

Finally, the rapid technological change that characterizes the IT field provides a disincentive for employers to provide training. In particular, training that relates to one technology or applications domain may—or may not—have direct relevance to a new generation of technology or a different domain. And if the value of such training is quickly outdated, then employers will have less of an incentive to provide it in the first place.

7.2.3 Other Factors Affecting Training

Other factors are important influences on the ability of workers to keep their skills current.

The first is that many workers are unable to spend sufficient amounts of off-hours time to keep their skills current. These include individuals with family commitments (whether to spouse, children, or aging parents), those unable to afford continuing education, and those working signifi-

[73]At site visits to systems integration firms in northern Virginia, the committee learned of this problem.

[74]Hyde, Alan, "The Wealth of Shared Information: Silicon Valley's High-Velocity Labor Market, Endogenous Economic Growth, and the Law of Trade Secrets," paper presented at conference, Corporate Governance Today, Columbia University, May 21-22, 1998, and revised September 1998. Available online at <http://andromeda.rutger/edu/`hyde/WEALTH.htm>.

cant amounts of overtime. While estimates of 20 percent as the fraction of one's working hours that should be spent in continuing education may be unrealistic in practice, even a more realistic estimate of 10 percent corresponds to a substantial reduction in the individual's leisure and/or work time. For these individuals in such a situation, employer-provided training during regular work hours may be the only way to regularly enhance their skills.

The second is the role of formal education in computer science. As noted in Section 7.1.2, computer science education has undergone considerable evolution in the last 25 years. While many of today's Category 1 IT workers did not have the benefit of modern computer science education (and indeed, may have initially acquired their skills through other channels such as employer-provided training, learning by doing, or study in other disciplines[75]), such career paths may well be more difficult in the future. To the extent that an IT worker lacks a modern formal computer science education, it may be more difficult for such an individual to learn to use emerging technologies than for someone with such an educational background.

The committee emphasizes that neither of these factors suggest that it is impossible for workers to keep their skills up to date, though they may help to explain why it is difficult for some workers to do so.

Finally, the previous work experience of a worker has an indeterminate effect on the ease of training him or her to learn to use new technologies. On the one hand, the difficulties of learning to use new technologies—which may require new ways of thinking about problems—may be worse for highly experienced individuals because of the need to "unlearn" previous approaches necessary to use more familiar technologies. (Box 7.7 provides more detail on this point.) On the other hand, a more experienced IT worker may bring to the training task more seasoning and maturity of judgment, qualities that can help someone more rapidly identify essential attributes of a new technology and be a more effective learner.

7.2.4 Support and Infrastructure for Training

Companies require infrastructure for the support of training if training is to become part of their corporate responsibility. Purchasing training generally requires less infrastructure than developing it internally. For example, only a small infrastructure is needed to provide tuition reimbursement to employees who attend classes. However, some IT firms

[75]Barley, Stephen R., and Julian E. Orr. 1997. *Between Craft and Science: Technical Work in U.S. Settings.* Ithaca, N.Y.: Cornell University Press.

BOX 7.7
Incremental versus Paradigmatic Change

Software technology has undergone some drastic changes in the last couple of decades. Although some computer programming languages are quite similar in their underlying constructs (for example, compare C and Pascal), the newest generations of languages are quite different from the previous generations (compare Pascal and Java).

For example, "objects" in Java and C++ are an entirely new concept that is not contained in C or Pascal or Fortran. Even more importantly, a large amount of the power of Java and C++ is embedded in the use of objects (so much so that these languages are regarded as being "object-oriented"). Thus, to use Java or C++ effectively, one must become familiar with an entirely new, object-oriented computing paradigm. Although a programmer trained in C can begin to do some things with C++ immediately (specifically, he or she can implement code that does not require objects), gaining a true command of the new language, with its object orientation, is much more difficult than learning new syntax.

The difference between procedural languages and object-oriented languages is only one example of an abrupt change in the paradigms of programming. Functional programming is another equally abrupt difference. It is true that one can implement any programming task in any language, but programming languages can differ dramatically in the extent to which they make it easy or difficult to express solutions in any given problem domain.

Outside the domain of programming languages, changes in software technology can become even more significant. For example, the difference between software development in a mainframe environment and a Web-based environment is essentially a matter of different operating systems, but these manifest themselves at every level, from detailed implementation to (most importantly) requirements specification. Furthermore, for many system development projects, an understanding of the computing infrastructure is essential (e.g., different forms of connectivity among applications)—and the infrastructure underlying mainframes and Web computing are fundamentally different.

Finally, it is important to understand that differences in work content can be as intellectually challenging for individual workers as a change in technological paradigm. Contrary to some popular beliefs, a worker's familiarity with and knowledge of an application domain have considerable influence on his or her ability to develop applications relevant to that domain. Thus, a person with experience developing business applications may well have difficulty in writing device drivers, even though he may well be a competent programmer. Problems involving real-time applications are often particularly difficult without the requisite experience. Graphics applications are difficult, even with considerable programming experience, because of all the new algorithms that have to be learned for coordinate transformations, projections, visibility calculations, lighting calculations, and texturing.

must provide the training themselves because they are the only parties capable of providing certain highly specialized skills (e.g., when a firm's business is based on a proprietary technology) or an appropriate company-specific "acculturation" (this takes the form of "boot camps" in some IT-sector firms). Developing and providing training internally require much more staff time and expertise.

The most precious kind of support from employers is release time from the job to take training so that the worker does not have to take the time "out of hide." Such support is rare compared to the support employers provide for tuition reimbursement and the like. For workers under the pressure of small and impending market windows or other tight project-delivery deadlines, time for training is at a high premium—and since training does not contribute immediately to product delivery, training is not practical during these periods.

All of these considerations suggest that a worker is likely to achieve an adequate level of continuous education only if the responsibilities are shared between worker and employer. Workers must be willing to spend some of their own time on training efforts, and employers must be willing to explicitly build some time for training into a worker's schedule.

7.2.5 Training Opportunities in the Economy and in High Technology

Before moving to a discussion of current training practices among employers of IT workers, it is useful to look at the overall patterns of training in the U.S. economy. Surveys of both employees and employers conducted over the past 15 years indicate that the *amount* of employer-provided training is slowly increasing. The most recent detailed information on training comes from the National Employer Survey conducted by the U.S. Census Bureau in 1994 and 1997.[76]

Lynch and Black analyzed the survey data and reached several conclusions.[77]

- Most employers (81 percent) provide some form of formal training.
- Employer-provided training is distributed unevenly across industries and occupations. Establishments in the nonmanufacturing sector

[76]The National Center on the Educational Quality of the Workforce at the University of Pennsylvania designed the survey and a nationally representative sampling approach. In 1994, the Census Bureau obtained responses from nearly 3,000 establishments (a 64 percent response rate). With new questions added, the survey was administered again in 1997, and responses were received from over 5,000 establishments (a 78 percent response rate).

[77]Lynch, Lisa M., and Sandra E. Black. 1998. "Beyond the Incidence of Employer-Provided Training," *Industrial and Labor Relations Review* 52(10): 64-82.

(where most IT workers are employed) are more likely to provide training than are manufacturing establishments.

- Establishments are statistically less likely to provide some type of formal training if they have a low proportion of educated workers, a high proportion of minority employees, or a low percentage of female employees.
- Establishments that had invested in improved technology and reorganized work for greater productivity were more likely than other establishments to also provide formal training.

In general, Lynch and Black concluded that employer-provided training complements, rather than substitutes for, investments in physical capital and education. Other studies indicate that when firms adopt several complementary human resource strategies (often including work teams, selective hiring, training, and innovative compensation schemes), they experience increased productivity and profitability, and quit rates decline.[78]

7.2.6 Training Realities

Extent of Training

Although many IT workers obtain education and training on their own initiative, many others rely primarily on their employers to keep their skills current. However, some evidence suggests that the average amount of training provided in high-technology industries, including IT industries, falls short of the estimated 1 to 2 hours per day required to keep an IT worker's skills current. Available estimates indicate that high-technology companies, including IT companies,[79] provide their workers with about 8 minutes of formal training per day (a level that is still higher than that provided to workers in non-high-tech companies).[80] Adding

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[78]See Becker, Brian E., and Mark A. Huselid. 1998. "High Performance Work Systems and Firm Performance: A Synthesis of Research and Managerial Implications," *Research in Personnel and Human Resource Management* 16: 53-101.

[79]Both of the estimates included in this paragraph are based on a definition of IT that includes manufacturers of computer and communications equipment, as well as computer services.

[80]The small group of training-intensive IT firms that belong to the ASTD benchmarking forum report that, during 1998, they provided their employees with 29 hours of formal training annually, the equivalent of 7 to 8 minutes per day. This is quite similar to the Bureau of Labor Statistics estimate that high-technology employers provide about 34 hours of formal training per year, based on a large, nationally representative survey. (See American Society for Training and Development. 2000. *State of the Industry Report 2000*. Alexandria, Va.: ASTD.)

informal training to these figures roughly doubles the amount of training, to about 15 minutes per day.[81]

Those IT firms that do invest in training try to target their training to specific skills. For example, one mid-sized Texas firm is investing heavily to retrain programmers skilled in C++ as Java programmers. Workers who wish to develop other types of skills, however, are expected to train on their own time, in addition to handling their existing duties. The company provides books, videos, and partial tuition reimbursement. Even while following these practices, managers at this firm are concerned about the lack of training in the industry. One manager said, "We are cannibalizing our future by emphasizing short-term productivity over long-term professional development."[82]

As discussed in Chapter 2, the majority of IT workers are not employed in the IT sector. The estimates cited above indicate that workers employed outside of high-technology industries receive less formal training than do workers employed in high-technology industries. Thus, the training gaps discussed here may even be greater for the majority of workers employed outside the IT sector.

Training and Firm Size

National surveys of workers and managers conducted over the past decade have consistently shown that large organizations provide formal training more frequently than smaller ones.[83] Small IT firms do not

[81]In response to a request from the American Electronics Association, Bureau of Labor Statistics staff compared data on training in IT with training in all other industries (Frazis, Harley, et al. 1998. "Results from the 1995 Survey of Employer-Provided Training," *Monthly Labor Review*, June). Drawing on a large, nationally representative survey of firms and a smaller survey of workers, BLS estimated that IT firms provide employees with 64 hours of both formal and informal training per year, or about 15 minutes per day. (The data for the BLS survey were drawn from the BLS 1995 survey of a nationally representative sample of companies with 50 or more employees. About 1,000 employers completed detailed logs on formal training activities, and about 1,000 randomly selected employees in the same firms provided detailed logs of informal as well as formal training. The employees were asked to report any activity in which they were taught a skill or were provided with new information to help them do their job better. The resulting data are more detailed and accurate than previous estimates of informal training, but the small sample size and relatively short time period of the logs make the data on informal training less precise than the data on formal training.)

[82]Manager, software firm, Austin, Texas (site visit by Committee on Workforce Needs in Information Technology, December 1999).

[83]Lynch, Lisa M., and Sandra E. Black, 1998, "Beyond the Incidence of Employer-Provided Training"; Frazis, Harley, et al., 1998, "Results from the 1995 Survey of Employer-Provided Training," *Monthly Labor Review,* June; Amirault, Thomas, and Alan Eck, 1992, *How Workers*

appear to be an exception. For example, one small new application service provider (about 200 employees) relies entirely on recruiting "pretrained IT personnel." A manager of this firm testified to the committee that it did not provide in-house training because of the rapid pace of change in technology and applications, the multitude of vendor products for which individuals had to have expertise, the short tenure of employees (less than 2 years), and a lack of funds to support training.

As a rule, smaller firms are less likely than larger firms to have the expertise needed either to develop courses internally or to make good decisions about the broad array of training available from outside vendors. For example, among the 70 percent of Massachusetts IT firms that have 25 or fewer employees, most do not have any full-time human resources staff.[84] In addition, smaller firms may find it even more difficult than larger ones to release personnel from production to spend time being trained because they have fewer employees to take up the slack left by an employee who has left for training (or any other purpose).

In contrast, large employers often have formal human resources departments with the resources to provide training, and because they are large enough to achieve significant economies of scale, do provide extensive training. For example, the Intel Corporation provides extensive training to newly hired recent college graduates, as well as more experienced workers. The company spends about $350 million a year on employee training, with a particular focus on areas such as chip design, where outside training programs are not available to prepare people for Intel jobs.

Larger firms can also more easily provide on-the-job training opportunities by linking training to internal mobility within the firm. Some firms provide formal training on a "just-in-time" basis to employees coming off one project and starting another project where different skills are required. The opportunity to work with employees in different projects or across corporate divisions also enhances informal "situated learning." These practices are more often found in larger, more stable firms, such as government contractors that are able to win longer-term contracts. With relatively long lead times, human resources and project managers are able to plan ahead to retrain and redeploy personnel within the company. Employees at one such company cited extensive training opportunities, the ability to move into different divisions and do different types of work, and the value of stock in the employee-owned firm as key reasons why

Get Their Training: A 1991 Update, Bulletin 2407, Washington, D.C.: Bureau of Labor Statistics, August.

[84]Joyce Plotkin, Massachusetts Software Council, testimony to the committee, December 1999.

they stay. This company has much lower annual turnover than is typical among IT firms more generally.

7.2.7 Historical Experiences in Training

Large-scale efforts to retool workers in companies that have reoriented their business strategies have succeeded in some cases and failed in others. For example, IBM was known for many years for its commitment to employment security. As its business began to shift away from a focus on mainframe computers to client-server systems, top management at first followed its historical approach of training current employees. However, training the mainframe-oriented workforce in the new systems proved difficult and sometimes impossible. According to one executive, "Retraining helped, but there were a lot of cases where retraining didn't help."

More recently, over the past 2 years, IBM has transformed itself into an electronic business, with requirements for workers with Web knowledge and Internet/Intranet experience. Again, it sought to develop such workers from within the firm. Following the earlier changes, the company now has a strong base of workers with skills in client-server hardware and software. Once again, however, training and moving these workers from client-server-oriented jobs into Web-based jobs have proved difficult. The bottom line, according to a senior IBM executive, is that despite the IBM history of investing time and money in training, IBM is now "looking to bring people in to fill those assignments."[85]

Other companies, however, have succeeded in training IT workers to work with new technology. For example, Novell (a much smaller company than IBM) has retrained about 2,000 programmers worldwide in Java skills. Most were C or assembly programmers, so they could be considered sophisticated "systems programmers" but they were not "object-oriented." At this point, after beginning the project in 1996, around 25 percent of all Novell code is written in Java and its products are deployed more rapidly and with greater flexibility into the marketplace.[86] Another example is Computer Associates, a large New York-area firm that "believes in re-inventing people." Five years ago, its work was focused on mainframes. Today, its portfolio is split about equally between mainframe and client-server applications, and this has been achieved without any layoffs. More discussion of employer efforts in training is provided in Box 7.8.

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[85]Nancy Stewart, assistant to the Vice President of Talent, IBM, in a presentation to the Committee on Workforce Needs in Information Technology, September 22, 1999.

[86]Holbrook, Steven. 1999. "Reengineering with Java: A Novell Perspective," *Distributed Computing* (October).

BOX 7.8
Training in ASTD Firms

Larger firms, and the human resources development experts they employ, often participate actively in the American Society for Training and Development (ASTD), a professional association.[1] In an ongoing effort to measure the value of training and skills, ASTD provides a free benchmarking service to organizations that provide detailed information on their training investments, innovative human resources practices, and performance outcomes. In 1998, about 750 organizations participated in this process, reporting on their training activities and expenditures during 1997. Large firms in several sectors that employ large numbers of IT workers, as well as the IT sector, participated in the study.[2]

Among this small,[3] self-selected sample, the IT sector was a leader,[4] with the highest training expenditures as a percentage of payroll and one of the highest expenditures per employee, when compared to other industry sectors. Not surprisingly, the IT sector led in the use of advanced training delivery technologies. Although reporting one of the highest levels of internal trainers per employee (compared to other sectors), IT firms also used a large percentage of outside trainers and independent consultants, educational institutions, and product suppliers.

During 1999, an even smaller group of 276 organizations responded to a new component of the ASTD benchmarking survey, designed to measure intellectual capital. Because this new portion of the survey is difficult and time-consuming, only those organizations most committed to innovative training and human resources practices are likely to respond.[5] Among this group of organizations, the single largest group is IT companies. Overall, the 276 firms, including large IT firms, had low turnover rates (averaging 11.5 percent) and high levels of basic IT literacy, and they spent an average of 2.2 percent of payroll on training.

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[1]Founded in 1944, ASTD focuses on workplace learning and performance issues. The association provides information, research, and analysis, as well as conferences, expositions, seminars, and publications. ASTD is made up of more than 70,000 people, working in more than 15,000 companies, government agencies, colleges, and universities worldwide. Additional information is available online at <www.astd.org>.

[2]In the financial, insurance, and real estate sector, Allstate, Aetna, Citibank, Chase Manhattan Bank; in manufacturing, Boeing, Caterpiller, Hoffmann-La Roche, Johnson & Johnson, Levi Strauss, Lockheed Martin; in government, the U.S. Departments of Energy, Health and Human Services, and Transportation and the Office of Personnel Management; in the IT sector (as defined by ASTD—see footnote 4), AT&T, Compaq, IBM, Intel, MCI, Motorola, Sprint, Qualcomm, Xerox.

[3]By comparison, the U.S. Census Bureau estimates that there are nearly 5 million private business establishments in the United States as a whole.

[4]The information technology sector—defined by ASTD to include computer, electronics, and communications equipment manufacturers; software designers; telecommunications services; and information technology services and consulting firms—made up 15.3 percent of the 750 respondents to the 1998 benchmarking survey.

[5]"Intellectual Capital: Measuring It Like It Matters," a presentation by Bassi et al., American Society for Training and Development, January 13, 2000, National Center for Postsecondary Improvement Policy Seminar (supported by the Office of Educational Research and Improvement, U.S. Department of Education).

7.2.8 Approaches to Shared Training

As they work to develop stable, successful employment and training programs, employers of IT workers may consider the model of regional training consortia. These consortia are organizations (often incorporated as nonprofits) that are funded primarily by member companies and that work in partnership with education, government, and/or organized labor.[87]

Such regional consortia can help to overcome the "free rider" problem that results when some firms (often the larger firms) invest in education and training, while other firms "steal" the trained employees. They also allow member companies to pool their training resources and achieve economies of scale. Many IT employers have already begun to develop shared education and training programs through organizations such as Joint Venture: Silicon Valley, the Massachusetts Software Council, the Maryland High Technology Council, the Northern Virginia Regional Partnership, and the New York New Media Association. One kind of economy of scale results from the fact that the number of personnel a single company can spare for training activities may not be large enough to justify the cost of that training if it is provided in-house. Banding together in a training consortia allows companies to provide a "critical mass" of employees for training that can be justified on a sufficiently low cost-per-person basis.

Often, the first step in developing shared education and training programs is to analyze the local education and training system. For example, Joint Venture: Silicon Valley commissioned a study that not only examined the availability of skilled IT workers, but also surveyed local high school students to assess their knowledge of, and interest in, pursuing IT careers.[88] This study found that the many business-education partnerships already working to educate and train current and future IT workers in Silicon Valley were "fragmented and unsustainable," and called for a "comprehensive and regional approach."

Another example of IT employers' efforts to share the costs and benefits of training is that of the Massachusetts Software Council (MSC). The MSC program sends volunteer IT workers into schools, both to improve network connections and to educate students about IT careers, and arranges internships for college students and recent graduates. For 3 years,

[87]There are currently 14 regional training consortia, or "high road partnerships." See Working for America Institute. 2000. *High Road Partnerships Report.* Washington, D.C.: AFL-CIO.

[88]Joint Venture: Silicon Valley. 1999. *Joint Venture's Workforce Study: An Analysis of the Workforce Gap in Silicon Valley.* San Jose, Calif.: Joint Venture: Silicon Valley.

the MSC operated a successful program that combined classroom training and internships to retrain and reemploy displaced workers in IT careers. Ninety percent of the workers, whose ages ranged from 40 to 60, were placed in new jobs, at an average annual salary of $55,000. However, this program lacked stable financial support from employers and was stopped when state and federal funding ran out.[89]

Existing organizations working to develop sustained infrastructure for shared training of IT workers might learn from the example of the training consortia that exist in other industries. Employers in a variety of industries, including the graphic arts industry in San Francisco, metalworking firms in Milwaukee, Wisconsin, and hospitals in Philadelphia and New York, financially support these consortia. For example, the graphic arts industry in San Francisco supports a consortium that provides workshops and courses to advertising, printing, and graphic design professionals, using the latest computer hardware and software. Consortia provide a cost-effective way to upgrade the skills of current employees, improving job performance and customer satisfaction.[90]

Most of these regional training consortia have won state and federal funding, allowing them to expand their pool of trainees beyond the employees of member companies. For example, the hospital consortium in Philadelphia currently trains about 10,000 people per year, about half of whom are hospital employees and half of whom are members of the public. Federal and state welfare-to-work grants support remedial basic education and occupational training for former welfare recipients, while federal displaced-worker funds support training and outplacement programs for laid-off hospital workers. Most recently, the consortium won a $560,000 discretionary grant from the U.S. Department of Labor, funded by H-1B visa fees, to provide technical training for RNs and LPNs. Hospitals that participate in the Philadelphia consortium rely on the consortium for help in recruiting and training nurses' aides and licensed practical nurses. Federal funding has helped employers tap labor pools, such as welfare recipients, that require remediation of basic skills and support services as well as technical skill training.

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[89]According to Suzanne Teegarden, former director of the Massachusetts State Training Agency, the small numbers of trainees involved (about 50 per year) made it impossible to justify further public funding.

[90]For example, the 12 hotels participating in the San Francisco Hotel Partnership Project have found that involving workers in designing and implementing training programs has resulted in higher scores on guest satisfaction surveys.

7.3 INTEGRATING WORK AND LEARNING

The committee has heard much testimony that employers prefer a combination of formal education and training with work experience, especially for positions above entry level. Chapter 2 discusses the notion of "situated" learning and the idea that formal education and training, by themselves, do not lead to true mastery of IT work. All workers, including IT workers, develop and refine some of their most critical skills on the job. Experts who have studied the reasons that formal training can fail to translate into improved job performance have identified social and contextual factors as critical. For example, if a worker receives training in a new skill but has no opportunity to apply and refine the new skills once back at work, the training will have a limited impact on job performance. Similarly, the degree to which the trained worker's supervisor supports that individual in applying the new skills influences the degree to which formal training and education transfer to the job.[91]

Against this background, employers who seek IT workers with some experience in addition to formal training are behaving rationally. To improve training transfer, many companies are experimenting with innovative approaches for training that integrate work and learning. For example, in 1995 Apple Computer reorganized its management training, based on the assumption that most "students" already understand the basics.[92] The reorganization shifted from a behavioral to an experiential approach that included shorter training sessions focused on existing work groups to build teamwork, classroom exercises based on participants' actual challenges and problems on the job, smaller class sizes, and providing training at the trainees' location. In short, the goal was to see training holistically, as an organizational intervention, rather than as a limited program.

The Xerox Corporation, which has sponsored extensive research into situated learning at its Palo Alto Research Center (Xerox PARC), has also adopted "situated" training for its sales agents. In so doing, the company decided to support and leverage the learning that already happens on the job by offering dedicated, field-based, new-hire learning support. The support system was designed to integrate learning with work, build on the new hire's knowledge and skill incrementally, and help the new hire develop relationships within his or her work communities. Its goal was to enable the new hire's ability to put the training into practice in the

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[91]Ford, J. Kevin. 1997. "Transfer of Training: An Updated Review and Analysis," *Performance Improvement Quarterly* 10(2):22-41.

[92]Keegan, Linda, and Betsy Jacobson. 1995. "Training Goes Modular at Apple," *Training and Development*, July.

context in which it would be used. Following a successful pilot test, this support system was implemented nationally in 1999.[93] Although national data are not yet available, anecdotal evidence indicates that the program has been very successful. For example, one group of new hires, while still participating in the 8-week training program, together sold over $1 million of Xerox equipment.

Companies that have drawn on the situated perspective to change their training programs have generally found that the new approaches are less expensive. They involve less time away from productive work, which is the most expensive component of most company training. In addition, they require less expense for classroom space and trainer salaries, because they more frequently take place in the regular workplace and may use a manager or facilitator, rather than a training specialist.

In practical terms, what does it mean to integrate work and learning? Consider one example found by many employers to be successful and effective: internships. Such experiences tend to be more successful at integrating work and learning when they expose students to various aspects of a company, various jobs within a company, and various types of assignments that might come up in a job, and internships should allow students to apply some skills they have learned in the classroom to a real-world project.

From the educator's perspective, structured internships that are closely related to the content of the courses can be a useful complement to those courses. The structure is needed to ensure that the internship does indeed include some training and is not just "work experience." However, structure does not imply taking the intern off the job and putting him/her into a training classroom, a move that would defeat the purpose of the internship. Instead, it might mean facilitating the intern's natural interactions with colleagues and encouraging informal learning. This could be as simple as planning deliberately who the intern should go to lunch with each day to get a good overview of the organization and jobs within it. Or it could mean assigning the intern one or two mentors. The mentors who guide interns in the workplace could also work as adjunct faculty in the educational institution. They could bring a bit of the real world into the classroom, whether as actual instructors or simply as regular visitors. This would allow them to get a better idea of the education students are getting, and help them place student interns into projects that will allow them to apply their "book learning."

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[93]Cefkin, Melissa. 1999. "The Integration of Work and Learning for Xerox's New Hire Sales Representatives: A Project Review," draft. Palo Alto, Calif.: The Institute for Research on Learning.

Finally, cognitive theory and an examination of actual engineering design practice suggest that engineering is more effectively learned through integrated experiences than through formal classroom teaching. In contrast to a pedagogical approach in which design and analysis are taught in separate classes, students might be engaged in exercises that integrate problem formulation, analysis, and synthesis. For example, these exercises and other classroom experiences might be based on videotapes that illuminate how students apply formal knowledge in practice, how they learn, and the social context in which they learn; in addition, these new exercises could be used as a form of educational assessment.[94]

Others argue that current engineering education focuses too exclusively on the abstract objects of engineering design,[95] ignoring the reality that design takes place within a larger social and organizational context. These authors suggest that engineering should teach all aspects of design, including the process of negotiating among interested parties, as well as the feasibility of manufacturing, construction, assembly, prototyping, and cost. Students should be presented with open-ended problems that encourage them to ask a variety of questions, and not only questions specifically related to engineering. This, in turn, suggests that engineering faculty should act as coaches or mentors, and should have broad backgrounds, not narrowly specialized expertise.

7.4 RECAP

Education and training are strategies for facilitating an upward shift in the domestic supply of IT workers. Education begins with high-quality K-12 education. In particular, improving secondary mathematics and science education can help young people develop intellectual, reasoning, and problem-solving skills needed to succeed in higher education for IT and in many IT jobs. In addition, because advanced high school mathematics and science courses are prerequisites for entry into many 4-year IT programs as well as some IT jobs, improvements in mathematics and science education should increase the number of college students who are able to graduate with IT degrees and succeed in IT jobs.

The supply of IT workers could also be increased if institutions of higher education increased the rate at which they educate and graduate individuals with IT-related degrees. The number of graduates with 4-year degrees in IT-related disciplines does not meet the current demand for IT

[94]Linde, Charlotte, M. Brereton, J. Greeno, J. Lewis, and L. Leifer. 1993. "An Exploration of Engineering Learning." Palo Alto, Calif.: Institute for Research and Learning.

[95]Bucciarelli, Louis L., and Sarah Kuhn, "Engineering Education and Engineering Practice: Improving the Fit," in Barley and Orr, 1997, *Between Craft and Science*.

workers (especially those doing Category 1 work), and employers now hire large numbers of college graduates without IT degrees for Category 1 jobs. However, formal exposure to computer science and related subjects will become increasingly important for Category 1 jobs in the future. College-level education in IT-related disciplines is generally of high quality, providing workers the skills they need to contribute to large IT projects and to adapt to changing technology. Workers with such degrees can be a key asset in helping companies succeed in the marketplace. However, the quality of both 2-year and 4-year programs in IT disciplines could be improved by increasing work-based internships, engaging IT professionals in design and delivery of instruction, and generally strengthening the linkages between the workplace and the classroom.

Institutional factors, such as a lack of qualified faculty, computing facilities, and classroom space, limit the potential for rapidly increasing the number of enrollments and graduates from 4-year IT programs. However, increasing the number of students with IT minors may be possible within a shorter time frame, enhancing the supply of IT workers.

Two-year colleges have the potential to rapidly increase supplies of workers qualified for some types of IT jobs. Currently, community colleges provide initial preparation to some students who transfer to a 4-year IT program, and graduate others with associate's degrees in IT fields. In addition, community colleges are playing a growing role in upgrading the skills of current IT workers and training workers from other occupations for IT careers. The number of schools offering IT training, and enrollments in those schools, are growing already, and could potentially grow even faster.

Increasing enrollments and graduates from advanced postgraduate education can also help to relieve labor market tightness. IT researchers and workers with advanced degrees may help to enhance the productivity of both current and future workers through research and development, thus slowing the rate of growth in demand for new workers. At the same time, postgraduate education provides the "seed corn" or faculty to educate the next generation of IT workers. However, current IT labor markets provide little financial incentive for individuals from the United States to obtain postgraduate degrees, particularly at the master's level.

The pace of technological change in IT increases the costs and benefits of training for both employers and workers. Employers gain by having an alternative to hiring new workers, and thus, appropriately structured training, involving the integration of work experience with "formal" learning, can help to relieve tightness in the IT labor market. On the other hand, workers who receive training may be more likely to leave, and economic and competitive pressures discourage employers from providing support for ongoing training. From the worker's standpoint, rapid technological change increases the intellectual burdens to stay current, but those who take on these burdens and keep their skills up to date are usually more employable than those who have not.

Over the longer term, ongoing training could relieve tightness in IT labor markets both by reducing turnover (which causes vacancies) and by increasing supply. Fully trained workers would likely be more productive, thus reducing the rate of growth in demand for new IT workers. And with well-established ongoing training systems in place, employers could more easily hire and productively employ workers from other occupations, thus increasing the total supply of skilled IT workers.

The potential contribution of ongoing training to increasing the supply of IT workers will likely be easier to realize over the long term because in the future, the IT workforce will include a larger proportion of workers with a formal IT education. With strong foundation skills, these workers may be easier to retrain than those in the current workforce.

Part III

8

Synthesis, Principles, and Recommendations

8.1 SYNTHESIS AND FINDINGS

As described in Chapter 1, the IT sector and the IT-intensive industries are key pillars of the U.S. economy, and they continue to remain competitive and be a locus of innovation. They are technologically dynamic, and they have had or been responsible for enormous economic success by any measure. IT is generally regarded as an engine of growth and change across the economy, and there is a growing body of evidence that IT is playing a significant role in improving national productivity, and that any constraints on IT production and support—such as those that might arise from excessive tightness in the IT workforce—may have a pervasive impact on the growth of the economy.

While market adjustment is occurring, the labor market for many IT positions is tight today and likely to remain so for the immediate future, barring dramatic change (Chapter 3). This tightness is not uniformly distributed across all positions, all geographic regions, or all levels.

There are many reasons for tightness in the IT labor market. The fundamental drivers of tightness are technological change and growth in the use of IT applications. To the extent that information technology continues to change rapidly and growth in the demand for IT applications continues to occur, individuals with experience in and/or knowledgeable about the newest technologies will be in relatively short supply. Furthermore, high growth creates conditions such as high wages in the IT sector and in IT-intensive industries that can drive turnover rates higher as workers seek jobs with higher wage offers with other firms—or that can lower turnover if the current employers are willing to match or exceed higher offers from those other firms. Nevertheless, turnover can occur for reasons other than wages as well.

Nevertheless, growth in the use of IT and technological changes would not lead to tightness in the labor force if the available supply of qualified labor were to grow at commensurate rates. Sources of qualified labor include new domestic entrants into the workforce, incumbent workers already in the IT workforce (both those with up-to-date skills and those who can be retrained for new jobs), incumbent workers who might otherwise drop out, workers in other fields who might enter IT work if appropriate training is available, currently unemployed workers, "discouraged" workers who do not count in unemployment statistics, and foreign workers who can either be brought to the United States or work in their home countries for U.S. companies.

Students, workers, and employers have started to respond to tightness in the IT labor market—for example, enrollments are up in computer science degree programs, and employers are taking many of the steps described below to increase supply. But under conditions of sustained growth in demand, it may be difficult for supply to ever "catch up" completely.

Under conditions of a tight labor market, employers must seek workers from the broadest possible pools of talent. On the assumption that the distribution of human talent does not respect ethnic, racial, or national boundaries, this is fundamentally the "enlightened self-interest" rationale for employers seeking out workers from underrepresented groups (e.g., women, minorities, older workers) as well as from the traditional pools, and it is also a major rationale for seeking talent abroad.

From the standpoint of individual employers facing hiring difficulties, one important way to fill vacancies is to increase employee retention—a job that is never vacant takes zero time to fill. Indeed, in analytical terms, the rate of employee turnover is as important a driver of vacancies in the workplace as is company growth, and empirically the data suggest that turnover makes a larger contribution to the vacancy rate than does growth. Many employers are indeed taking steps to reduce turnover by making existing jobs more attractive.

If retention is insufficient, and/or if a company is growing, other sources of qualified workers must be developed and/or expanded (Chapters 6 and 7). Different types of IT work call for different types of IT training. The duration of the necessary training (and/or development of experience) depends on the individual's prior background and the desired level of proficiency in the new area of work. For some types of IT work, an individual with substantial background in a related IT area can achieve basic proficiency in a matter of days or weeks (e.g., someone with training in Pascal can probably learn C well enough in a few weeks to do many things). For other types of IT work, even an individual with substantial background will require years of preparation (e.g., an individual with many years of experience in Pascal or C may take 6 months to a year or more to understand and program effectively in object-oriented languages such as C++ or Java, while an individual with an undergraduate degree in computer science will take several years to obtain a Ph.D. in computer science that enables him or her to do cutting-edge IT research).

Formal education has a role to play in training for IT work, but it is by no means limited to baccalaureate work in computer science. It is certainly true that certain Category 1 work (e.g., IT development) increasingly requires substantial amounts of formal training—more so than has been true in the past. But the requirements of some such jobs may be met by individuals with substantial exposure to formal computer science education (whether through IT minors rather than majors, areas of concentration in IT, or even an array of several IT courses) that can be offered by colleges, universities, and community colleges. And various forms of continuing education (e.g., short courses) can provide some job opportunities—especially in areas for which business understanding and knowledge are more essential than detailed IT knowledge—to those without degrees in IT.

Finally, for education and training to be most beneficial to workers, they must be integrated in appropriately situated real-work contexts. Cognitive theory and workplace experience both suggest that such integration is necessary for workers to use their learned skills most effectively. Employers, understanding this phenomenon, value job applicants who have a proven track record of such experience.

For many of the job areas in which there is tightness today, training sufficient numbers of individuals on a time scale that responds to changes in the market remains a daunting task. Thus, while individual firms may be able to raise wages and compensation high enough to recruit workers doing comparable work from other firms, for the industry as a whole, the short-term elasticity of supply in the overall IT labor force is quite low.

Short-term supply inelasticity in the overall IT labor force is exacerbated by the fact that the U.S. economy today is experiencing unemployment levels that are very low by all historical precedents. Because there is record low unemployment across the board, workers have many options—and thus workers in other fields are less likely to turn to IT than they might be if overall unemployment levels were higher. However, if and when overall unemployment rises significantly, a sector that continues to experience low unemployment (perhaps the IT sector) will become considerably more attractive to workers in other fields, thus making available a larger supply of potential willing new IT workers.

Finally, the committee has heard many allegations of age discrimination in the IT industry (Chapter 4). It would be naïve to assert that no age discrimination exists. Some employers, managers, and hiring teams do operate from inaccurate assumptions and stereotypes about older people that may cause age discrimination to occur in individual cases. At the same time, workers who lose their jobs or are not hired for whatever reason (company mergers or acquisitions, downsizing, end of life of a product or service, obsolete skills, poor performance, and so on) may inaccurately attribute the cause of this action to age discrimination.

Based on the available empirical data and a variety of anecdotal testimony, it appears that, on average, older IT workers have different experiences with displacement and possibly with post-displacement income than do younger workers. However, these data do not allow the committee to determine whether the differences indicate age discrimination on the part of employers, legal conduct by employers that may be perceived as discriminatory, personal choices made by individual employees, or the ramifications of a rapidly changing industry. To the extent that discriminatory treatment of older workers does exist, policymakers should address this issue—not because the elimination of all such discrimination would have a significant impact on tightness in the labor market, but rather because IT employers, and the nation as a whole, would, by underutilizing valuable human resources, be depriving the economy of a valuable source of talent.

The following observations and findings elaborate the basic picture painted above.

8.1.1 On the Available Data

• The best available data sets are for the most part inadequate to provide a definitive description of workforce needs in information technology.

—Definitions of occupations—which are necessarily relatively stable over time—do not necessarily reflect the IT job titles of today because new types of jobs emerge quickly. In particular, occupational categories are generally too coarse and do not reflect important distinctions among IT jobs.

—Some data are not timely enough. Data that are 2 years old are unlikely to reflect accurately today's state of affairs in the rapidly changing IT sector or in IT-related jobs in other parts of the economy.

—Government data on IT workers in H-1B or other visa categories have been severely lacking, with only limited information available on country of origin, occupational category, degrees and experience, total compensation, age, nature of employer (industry, number of employees, revenues), change in employment, previous immigration status, adjustment to permanent status, and so on.

• Thus, policy recommendations from all parties—including this committee—are inevitably based on a mix of judgment and interpretation of whatever trends are visible in the existing data, however sketchy and incomplete those trends are.

8.1.2 On the Nature of Business in the IT Sector (Chapter 3)

• If past trends continue, the IT sector and the use of IT in IT-intensive industries will likely grow significantly in the long run. However, it is certain that such growth will be interrupted or at least curbed during certain periods (e.g., economic recessions) that no one can predict. Such periods are likely to relieve then-current tightness in the IT labor market (though they may discourage new entrants from going into IT work shortly thereafter).

• Because of the competitive premiums on speed within IT, employers want to be able to respond quickly to workforce needs that change as fast as new technology and/or applications emerge.

• The universe of IT employers is highly heterogeneous, involving firms or organizations ranging from finance, manufacturing, and government to IT firms that sell IT products, services, and applications. However, stereotypes of IT work as involving workaholics, dot-com millionaires, and very long work hours and pressure appear to drive many public perceptions of such work, even though they likely reflect only a small segment of all firms employing IT workers.

• The development side of the IT sector and of IT-intensive industries is particularly dependent on human talent, with the consequence that capital cannot easily be substituted for labor to increase productivity. Research continues on technology-based tools for improving the productivity of IT workers (and indeed, a number of such tools that have increased productivity are now in wide use—e.g., integrated development environments for software engineering) and on different types of organization and management for software engineering that improve productivity. However, due in part to growth in demand for IT products and services, it is unlikely that the use of tools or management techniques for increasing productivity will have a significant impact on tightness in the IT labor market in the current decade.

• For the development of business-specific or company-specific IT applications, knowledge specific to the business dimensions of the application is as necessary as IT-specific skills.

8.1.3 On the Assessment of Talent (Chapter 6)

• For an industry that is so dependent on human talent, reliable identification of the most qualified and productive individuals is critically important. However, many of the techniques used today to identify these individuals are poorly matched to determining an individual's qualifications for the relevant jobs.

• Systematic efforts to determine the duties, responsibilities, and requirements of a job are most successful when the job in question is relatively stable and well-defined. Because the IT industry is changing so rapidly, it is very difficult to apply these traditional methods. Even recognizing this rapid change, however, existing methods for job analysis are not sufficiently detailed to describe such work attributes as abstract analytical work, skill in the use of information technology, teamwork competencies, and interpersonal skills.

• Assessment tools almost always involve tradeoffs between speed/simplicity and thoroughness/accuracy. Some structured assessment methods (i.e., procedures used to evaluate a job applicant that are administered in a standardized and uniform manner, scored in a consistent manner, and validated against indicators of job success) have a solid empirical basis in identifying the most productive workers, enjoy a long and consistent record of validity and cost-effectiveness, and have proven to be fair and practical. On the other hand, structured assessments are often more expensive and time-consuming than unstructured methods, and they often depend on the quality of the information available about the content and requirements of the job.

• The unstructured assessment methods commonly used to select IT employees today (such as unstructured group interviews) can raise suspicion of discrimination on the basis of age, race, and gender. In general, job applicants tend to view certain structured assessment methods as more fair and less arbitrary than unstructured methods, even if the use of unstructured methods is legally defensible.

8.1.4 On Education and Training (Chapter 7)

• A factor currently limiting domestic production by 4-year colleges and community colleges of individuals with degrees in computer science is the availability of qualified faculty and facilities. Today, there is more student interest in such courses of study than can be accommodated. However, elimination of this limiting factor would increase production only if student interest in such careers matched the number that could be taught with newly available resources.

• Many of the most promising students—at various levels from high school to graduate student—are drawn away from academic study to pursue the lure of riches offered by the IT sector. While these individuals themselves may benefit if their ventures are successful, the potential long-term loss to the IT academic research and education enterprise is severe.

• Skills are needed, but formal training is not enough. Employers want to know that someone can actually complete a project applying the skills learned in a training course, and educational or training programs that incorporate real-world internships are more likely to lead to job placements. Thus, any retraining program intended to bring workers into the IT workforce, or to keep the skills of today's IT workers current and relevant to new technologies, must provide work experience as well as training to succeed.

• Professional societies have played an important role in supporting education and training through model curricula, accreditation programs for undergraduate computer science degree programs, and technical journals and conferences.

8.1.5 On Age Discrimination (Chapter 4)

• A perception among certain parts of the IT worker community is that discrimination against older workers is rampant. A complaint coming from older workers is that they believe they are more likely to be laid off than younger workers and then, once without a job, they will find it much harder to obtain new employment.

• Actions motivated by legitimate business reasons that also have disproportionate adverse effects on older workers do not necessarily constitute illegal age discrimination. Such business reasons may include the desire to reduce labor costs, to increase operating flexibility, or to seek workers with experience in new technologies.

• There is evidence that the experiences of older workers in IT may be different from those of younger workers. The available data indicate that:

—The IT workforce is younger than that in other occupations with workers of comparable educational attainment;

—Older IT workers (those 40 years and older) are more likely to lose their jobs than younger IT workers;

—Older IT workers are just as likely as younger IT workers to find new jobs; similarly, the length of time it takes for them to find new jobs is similar to that for younger IT workers. However, older IT workers may compromise more on new jobs than do younger workers.

However, these differences—by themselves—do not allow the committee to determine whether they are the result of age discrimination on the part of employers, other employer behavior and conduct that, while legal, may create perceptions of age discrimination, personal choices by employees, or the ramifications of a rapidly changing industry. Thus, the committee cannot determine whether illegal age discrimination exists to a greater or lesser extent among employers of Category 1 IT workers as compared to employers of other professional occupations.

- Difficulties that older IT workers perceive in finding suitable employment exist largely apart from the availability of H-1B visas, as discussed in Chapter 4. Moreover, elimination of all potential age discrimination in the IT workforce would not likely have a significant impact on tightness in the IT workforce in the long term, although it could have a small, but important, one-time effect.

8.1.6 On the Use of Foreign Labor (Chapter 5)

- The IT sector and IT-intensive industries are fundamentally global, both with respect to markets and talent.
- Foreign-born workers can make an important contribution to the U.S. IT workforce. Furthermore, foreign entepreneurs, scientists, and engineers—like domestic ones—create jobs. Entepreneurs create businesses that hire others, while scientists and engineers—through the science and engineering that underlie new technologies—create jobs for other scientists and engineers working with those technologies.
- U.S. IT companies (and those engaged in the advanced use of information technology) can and do move work overseas for a variety of reasons. Sometimes they do so because labor costs are significantly lower, or because local markets require a local presence, or because they wish to tap a local talent pool with specialized expertise, or because a clean separation from the parent company can allow different "cultural" environments to flourish.
- Given the assumption of continued growth in the use of IT, pressures will increase to locate development work abroad that would otherwise be performed in the United States. Such pressures are to some extent independent of the availability of foreign workers (either temporary or permanent) in the United States. Instead, these pressures are driven by a variety of other factors, including the significant cost advantages of relocating work to countries that have substantially lower wage structures than the United States, the need to tailor products to the requirements of foreign markets, and better access to foreign markets. This is not to deny the many difficulties and inefficiencies of coordinating offshore work with work performed in the United States, but many of these difficulties and inefficiencies are likely to be ameliorated by future generations of technologies to facilitate cooperative work.
- Growth in the IT industries abroad and the accompanying competition for talent from nations such as India may restrict the supply of

foreign workers to the United States. Of course, because the trajectory of future demand for foreign IT workers here and abroad is unknown, as is that of production rates of qualified foreign IT workers, this outcome is by no means a certainty.

- It is the committee's judgment that the use of foreign workers will continue to be necessary for the immediate future, and that foreign workers will continue to make important contributions, but policy governing the use of foreign workers must consider not only the benefits of admitting foreign IT workers but also potential negative effects on the domestic workforce and take steps to ameliorate those negative effects.

8.1.7 On the Use of Temporary Foreign Nonimmigrant Labor (Chapter 5)

- From the employer's perspective, the critical element of the H-1B program is that it enables employers to engage nonimmigrant foreign labor in useful work on a time scale of several weeks to a few months rather than years, a fact that makes obtaining foreign labor through the H-1B program convenient, given the time scales of change in information technology.
- The committee estimates that temporary nonimmigrant workers (mostly with H-1B visas) constitute about 10 percent of the Category 1 IT workforce, though this figure likely represents an upper bound. While H-1B visa holders are far from the dominant influence on the IT workforce, their number is large enough that without these workers there would likely be a slowdown in the rate of growth in the IT sector.
- Economic theory implies that an increase in the supply of IT workers, including temporary nonimmigrant workers, will cause the corresponding IT wage rates to be lower than they otherwise would have been. Theory alone does not imply any particular numerical magnitude of this effect. It is the committee's judgment that the current size of the H-1B workforce relative to the overall Category 1 IT workforce is large enough to exert a nonnegligible moderating force that keeps wages from rising as fast as might be expected in a tight labor market.

8.1.8 On Workforce Needs in Biotechnology as a Point of Contrast and Comparison

- Product innovation and development in biotechnology are based on advances in the quality and amount of scientific information. Consequently, the paths to biotechnology careers—including those for technicians—require substantial formal training in a number of highly specialized scientific disciplines, including molecular and cell biology. This contrasts with IT, for which individuals can enter through a wide range of educational paths.

• Barriers to the entry of new biotechnology products into the marketplace—especially drug products—are significantly higher than the barriers for IT products. Among the reasons for such high barriers are the large investment required in product discovery, the high rate of product failure in the preclinical and clinical trial phases, the need for the investment in product development to be protected by a strong proprietary position, and the high cost of product development (a large part of which can be ascribed to the need for extended (often worldwide) clinical trials).

• Despite an abundance of individuals with Ph.D.s in the life sciences, the biotechnology industry is currently finding it difficult to find Ph.D.-level specialists in analytical chemistry, instrumentation, organic synthesis, clinical biostatistics, bioinformatics, production quality assurance, and regulatory affairs. Training in these science disciplines is sufficiently specialized that it is a nontrivial matter for a holder of a graduate degree in a branch of the sciences not mentioned above to shift into the kinds of work required.

8.2 PRINCIPLES FOR ACTION

As noted above, issues related to the IT workforce are multidimensional. Many employers do experience real difficulties and problems in hiring, but these problems are complex enough to defy simple solutions. Indeed, one of the major confounding factors in the public debate over the IT workforce is a plethora of simple solutions that address the problems from a single perspective.

The committee believes that actions to address tightness in the IT labor market and the consequences for individual employers should be governed by a number of principles:

• There is no single solution to relieving the tightness in the IT labor market, and multiple approaches will be necessary.

• All stakeholders have a role in helping to address problems resulting from tightness in the IT labor market. These stakeholders include government policymakers, the IT sector, IT-enabled firms, educational institutions, and individuals. A corollary is that U.S. IT-sector employers have a long-term role (though not the exclusive or even primary role) in training, developing, and maintaining the IT sector's workforce.

• Effective approaches to addressing tightness in the IT labor market must be responsive on the time scale of significant change in information technology. Employers must be able to hire workers on a business time scale (i.e., weeks or months), while policy actions taken to relieve tightness in the IT labor market must be reversible or capable of being moderated if and when such tightness no longer obtains.

• All approaches to deal with tightness in the labor market have costs and benefits. For example, subsidies provided to increase employer-provided worker training in IT would increase the levels of training that workers receive, but might also result in subsidies being paid to employers to do what they would do anyway.

8.3 RECOMMENDATIONS

In the long run, a systematic effort to nurture an adequate IT workforce depends on several premises for action:

• A broad base of citizens with basic fluency with information technology must be developed. Even if most of these citizens do not go on to be IT workers, future IT workers are inevitably drawn from this pool. In addition, educational efforts at the K-12 level must be conducted in such a way that postsecondary study of IT-related subjects is not precluded.

• Awareness of IT careers must be promoted, and the reward (financial and otherwise) of pursuing such careers must be widely understood.

• Educational institutions at all levels must provide (and be given) the resources for IT-related programs to the extent warranted by student demand. When changes in student demand for IT-related study require nontraditional approaches to education, changes from the status quo should be supported.

• Especially in a tight labor market, employers must draw on and develop all sources of talent, both domestic and foreign. As a matter of enlightened self-interest, employers should be loath to overlook possible sources of good IT workers—even if those workers may require some training to make them productive.

• The data to support informed decisions must be available. Such data should be collected more frequently, be made available more rapidly, and have a much higher specificity that accurately reflects the nature of the IT-related jobs.

All actions taken to relieve tightness in the IT labor market by increasing the supply of IT workers will take time to show results. Some actions will result in relief in the short term, and others will result in relief in the long term, and actions with a long-term time horizon (such as those described in Chapter 7) are especially important in the event that the tightness of the IT labor market increases.[1] But these actions have costs as well as benefits that should be explored before they are pursued. And policies with short-term benefits may have an unintended negative effect on the viability of policies for the longer term. These tradeoffs must be balanced against the economic consequences for both production and IT employment, as well as for the nation as a whole with respect to issues related to overall national productivity.

This section on recommendations is organized by the parties on whom responsibility falls for taking action: IT employers, educational institutions, IT workers, and government. A final section describes actions that should most likely be taken in partnership among the parties.

The number of new recommendations described below is small, and many are already being followed by the actors in question. However, the rationale for some of these recommendations may be different, even if the recommendations themselves are not original to this committee.[2] The committee offers its recommendations to encourage what is already being done, and to inspire to action those who are not already taking steps such as these. The committee also calls attention to the very important fact that the manner in which these recommendations are implemented has a great deal to do with their success. Thus, even if some of the recommendations "merely" reflect common sense, the unfortunate reality is that common

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[1]Even if tightness in the IT labor market does not increase, education and training measures for workers would still be helpful in an economy that is increasingly based on knowledge and information.

[2]Some of the other reports that have made some similar recommendations include:

- Computer Science and Telecommunications Board, National Research Council, *Making IT Better: Expanding Information Technology Research to Meet Society's Needs*, 2000; *Scaling Up: A Research Agenda in Software Engineering,* 1989; *More than Screen Deep,* 1997; *Computers at Risk,* 1991; and *Trust in Cyberspace*, 1999 (Washington, D.C.: National Academy Press).
- Council on Competitiveness. 1998. *Going Global: The New Shape of American Innovation,* September. With regard to software, the report observes, "Although software companies invest heavily in R&D, their focus is more toward the 'D' side. This emphasis tends to create a gap in fundamental research, particularly in software productivity. As demand for information technology explodes and information networks grow more complex, the need for automating the software process will be critical."
- President's Information Technology Advisory Committee (PITAC). 1999. *Information Technology Research: Investing in Our Future.* Report to the President, February. Available online at <http://www.ccic.gov/ac/report>. The PITAC report stresses: "We have become dangerously dependent on large software systems whose behavior is not well understood and which often fail in unpredicted ways. Therefore, increases in research on software should be given a high priority."
- *Information Technology for the Twenty-first Century: A Bold Investment in America's Future* (<http://www.ccic.gov/it2/initiative.pdf>, January 24, 1999) is the President's response to and endorsement of the PITAC recommendations.

sense is not always honored in practice. To the extent that some of the recommended actions are being implemented successfully by various individual stakeholders, the description here can be regarded as a description of "best practices" that others may wish to emulate.

8.3.1 For Employers of IT Workers

Change recruiting practices.

Today, IT employers spend considerable recruiting effort on college campuses in the search for top technical talent to meet their immediate needs for IT professionals. However, employers have also pointed to difficulties in finding good managerial talent for their IT projects. Because management requires a maturity and perspective not often found in recent college graduates, recruiting efforts directed at older workers with necessary technical skills and managerial experience might yield a rich return on effort invested.

Build deeper relationships with universities and other sources of talent.

While most employers do recognize the value of active recruiting at colleges and universities, it stands to reason—and is confirmed by experience—that the larger and more substantive the campus presence of an employer, the greater will be student awareness of that employer. An employer that sets up an employment booth at a job fair once or twice a year will naturally have less visibility than one that meets regularly with the IT faculty, gives seminars to the computer science department, provides financial support and co-op opportunities for students, and works to develop relevant curricula.

Make more use of structured assessment methods.

Unstructured assessment methods, such as informal interviews, are easy to use. They take little time to develop and less time to administer than more structured methods. But employers would increase the likelihood of identifying good performers if they used more structured assessment methods, such as structured interviews in which assessors pose the same questions to every applicant and score the results in a uniform manner.

One method of structured assessment that may be especially valuable for IT employers is the work sample or simulation. An employer could ask an applicant for a programming job to develop an algorithm to solve a particular problem—or even to write a program to solve it, either in a language that the employer uses or in pseudo-code. An applicant for a position as network administrator or manager can be asked to solve a real networking problem, much as some vendor certification programs require candidates for certification to do. Because an individual's formal knowledge becomes useful to the employer only when that individual can apply the knowledge to a business problem, a work sample or simulation is likely to be a better predictor of future job performance than other, decontextualized assessment methods.

Work sample and simulation methods can also be used to identify individuals who will perform well in a team setting. Since much of IT work is a team effort, team skills are essential. One method that has been used to assess persuasiveness, self-confidence, oral communication, and interpersonal skills is the leaderless group discussion. In addition, new methods of assessing teamwork skills could be developed specifically for IT work.

Avoid discriminatory behavior.

Employees who participate in hiring in any way must avoid hiring practices proscribed by law. It is well-understood that hiring managers should be educated in this manner, but it seems less well-understood that the rules on proscribed behavior apply to members of project teams who interview applicants, as well as the managers that make the final decisions. Furthermore, more structured methods of assessing and selecting job candidates are in general less susceptible to sustainable charges of discrimination.

To the extent it is possible to use them, blinded assessments can help to reduce unconscious bias. Just as candidates for symphony orchestra jobs often audition behind screens (so that judges can hear but not see them play), programmers—for example—can submit coding samples without ever having been seen. And they can sometimes answer questions without needing to interact face to face. Under some circumstances, blinding is not possible (e.g., when evaluating teamwork exercises that are part of an interview, or when extended dialogue is necessary to probe more deeply into an applicant's work sample). Nevertheless, the use of blinding when appropriate can be helpful for institutions wishing to reduce their vulnerability to charges of discrimination.

Improve worker quality of life.

Because many IT workers rate nonpecuniary factors as highly as—or more highly than—wages or compensation in their decisions to accept or stay with a given job with a given employer, employers have a great deal of latitude in customizing their environments to better meet the non-pecuniary needs of their employees. For example, telecommuting or other alternative work arrangements can reduce the pressures that result from commuting in areas with high traffic volume. (A further benefit of policies that allow telecommuting is that an employer can begin to use IT workers who are far removed from employer work sites—thus enabling the employer to draw on a national rather than a local talent pool.[3]) Policies that help to support better work-life integration (e.g., onsite or employer-provided day care for workers with children or elderly parents) can also play an important role in employee recruitment—and especially in employee retention. Policies that allow more time off the job, whether in the form of compensatory time following peak work periods, vacation time, or a moderate work pace throughout the year, might well aid retention.

Practices that improve the quality of life for workers may also help to avoid or reduce the impression of discrimination against older workers; such practices can include recruiting more widely or providing greater flexibility in working conditions.

Promote training.

Human capital theory predicts that employees who receive training become more marketable to other employers and thus become less likely to stay with the original employer. But as noted in Chapter 7, some recent empirical and theoretical research has called this assumption into question. For example, providing training has in some instances been an effective tool in helping to reduce turnover because it increases employee loyalty. And employees who receive training may not find it easy to transfer their training to other firms.

With this perspective in mind, training and continuous learning become realistic and reasonable options. Thus, more employers should:

- Consider explicitly the wait time involved in identifying and hiring an appropriate candidate against the time it would take to train (retrain) someone to perform the job for which the employer is hiring. In instances in which the training time is less than the time needed to find an appropriate worker, it generally makes more sense to provide such training.
- Collaborate with other employers to provide opportunities for generic training (i.e., regional training consortia that can be used to train

[3]Workers located abroad could also be accommodated in this manner. But for some of the reasons discussed in Chapter 5, it is probably easier to use domestic workers—who share common cultural and linguistic referents—than foreign workers.

workers for a wide range of employers). An important part of such collaboration would be to provide internships or other opportunities for integrating work and learning for those being trained. Such actions help to build the local workforce, to the benefit of all employers in the region.

- Consider assigning employees to projects and tasks that broaden and update their skills, rather than assigning them to the tasks for which their skills are greatest. Although assigning people in ways that enhance their skills may reduce productivity in the short term, it could yield greater organizational productivity over the long term by increasing retention of company-experienced personnel. Such in situ training would enable employees to better situate their learning in a real-world experience, and would provide better work-learning integration.
- Provide internships for unemployed workers who have been retrained but who need on-the-job experience to hone and contextualize their skills. Of course, pay scales for such internships would be discounted to account for reduced productivity during the period of the internship, but whether or not the intern remains with the company providing the internship, the worker will obtain valuable experience that will be helpful in obtaining his or her next job.
- Provide management training to IT workers who recruit, hire, train, and supervise. Such training is likely to be especially helpful in those instances in which younger managers supervise older workers. Note that there are well-understood and tested "best practices" for managing the software development process.[4]
- Provide resources that will allow workers to stay current (e.g., financial support for conferences, journal subscriptions, courses).
- Define and/or select courses and subjects of training that employees can benefit most from. Some evidence suggests that employers are better trainers than schools and better able to select effective school-based programs for workers than are the workers themselves.[5] It is thus appropriate that employers provide some guidance for workers who wish to retrain, even if the employer does not pay for training at all.
- Evaluate managers at least partially on the basis of the training their subordinates receive. It is well known that the behavior of individuals in an organization is shaped by the dimensions along which they

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[4]See, for example, McConnell, Steve. 1997. *Software Project Survival Guide: How to Be Sure Your First Important Project Isn't Your Last*. Redmond, Wash.: Microsoft Press. Available online at <http://www.spmn.com/>.

[5]See Bishop, John H. 1997. "What We Know About Employer-Provided Training: A Review of the Literature," *Research in Labor Economics* 16:19-87. An implication is thus that if employers do not themselves support and pay for worker training, they must at the very least provide guidance to workers about courses of training that would be most helpful.

are evaluated, and so manager support of training can be encouraged by such evaluation.

Finally, given the difficulties that institutions of higher education have in finding qualified faculty to teach IT-related subjects, employer encouragement of software developers to take adjunct teaching positions in colleges and universities could provide a mutually beneficial arrangement (as discussed below). Although companies are understandably hesitant to lose the services of talented developers, it is sometimes possible to offer as an employment *benefit* the opportunity to engage in occasional teaching.[6]

Organize work for productivity.

As discussed in Chapter 3, organizational changes can sometimes make a significant difference to productivity and to personnel requirements. For example, IT employers should consider up-front investments in product design to reduce personnel needs later in the development cycle—and such investments should be explicitly noted in the funding plan. IT employers may also wish to consider the use of applications service providers and industry/enterprise-wide software to reduce personnel requirements, and thus possibly lower the need for IT workers nationally.

8.3.2 For Educational Institutions

Improve secondary mathematics education.

The conclusion that mathematics education needs reform is hardly original with this committee. For example, there is a broad consensus among experts in mathematics education on the need to make the mathematics curriculum for all students richer, more challenging, and more focused. In response, the National Council of Teachers of Mathematics has developed challenging standards for mathematics education that embody the elements outlined above. Curricula based on these standards tend to be problem-centered, stress problem-solving and reasoning skills, and address the motivational issues by connecting skills to problems that students might encounter in real life. Often, students in these mathematics

[6]Roberts, Eric, with the endorsement of the ACM Education Board, "Computing Education and the Information Technology Workforce," white paper provided to the Committee on Workforce Needs in Information Technology, 2000.

programs work in groups and pairs, as well as individually, just as IT work often involves project teams or groups. And finally, these new curricula attempt to integrate information technology into the instruction.

Promote IT fluency in K-12 and in colleges to a greater degree.

A familiarity and comfort with IT would seem to be a necessary prerequisite for individuals who will become IT workers. Indeed, educational specialization for IT work can build on a basic level of fluency with IT that is accessible to all. The committee endorses the sentiment contained in the 1999 CSTB report *Being Fluent with Information Technology*,[7] which puts forward the proposition that some degree of fluency with the concepts, skills, and intellectual abilities associated with information technology is appropriate (and increasingly necessary) at the college level, and certainly accessible to lower grades in K-12.

Further, a variety of education reform efforts seek to improve mathematics and science education in K-12. The underlying philosophy of these efforts is to present all students with a robust and intellectually challenging curriculum. If the assumption on which these efforts are founded is valid—that students are in general much more capable of absorbing mathematical and scientific content that was previously thought to be accessible only to a select few—these efforts at reform are likely to produce a much larger pool of individuals who are suited to pursue and are interested in pursuing further education in IT.

The committee recognizes that most K-16 educational institutions are undertaking efforts in this area—but it underscores the importance of creating the widest possible pool of individuals comfortable with using information technology from which IT workers will ultimately be drawn.

Better align educational programs in IT with employer needs.

For a dynamic field such as IT, which exhibits close coupling between the industrial and the academic worlds, it is quite sensible and appropriate to take advantage of possible synergies between the two.

One of the most important points of coupling is providing the opportunity for students to participate in co-op arrangements and internship programs in industry. The committee heard repeated testimony, which incidentally corroborated its own members' experience, that formal knowledge obtained in the classroom is placed into context best in real

[7]Computer Science and Telecommunications Board, National Research Council. 1999. *Being Fluent with Information Technology.* Washington, D.C.: National Academy Press.

work environments. Thus, educational programs in IT should offer real-world work exposure and experience as a part of such training, e.g., through co-op arrangements and internships. These comments are especially true for educational and training programs for older workers, which should provide work experience as well as certification. Indeed, it is not unreasonable for an employer to want to know that a potential new worker can actually complete a project using the skills for which he or she is certified.

A second point of coupling is the fact that many of the IT problems faced by industry are worth studying in academia, especially in professional-level academic programs. The potential practical benefits are large, and in addition they often provide challenging intellectual problems that are as worthy of research as much more theoretical problems even though they appear in an applied context. A corollary is that it is not unreasonable for academicians to seek employer input in formulating curricula, especially in advanced subjects. Indeed, seeing how IT workers steeped in their business problems approach the intellectual content of a computer science curriculum is bound to have salutary effects on students.

An offshoot of the above point is that a concentration on technical knowledge to the exclusion of soft but enduring skills (see Chapter 2) such as communication, teamwork, and management does not serve students well. Traditional education in software engineering has often emphasized "hard" but perishable skills, e.g., knowledge of specific languages such as FORTRAN, C, and Java. However, because soft but enduring skills such as project management and people skills do not become obsolete as technology changes and are themselves critical in the marketplace, they warrant explicit attention in formal curricula (though it is especially important that these be integrated into some work experience).

These comments are not meant to denigrate "hard" skills that endure. For example, system design and architecture are increasingly important, and even a relatively small number of well-trained systems architects could contribute greatly toward the successful development of enterprise-wide software. Techniques for implementing the "ilities" (e.g., security, reliability, trustworthiness, manageability, quality of service, modifiability, scalability, and flexibility) in large systems are also important, and likely to be enduring. Curricula better aligned with business needs would increase emphasis in both these areas.

Employers often say that they want graduates who are able to "hit the ground running" and are then able to stay current with rapidly changing demands of the marketplace. That view argues for a stronger integration of marketplace requirements into traditional computer science training. To the extent that educational institutions can work with professional societies and employers to identify and promote core knowledge and skills that could be addressed by an IT minor or area of concentration, a pool of skilled individuals larger than those of computer science (CS) graduates alone would be available to employers.

Finally, educational institutions can better facilitate the education-to-work transition. Of course, an important part of this transition is teaching skills that can be used in work and providing venues in which those skills can be practiced and enhanced in worklike environments. But equally important is educating workers-to-be about the realities of a changing workplace. Indeed, many of the difficulties encountered by workers in the workplace stem from a mismatch between their expectations and today's marketplace realities.

Another way to facilitate the education-to-work transition is through placement services. Most universities and colleges have placement offices, but an effective job placement operation entails much more effort than is implied by a placement office that does not interact with content-providing departments. Colleges and universities can improve their placement efforts by promoting close and ongoing dialogue between senior academic leaders and local IT employers and by making special efforts to talk up the benefits of hiring nontraditional students.

Expand faculty recruitment pools.

Universities and colleges are seeking to increase permanent faculty in CS undergraduate and graduate programs. However, while research support for faculty seems likely to increase in the future (largely as the result of various new government initiatives to support IT research and development), university administrators are unlikely to allow growth in these programs at the same rate at which demand for IT workers is increasing (especially since they fear that over the long term, traditional tenured appointments in CS may not be justifiable given ups and downs in the demand cycle and may upset the balance among academic departments). And qualified faculty are increasingly difficult to find.

Given such difficulties at all levels, educational institutions will have to consider other options such as the following for faculty recruitment:

- Make greater use of adjunct faculty drawn from industry. Students benefit intellectually from contact with teachers with intimate knowledge of business needs (as described above), and often faculty members from industry are prime channels through which students (their own or others) can be placed and/or recruited.
- Upgrade the skills of existing faculty. For example, some colleges are training electronics teachers in computer science, drafting instructors

(including computer-aided-drafting instructors) in digital media, and art teachers in Web design.

- Use faculty in other departments to assume some of the teaching load. Such an approach is particularly effective for faculty members in related disciplines (e.g., engineering) or in institutions that offer IT minors or concentrations (see below).

In addition, educational institutions can spread existing faculty expertise across more students by offering courses online, hiring teaching assistants, and increasing the work-based component of the curriculum.

Finally, in order to create an environment in which IT-supported intellectual inquiry can flourish across the entire curriculum, faculty in all disciplines should be supported and encouraged to acquire some basic level of fluency with information technology. Only with such fluency will they be able to expose students appropriately to IT in its many pedagogical applications.

Promote formal IT education for students who concentrate in non-IT-related disciplines.

While a formal computer science background is increasingly necessary for many IT occupations, that background is not necessarily or only supplied by a bachelor's degree in computer science. Individuals who concentrate (or have concentrated) their major study efforts in some business domain or some other field should also be able to take computer science or IT minors or concentrations that provide significant exposure to the formal content of computer science curricula. Such individuals are likely to bring special value to employers in those primary areas of study, because they should be able to more effectively apply their IT expertise to problem domains of interest to their employers. Both 4-year colleges and universities as well as community colleges have important roles to play in this regard.

However, such minors or concentrations are not likely to succeed absent close interaction between the faculties in IT and those in the "other" department. Faculty members in the other department should be sufficiently conversant with the basic concepts and fundamentals of computer science to be able to convey those ideas in an appropriate context. And faculty members in IT should be open and sensitive to the field-specific issues that arise in any such collaboration.

The benefits of providing IT-based areas of concentration in other departments should not be lost to those departments. In particular, departments whose enrollments are declining may well be able to boost those enrollments by offering courses that help to prepare students for IT work.

Use professional societies and groups to support educational efforts.

Professional groups should offer more training courses (via distance learning or otherwise), workshops, and publications aimed at keeping the skills of readers current. They can also encourage more young people to enter IT occupations by establishing a curricula "family" that encourages entrance to the IT field through multiple disciplines. Finally, professional societies can provide high schools, parents, and guidance counselors with information about IT career paths, IT occupations, and the skills required for those occupations.

8.3.3 For Individual Workers

Given the realities of today's workplace and likely trends toward high-mobility employment, individual workers are likely to have to assume more responsibility for maintaining the currency of their technical skills in the face of rapidly changing technologies.

- IT workers should seek to negotiate release time for training and professional development where possible and employer financial support for training and professional development. Likewise, they should seek placement into jobs that will develop and enhance skills with current technologies. Such placements are likely to be more accessible when the individual is already employed in a company and is seeking other work inside the company.
- When using formal education to learn new skills, IT workers should seek a project or internship in order to obtain experience applying the new skills. Employers are often reluctant to hire those with classroom training but without actual work experience.
- IT workers should take advantage of training opportunities offered by their employers.
- IT workers should seek to stay current with advances in technology and underlying science through participation in professional societies that publish technical journals and sponsor technical conferences and tutorials. Note also that membership in professional societies can help to inform members about the nature of the employment market as well as provide information relevant to their technical skills.
- IT workers should take advantage of self-study programs, community college and university courses, vendor certification programs, and

other resources for updating their skills in programming tools and languages.

8.3.4 For Government Policymakers

Provide incentives for employers to increase training.

Coupled with the speed at which IT changes, the trend toward high-mobility employment is largely incompatible with significant amounts of training provided by employers, large amounts spent by many IT employers notwithstanding. Yet if workers are to remain competitive in the IT labor market, mechanisms must be found to ensure that they receive the training they need to stay current. However, these same trends that drive the requirement for continuous learning also encourage high worker turnover and discourage employers from investing in worker training.

If one reason that the employment experience of older workers differs from that of younger workers is that older workers lack the up-to-date skills required in this rapidly changing field (a possibility requiring further study), then policymakers may want to consider the access that older workers have to training opportunities. Because of the impediments to training that are described in Chapter 7, government assistance may be necessary to provide that access.

According to neoclassical economics, if training is valuable to firms and workers, they should undertake the necessary amount without inducement from the government.[8] However, there are several reasons why the market may not provide the "right" amount of training, providing both a justification for government intervention and a road map for policy:[9]

- *Lack of access to capital.* Both firms and workers may not be able to borrow the money needed to pay for training. Because human capital resides in the workers and cannot be used as collateral, firms and workers may not be able to borrow against the asset or may have to pay a prohibitively high interest rate.
- *Imperfect information.* Although the economic benefit of higher education has increased dramatically in recent years, workers and firms may

[8]A competing view argues that limited public resources would be better invested in promoting early childhood development and achievement rather than in providing subsidies for training. See Heckman, James J. 2000. "Policies to Foster Human Capital," *Research in Economics* 54(1):3-56.

[9]List based on Barnow, Burt S., Demetra Smith Nightingale, and John Trutko. 1996. *Building the Capital Market for Employer-Funded Training and Education: Background Paper.* Washington, D.C.: The Urban Institute.

not be aware of the magnitude of the increase, or they may not know how long the current high benefits will persist.

- *Greater social than private benefits to education.* It is possible that the value placed on training by society as a whole exceeds the value to individual workers and firms because of "externalities." (For example, increases in training may increase income and therefore reduce dependence on public assistance programs.) As a result, without government subsidization, firms and workers will underinvest in training, relative to the level of investment desired by society as a whole, since they will not reap the full social benefits (only the private benefits).

Training for IT workers can be undertaken by both workers (as described above) and firms. But because firms are hesitant to invest in their workers' general skills given that the workers might leave before the firm can recoup its investment, the committee focused on approaches that have been used or proposed for government to compensate the employer for part of the costs that result from training an employee.[10] Potential government incentives include the following:[11]

- *Tax credits.* If firms were permitted to take tax credits for qualified training activities, the cost of training to firms would be reduced, and they would likely expand their use of training. Tax incentives have been used in the United States to encourage expanding employment, hiring workers with particular characteristics, expanding investment, and expanding research and development. Evaluations of these activities have shown mixed results, so the design must be carefully crafted to achieve the desired results and preclude windfalls.
- *Subsidized loans.* The federal government already offers subsidized loans for education, disaster relief, and establishing or operating small businesses. For several years, the U.S. Department of Labor has been exploring the feasibility of a loan program to encourage more employer training.
- *Direct grants to employers for training.* Several states have operated training grant programs for a number of years. States that operate such

[10]Such actions may also help to relieve perceptions of age discrimination on the part of certain older workers. Because companies may be reluctant to hire individuals who have retrained themselves in new technologies but lack experience in working with them in an on-the-job setting, recent college graduates who have had internship opportunities to obtain work experience that supplements classroom training have an advantage over older workers who would rarely have such opportunities.

[11]See Barnow, Burt S., Amy B. Chasanov, and Abhay Pande. 1990. *Financial Incentives for Employer-Provided Worker Training: A Review of Relevant Experience in the U.S. and Abroad.* Washington, D.C.: The Urban Institute, March.

programs generally require detailed applications from employers to ensure that the training is targeted to the types of training the states wish to encourage.

- *Levy/grant or mandatory training programs.* Under a levy/grant program, employers are required to make payments based on some measure of their ability to pay or their perceived need to train; the funds are then rebated to contributing employers based on their expenditures on training. In contrast, mandatory training programs require employers to spend a specified share of their payroll on training, or they forfeit the unspent funds to the government. Both of these approaches have been used in Europe and Asia to promote training.

The committee is explicitly silent on which, if any, of these mechanisms have proven successful or would be appropriate for the IT sector or IT-intensive industries, and on how strong the incentives should be. However, experience does seem to indicate that employer contributions to training programs (e.g., on a partially matching basis) are needed to obtain employer buy-in—without such contributions, employers have no real incentives to make the program work. With this caveat, the committee encourages all levels of government to consider expanding the use of various training incentive policies.

A final point is that the source of funds for training subsidies is unclear. An argument could be made for the use of general tax revenues, on the grounds that the IT sector is one of strategic importance to the nation. Alternatively, the use of H-1B fees to support training subsidies that are directly linked to the fields in which H-1B workers work is certainly within the spirit of the legislation specifying the disposition of such fees. Again, the committee is silent on which of these sources of funds (or perhaps others) is most appropriate.

Support regional training consortia.

Regional training consortia are useful because they help develop the regional workforce. When employers help to define the training program, its effectiveness and relevance to their needs are likely to be increased. Universities and colleges and community colleges, too, have a role in providing pedagogical expertise and access to intellectual resources that are not usually available in commercial firms. Government support is useful for catalyzing such efforts.

When training consortia succeed, they do so because they provide a mechanism to overcome some of the disincentives to training described above. For example, lack of capital for training can be overcome if larger firms, with more capital, share training costs with smaller firms. More importantly, regional training efforts can overcome the "free rider" problem that results when some firms (often the larger firms) invest in education and training, while other firms steal the trained employees. Regional training consortia also allow member companies to pool both expertise in training and trainees, in order to achieve economies of scale.

Many employers of IT workers already participate in trade associations. However, as discussed in Chapter 6, training and retraining initiatives organized by trade associations are not always successful in helping trainees obtain IT jobs, and they sometimes falter when public funds run out. With stable funding from member firms, regional training consortia would be better able to develop and refine training and employment initiatives. Employers who were financially committed to a regional training consortium might be more likely to provide the internships and structured on-the-job training opportunities that are likely to lead to employment.

Collect better data.

The committee believes that in a highly dynamic field such as IT, better data are required to help policymakers, employers, workers, and students make appropriate decisions. To enable better understanding of the workings of the IT labor market and intelligent policy decisions, both stock (point in time) and flow (changes over time) data are required. Specifically, data are needed on the size of the IT labor force by detailed occupation, industry, and firm characteristics (such as size and type of IT work) and should cover all forms of compensation, including bonuses and stock options. Data that trace work histories are also needed to characterize where IT workers come from (e.g., country of origin, postsecondary education, previous occupation) and the qualifications they bring to the job, as well as exit rates and the occupational destinations of workers who leave IT work. These data must be available more quickly, in more detail, and for larger samples than the government typically collects through surveys such as the Current Population Survey and the Occupational Employment Survey program. Finally, the Immigration and Naturalization Service and the Department of Labor must improve the data they collect and publish on the role of foreign workers in the IT labor force, including—in addition to the categories mentioned above—data on the previous and subsequent immigration status of H-1B workers.

Taking special note of the inadequacy of the available data to address questions of age discrimination, the committee recommends the collection of high-quality data to directly address such questions, such as the data provided by well-designed and properly executed audit studies. The committee recognizes that no single study can establish the existence and/

or extent of discrimination, because almost every study has one limitation or another. Rather, a finding of widespread discrimination must be based on an array of evidence and data. As some courts have found, audit studies can be one important element of such an array. While not every audit study is of high quality, the methodological intent of an audit study is to focus on the experiences of individuals whose characteristics and qualifications are comparable in all ways except for the protected characteristic (e.g., age, race). As a result, they suffer from fewer of the problems that plague studies that rely on survey and administrative data alone, as discussed in Chapter 4. As such, timely and properly performed audit studies provide important evidence relevant to the existence or non-existence of discrimination.

Though some improvements in the federal data-gathering process may result in more and/or better data becoming available in the next few years, the committee recognizes that federal funds for data gathering are limited. Moreover, private efforts to gather such data have sometimes been viewed skeptically because of potential conflicts of interest. The committee therefore suggests that the IT sector and IT-intensive industries work jointly with the government to improve the data collection system for the IT workforce and that the IT sector and IT-intensive industries consider sponsoring specific data collection activities by the Bureau of Labor Statistics and other government statistical agencies.

An important corollary of the recommendation to collect better data is that when more adequate data do become available, policymakers should once again examine the issues that motivated this study in the first place. Many of the questions that the committee would have liked to answer definitively were simply impossible to address given the paucity and poor quality of data available. In the absence of definitive evidence, the committee chose to focus its best efforts on explicating the relevant issues, in the hope that a future analytical effort drawing on data to be available in the future will be able to shed further light on questions of interest to policymakers.

Change funding formulas for state-supported educational institutions.

Today, state and local governments often allocate funding to public educational institutions on the basis of their full time equivalent (FTE) student enrollment. Such formulas make it difficult for these institutions to respond quickly to changes in “hot” areas, such as IT is today. Changes in funding formulas—such as the allocation of discretionary funds for “hot” programs—would help to increase program flexibility and responsiveness, and allow public institutions to bid more effectively on the open market for talent.

Support research.

The federal government has an important role to play in identifying and supporting areas of research that may help to relieve tightness in the IT labor market in the long term. Some of these areas of research include:

- *Work organization, situated learning, and productivity.* By and large, little is known about the kinds of work organization that lead to increased learning and greater productivity among IT workers. In particular, the best approaches to organizing work and training workers who develop or create IT products or applications-based services (Category 1 work, as described in Chapter 2) are not yet clear. It is unlikely that one type of work organization is inevitably superior to others under all circumstances, so a key component of this research would be to identify the circumstances under which one type of organization is better than another. Further, such research should aim at providing managers and corporate executives with actionable guidelines to help them make appropriate decisions before projects are started.
- *Assessment tools for IT jobs.* As noted in Chapter 6, one of the impediments to the use of structured assessment methods in IT is that their administration is resource-intensive. This is a particularly serious issue for undertaking initial screening. One possibility is to explore the notion of an online assessment tool that can be used to identify highly skilled individuals in a nondiscriminatory manner.
- *Software engineering.*[12] A better understanding of the "ilities" (e.g., flexibility, security, reliability, manageability, quality of service, modifiability, and scalability) and how to incorporate them into large systems would be useful in identifying bottlenecks in the software development process. Likewise, software reuse is poorly understood, with outstanding issues about where and under what circumstances software reuse is beneficial in software development, what the benefits are, and how software reuse could be implemented on a wide scale to make a significant improvement in software development productivity.
- *Better integration of the above areas (work organization, assessment, and software engineering).* Because many IT managers were once IT workers themselves, it is important to understand how IT workers can develop key managerial skills. A better understanding of career paths from IT worker to IT manager—and of how the individuals successful in such

[12]For example, a recent NRC report (Computer Science and Telecommunications Board, National Research Council. 2000. *Making IT Better: Expanding Information Technology Research to Meet Society's Needs.* Washington, D.C.: National Academy Press) makes recommendations for increased fundamental research on improving productivity in the design and implementation of IT systems.

transitions integrate technical and managerial knowledge—is likely to enhance the quality of IT management in the future.

More generally, support of high-risk, high-payoff research would help to retain and attract top researchers in and to academia. As noted in Chapter 6, it is hard for the nonprofit academic sector to compete with the commercial sector on the open market for top IT talent. Indeed, those who choose to remain in academia are usually motivated for reasons other than financial ones—reasons such as the desire to teach and to engage in high-risk research that does not necessarily have immediately foreseeable commercial payoff. But the hassles of being an IT academic faculty member are increasing—larger class sizes, increasing difficulty in obtaining research grants, decaying infrastructure, and so on.[13]

A number of reports[14] have called on the U.S. government to increase levels of support for IT research and to support a larger proportion of high-risk, high-payoff research. The committee adds its voice to these reports calling for such action, because of the impact they will have—if successful—in reducing the difficulties involved in conducting university-based research.

Ensure that foreign workers are as free as domestic workers to change jobs, and streamline the green-card process.

Comprehensive and effective reform of law and policy regulating the use of foreign workers in the United States depends on a statutory and regulatory apparatus that does not introduce excessive delay in the processing of individual workers. As noted earlier, employers turn to the H-1B

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[13]One study undertaken by the National Science Foundation (Curtis, Kent. 1983. *Computer Manpower: Is There a Crisis?* Washington, D.C.: National Science Foundation. Available online at <http://www.acm.org/sigcse/papers/curtis83/>) found that most faculty who left academia for industry did not cite economic motivation as the primary reason for the shift. Instead, those faculty identified a range of concerns about the academic work environment—huge class sizes, heavy teaching loads, inadequate research support, the uncertainty of tenure, and bureaucratic hassles—that the NSF study refers to collectively as "institutional disincentives." As enrollments in computing courses rose, these institutional disincentives increased in severity, to the point that faculty became overwhelmed and sought other opportunities elsewhere. While dated, the lessons of this study characterize a substantial fraction of faculty sentiment today.

[14]Computer Science and Telecommunications Board (CSTB), National Research Council, *Funding a Revolution*, 1998; *Trust in Cyberspace*, 1999; and *Making IT Better: Expanding Information Technology Research to Meet Society's Needs*, 2000 (Washington, D.C.: National Academy Press). President's Information Technology Advisory Committee (PITAC). 1999. *Information Technology Research: Investing in Our Future.* Report to the President, February. Available online at <http://www.ccic.gov/ac/report>.

visa program because it provides a route through which foreign labor can be legally hired in the United States in a timely manner. Whereas it can take 5 to 8 years to obtain a green card for an individual worker, an H-1B visa can usually be obtained in a matter of months. Much of the controversy over the H-1B program is rooted in the belief that the use of H-1B workers places U.S. workers at a disadvantage, because of H-1B workers' lack of mobility and their status as "temporary" in the labor force. Based on these problems with the program, the committee makes the following recommendations:

- H-1B visas should be more portable than they are today, thus allowing H-1B workers to change jobs more easily.[15]

Today, H-1B workers cannot change jobs unless and until a new employer files an H-1B petition accompanied by a new labor certification application. In addition, if an H-1B worker who wishes to obtain permanent residency changes employers, is promoted such that his or her job duties change, or relocates with the same employer, he or she may have to start the green-card process all over again, may lose his or her original priority date,[16] and may not complete the process prior to the expiration of his or her H-1B status. In short, many H-1B workers are bound to their employers for immigration-related reasons.

- The green-card process should be reformed and significantly streamlined, thus reducing the time needed to obtain green cards.

The current green-card process for certain categories of employment-based visas is based on legislation dating from 1952 and consists of two components: a labor certification administered by DOL, and an INS review of the foreign worker's proposed employment and credentials, as well as his or her personal history, culminating in issuance of a green card. Both components are in need of reform. One problem with the labor certification process is that it requires a labor market test for certain categories of employment-based immigration that does not reflect inno-

[15]Note that if H-1B visas are allowed to be more portable, a set of circumstances is eliminated in which employers can take advantage of an employee's dependence on remaining in the same job for immigration-related issues; thus, the labor market should become more competitive. In addition, many employers would benefit since it would allow them to reassign employees to new positions more easily; if DOL also developed a more flexible approach to employment changes during labor certification, as recommended below, then H-1B portability would also allow employers to reassign prospective permanent residents to new positions without interfering with their green-card processing.

[16]Recall that the "priority date" is the date that establishes an individual's place in the queue for permanent residency. The priority date is highly relevant because of the per-country numerical yearly quotas for permanent residency.

vations in recruitment practices, such as recruiting at professional meetings or advertising positions on the Internet. More generally, it is widely acknowledged that the current process is delay-ridden, cumbersome, and overly complex. As a result, a labor certification that takes from 6 months to 4 years to obtain may be entirely overtaken by changes in the labor market by the time the certification is granted. Another problem that delays issuance of green cards is that the INS allocates immigrant visas based, in part, on country of origin, resulting in per-country limits on the number of green cards that can be issued each year. Because the limits are reached in several countries where there is high demand for visas (such as China and India), substantial backlogs occur, making the green-card process particularly slow for nationals of those countries.

Recognizing these problems with the current green-card process, the committee recommends that it be reformed according to the following policy principles:

1. The green-card process must be streamlined in a way that significantly reduces labor certification processing and limits total processing times to a time scale of a year or so, rather than the current total of 5 to 8 years. In principle, this is an implementation issue, but policy decisions are likely to be necessary to achieve such changes in implementation. The Department of Labor should develop rules enabling labor certification applicants to change job duties as a result of promotion, change their place of employment, or change employers more easily without invalidating their green-card processing, and Congress should consider changing the "per-country" limits to reflect current immigration patterns. More generally, where possible, steps in the green-card process should be conducted in parallel rather than serially. For example, as noted in Chapter 5, the INS portion of the green-card process involves two distinct steps that currently must be conducted sequentially. INS should consider conducting these steps simultaneously.

2. Any streamlining changes to the green-card process should exist as a matter of regulation or statute, and be administered uniformly throughout the nation. A program based on regulatory or statutory authority is subject to public comment and has a degree of legitimacy not enjoyed by programs based on directives. It is therefore more likely to be administered consistently throughout the nation. Similarly, employers need clear rules and requirements that allow them to know when they are in compliance and what applications will be approved.

3. Labor certification requirements should reflect innovations (such as the use of the Internet) in recruitment and should also reflect that recruiting practices may vary by industry and occupation (professional

employees in some occupations, for example, are recruited at professional meetings).

The DOL has acknowledged a need to reform the labor certification process.[17] In addition, DOL has already undertaken some efforts at reform, e.g., its "reduction in recruitment" (RIR) process. However, while these reforms are a step in the right direction, they do not go "far enough" and likely violate one or more of the committee's articulated policy principles. For example, the RIR process is intended to take into account recruitment practices normal to industry today, and thus to reduce the time needed to process labor certifications. However, the basis for RIR is a DOL administrative letter, which has not been uniformly implemented throughout the nation; different regions vary in both procedures and processing times—from 3 months to 2 years.

In addition, while the committee recognizes that an important controversy regarding the H-1B visa program is its size, it has found no analytical basis on which to set the "proper" level of H-1B visas, and thus decisions to reduce or increase the cap on H-1B visas are fundamentally political. Furthermore, since the H-1B program is used to supply skilled labor in many fields other than IT, an IT-centric analysis is clearly inadequate. At the same time, the current situation, in which the H-1B cap is reached early in the fiscal year, resulting in INS freezing H-1B approvals until the following October and using H-1B numbers from the next year's allotment to satisfy pent-up demand from the prior year, is unacceptable. In order to alleviate this problem, it may be worth considering approaches that either distribute allocation of the visas throughout the year or that move away from the notion of a fixed numerical cap.[18]

Finally, the committee urges policymakers to look ahead several years and consider the effect of having increased the numbers of H-1B visas

[17]For example, the DOL recently published in the *Federal Register* general principles that will "guide the development of proposed regulations to effectuate the redesign [of the labor certification process]" in ways that will "streamline the process, save resources, improve the effectiveness of the program, and better serve the Department of Labor's customers." (See *Federal Register* (20 CFR Part 656, RIN 1205-AB), August 25, 2000, p. 51777.)

[18]Some of the approaches discussed with the committee include auctions of H-1B visa-sponsoring privileges to employers (perhaps periodically to distribute the visas throughout the year); a floating cap that varies with some statistical indicator such as occupational unemployment rates or vacancy rates, with floors and/or ceilings on the cap; and pre-qualification of an employer to use H-1B workers up to some percentage of its workforce (perhaps depending on size), based on attestations and certifications about that employer's hiring and recruitment practices. Because of a lack of time and necessary expertise, the committee did not conduct an analysis of these alternatives, and thus is explicitly silent on expressing a preference among these approaches. These approaches are mentioned simply to demonstrate that a fixed numerical cap is not the only way to approach the issue.

without having significantly streamlined the labor certification process or having reevaluated the numerical limits on immigrant visas available in the U.S. current employment-based immigration program (i.e., the number of permanent visas available to foreign workers based on their job skills and country of origin). The committee believes that it would be a mistake to adopt "stopgap" measures related to this group of nonimmigrant workers and miss the opportunity for a considered debate on the nation's policies regarding employment-based immigrants, given the fact that our economy is rapidly becoming more global.[19] Some of the issues for the national debate include the nature of the appropriate criteria for different classes of immigration (e.g., employment-related skills, family ties, political status), the allocation of visas of different types among occupations and nationality, the number of visas available in each category, and the appropriate balance of indigenous and foreign labor in the United States.

8.3.5 For the Federal Government as a Major User of IT

The government depends heavily on IT systems to conduct business and, more importantly, to provide for the security and welfare of the nation. In many cases, these operations are handled by contractors who develop and operate IT systems for the government. But the government employs many IT professionals directly. One reason is that government systems may contain sensitive data to which contractor access would be inappropriate. A second important reason is that government needs considerable IT expertise to exercise appropriate management oversight for its many IT-related contracts. As described in Chapter 3, the federal government faces a number of specific challenges when seeking to recruit and retain IT workers, including an inability to match private sector compensation, an impending retirement bulge, and a statutory inability to tap foreign workers for certain sensitive positions.

In addition to some of the actions (mentioned above) that all large employers of IT workers can undertake, the federal government should take the following steps.

[19]As noted above and in Chapter 5, H-1B workers seeking green cards may be subject to years of processing delays due to visa backlogs (either because the quota for employment-based immigration is inadequate to handle the growing number of cases or the per-country limitations are inadequate to avoid backlogs for the large number of H-1B workers born in countries such as China and India). Unless Congress also addresses these backlog issues, many of these green-card applicants may not finish their processing prior to the expiration of their H-1B status, forcing them to terminate employment, leave the United States, and wait abroad until an immigrant visa becomes available.

Emphasize the fulfillment that comes from working in responsible positions serving the nation.

In the past, IT and other technical workers have often had great responsibility for implementing and managing complex and important systems. In many cases, government employees have had far more responsibility than they would normally have in private industry. As the amount of contracting out increases, government workers will assume the responsibility for managing large teams of contractors. This can be very fulfilling work. At the same time, IT operations that must remain within the government because of the sensitive nature of their processing can also provide technically challenging work that is of national significance.

A deliberate effort to publicize accomplishments of IT professionals in government would be consistent with such an emphasis. For example, well-publicized award ceremonies, write-ups in trade journals, and some high-level attention to successes working in challenging areas (such as those posed by large federal systems) could well be part of such an effort.

Be more flexible in remuneration and recruiting methods.

The government can take several steps to achieve greater flexibility in remuneration and recruiting:

- Make government compensation systems more competitive with the private sector. The present system cannot react rapidly enough to the rapidly changing IT workplace. Temporary relief is needed to the Civil Service Title 5 rules for as long as the IT labor market remains tight and dynamic. Congress has sometimes provided waivers for demonstration projects, for example, to retain key technical people in Department of Defense (DOD) laboratories. Such programs can provide more flexibility, such as signing bonuses, entry at higher than normal civil service positions, substantial bonuses to outstanding workers, and rapid promotion.[20]
- Update the occupational structure of IT work done in federal service. The current structure does not match the occupations recognized in the IT industry today. Advances in technology mean that IT jobs change rapidly. Broadening the occupational structure of IT work will allow

[20]A first step is to understand the differences in compensation systematically. The federal CIO Council's IT Workforce Committee has partnered with the National Academy of Public Administration (NAPA) and the Office of Personnel Management (OPM) to sponsor a study to document the compensation differences between the federal government and private sector.

greater flexibility for managers to react to changes in the nature of the work.

- Eliminate the restrictions on the remuneration of retired federal employees. Retired federal workers (military and civilian) are an important potential source of IT skills and experience. However, laws on dual compensation prohibit civilian retirees from getting the full combined value of their salary and annuity upon reemployment in the federal service. Recent legislation removed this restriction for retired military personnel. Rehired civilian annuitants, however, only get the difference between their retirement pay and what would have been their salary. This restriction discourages civilian retirees, who therefore take jobs in the private sector.
- Emphasize the special advantages of working in government as an employer for those from nontraditional labor pools: women, minorities, persons with disabilities, and unemployed and underemployed mid-career technical professionals. These advantages include the defined hours, the family-friendly work environment, the stability of employment, and the health and pension benefits.
- Make greater use of intern programs, possibly augmenting them with stipends for course work and term papers that are directly applicable to government problems. Internships are popular in the private sector, and DOD, for example, has had a fairly successful program in the past.

Improve working conditions.

The government should make much greater use of telecommuting and other practices to improve IT working conditions. Telecommuting, flex time, and flex place are standard practice at many companies. Some of these programs are implemented ad hoc in the federal government, but more systemic utilization of new business work models could motivate workers to join or remain in government service.

Make more resources available for training.

The federal government should raise its investment in IT training to the best levels in the private sector in order to maintain the skill levels of its employees and to help with staff retention. For many years the military has provided substantial education and training to its employees. This has been an important factor in retention. Some of these same principles (e.g., tuition reimbursement) can be applied in federal civil agencies.

Use contractors more effectively.

The government should provide contractors with more flexibility in staffing projects. In some cases contracting officers have set unrealistically high educational and experience requirements and compensation rates that are too low. They have also set severe restrictions on the extent to which training can be billed to government contracts. Such measures exacerbate the tightness in the IT labor market that the government feels. For example, requiring a 4-year degree eliminates many highly qualified people from working on government contracts. Loosening these restrictions will increase the pool of qualified workers available to work on government contracts and help companies to maintain the skills of their employees.[21]

The government should continue to innovate in the area of contracting as it has over the past few years and should continue to make greater use of off-the-shelf hardware and software, rather than more expensive and inflexible custom programming. Agencies should take advantage of contracting vehicles that have become much more flexible, allowing government managers to reward good contractor performance and not make awards to contractors with bad records, even though their bid price may be low. Local managers should be given more authority but should be held accountable for the systems that their contractor teams implement. This kind of flexibility will be even more important as the demands for e-government increase in order to be more responsive to citizen needs.

Support a next generation of (federal) IT workers.

Analogous to U.S. government programs that support the education of physicians in return for a number of years of service to medically underserved areas, the government should consider establishing a federal "cyber service" program. For many talented high school students the high cost of college education is a barrier to continued education. An IT scholarship and intern program would provide the financial means for these students to gain a college-level education in IT. The government would pay for a student's undergraduate and/or graduate IT education in return for the student's commitment to government service.

Another aspect of promoting federal service in IT relates to the cultivation of future federal leaders in IT, giving them greater responsibility early in their careers and regular job rotation. For example, the CIO

[21]On May 2, 2000, the House passed a bill (HR 3582) that calls on federal agencies to ease educational requirements for IT workers on government contracts.

Council has recommended that the Office of Personnel Management prepare a program to develop better managers and supervisors for new IT workers who may have many nontraditional work preferences. Such measures are a helpful step that will nurture a next generation of IT workers.

8.3.6 For Joint Action

While federal and state governments, companies, and academia can do more individually to relieve the tightness in the IT labor market, cooperation among these groups is also necessary on a national and regional basis. These constituencies need leadership and motivation to work together, and this can best be provided by the federal and state governments. Examples of actions that can be taken are described below.

Promote awareness of and interest in IT careers.

Stimulating awareness of and interest in IT careers should engage both the public and private sectors. For example, the Department of Commerce noted in mid-1999 the need for greater awareness of opportunities, reporting on an apparent need to improve the image of IT jobs to attract young people[22] and launching an initiative to promote better image-making through the mass and entertainment media as well as renewing emphasis on K-12 education as the time and place to stimulate interest in IT careers. Stimulating youth interest in IT careers has, of course, long been the province of relevant professional societies, and concern about labor market tightness has further stimulated such efforts. The Association for Computing Machinery and the Computer Society of the Institute of Electrical and Electronics Engineers, which represent both Category 1 and Category 2 IT workers, as well as other organizations more focused on Category 2 IT workers, have long been involved in planning for education, mentoring, and youth outreach, including programs for disadvantaged youth as well as youth generally. Professional societies aggregate information about IT careers, education, and training at the national (or international) level and publish it; many outreach activities are developed and undertaken at local levels and in communities. These efforts may provide a useful platform or social network on which to build.

[22]Meares, Carol Ann, and John F. Sargent, Jr. 1999. *The Digital Work Force: Building Infotech Skills at the Speed of Innovation*. Washington, D.C.: U.S. Department of Commerce, June.

Expand opportunities for groups underrepresented in IT.

As noted in Chapter 6, the full utilization of all sources of labor is necessary to cope with a tight labor market. Considerations of fairness, equity, and civic engagement in a democratic society also imply the same course of action. The discussion of structured assessment in Chapter 6 suggests that expanding the pool from which qualified workers can be identified is not inconsistent with meritocratic hiring principles. However, to the extent that groups underrepresented in IT are underrepresented because they have not been attracted to IT work and/or had the appropriate educational and training experiences, government, employers, and educational institutions all have particular roles to play. The following list of actions to be taken by some or all of these parties is derived largely from a paper originally intended to address the issues of women in IT careers;[23] however, the list is applicable with minimal modification to members of all underrepresented groups.

1. Collect better data on the status of underrepresented groups in CS and in IT. Little is known about what encourages youth and adults to pursue IT, what helps to retain them in the field, and what enables them to succeed. Research also needs to be sensitive to the differences between demographic groups (Native Americans may have needs and issues very different from those of African Americans) as well as to the differences within groups (Hispanic Americans have many different countries of origin, as well as backgrounds in different social classes, and also have many individual differences). Thus, research should address how the patterns of access, experience, and attitudes differ across various groups underrepresented in computing fields.

2. Provide role models for all age levels so members of underrepresented groups can imagine themselves as IT professionals. Members of underrepresented groups have entered IT careers in the past despite having few or no role models, but pioneers can pay a high price for their success. To make a substantial increase in the numbers of people from underrepresented groups who select IT careers, it is important to have visible role models who by their presence convey the message that IT is open to all.

3. Provide mentoring for all age levels so that members of underrepresented groups can receive the support they need to scale the professional ladder. Mentors can be from the same demographic group or from

[23]Gurer, Denise, 3Com Corporation, Association for Computing Machinery Committee on Women in Computing (ACM-W), white paper provided to the Committee on Workforce Needs in Information Technology, 1999.

a different group; they can be teachers, supervisors, more experienced workers, or others; they can be volunteers or people who mentor as part of their job. Research shows that personal relationships and mentoring are important components of career success.

4. Recruit additional members of underrepresented groups into CS faculty positions at universities and key IT positions in industry. This recommendation speaks to both role modeling and mentoring at the level of higher education, but it also does more. Diverse faculty can help to shape the field of CS in important ways, and help to educate a new and more diverse generation of IT professionals.

5. Encourage industry to produce products aimed at the interests of underrepresented groups. IT products themselves can by their nature send a message to users about whether or not IT includes them and serves their interest. Even computer games, if sensitively designed, could help to attract to IT careers those who might not otherwise have thought to pursue them.

6. Enhance the public image of computer scientists and engineers. The belief that, for example, one must be a "nerd" to be successful in IT can be a significant barrier. Also, the false perception of IT careers as requiring an 80-hour work week may be particularly discouraging to some groups. IT employers and professional societies would be particularly appropriate stakeholders to pursue an effort such as this.

7. Encourage programs that provide a friendly atmosphere for members of underrepresented groups in academe and industry. Reports of harassment, of "chilly classrooms," and of cultural mismatches for underrepresented groups are frequent in some industrial and educational settings. These problems are not unique to IT, but a tight labor market and declining participation by female students make these issues urgent to address. Also potentially helpful could be an examination of the degree of "social relevance" of educational curricula, as this might be a factor in attracting and retaining underrepresented groups.

8. Provide programs that allow members of underrepresented groups to enter the IT field through alternative programs such as reentry programs. A member of an underrepresented group who chose an alternative career path because he or she was not encouraged to pursue IT should have access to alternative points of entry. Reentry programs, mid-career programs, and the like can help to create alternative paths to a successful career in IT.

Appendixes

Appendix A

Biotechnology

A.1 A SHORT HISTORY OF BIOTECHNOLOGY

Biotechnology dates to ancient times, having been applied to the making of bread by the early Egyptians, the selective breeding of animals (sheep, dogs, cattle), and the domestication of grains. The first major scientific underpinning of biotechnology emerged in 1953, when James Watson and Francis Crick published their paper describing the double helix structure of DNA. In the 1970s and 1980s, biotechnology focused primarily on the production of therapeutic proteins using recombinant DNA technology. In 1970, restriction nucleases were identified, opening the way for gene cloning. Three years later, genetic engineering techniques were developed for isolating and inserting DNA into bacteria so as to reproduce that DNA. Genentech, one of the first biotechnology companies, was started in 1976 with the goal of cloning human insulin. Genentech eventually licensed the human insulin technology to Eli Lilly, and in 1982, human insulin became the first recombinant DNA drug approved by the Food and Drug Administration (FDA). In 1985, Genentech became the first biotechnology company to market its own biopharmaceutical product—a growth hormone for treating children with growth disorders. In 1995, the first complete genomic sequence—for *Hemophilus influenzae*—

NOTE: As noted in the preface, the report addresses biotechnology as a less detailed point of comparison with information technology. Where appropriate, insights from this appendix have been inserted into the main body of the report.

was identified. In 2000, a rough draft of the DNA sequence of the human genome was announced.

A.2 BIOTECHNOLOGY TODAY AND TOMORROW

Modern techniques of cell and molecular biology, combined with capital investment from government, venture capital funds, and the pharmaceutical industry, have helped to create an important new industrial sector, biotechnology. Biotechnology has close ties with academia, which contributes important fundamental research in the underlying science and engineering and also educates a skilled biotechnology workforce. In a recent report, the Biotechnology Industry Organization suggests that biotechnology encompasses a collection of technologies—namely, monoclonal antibody, cell culture, biosensor, genetic modification, antisense, and protein engineering technologies—as well as genomics and informatics. It defines the "new" biotechnology as the use of cellular and molecular processes to solve problems or make products.[1] Currently the main applications of biotechnology are in medicine, agriculture, industrial processes, and environmental management.

By the end of the 1990s, genomics (the use of DNA sequence information to analyze gene products and their biological interactions) and proteomics (the use of databases of protein sequence and structure information to derive general principles of the biological functions of proteins) had begun to change the biotechnology industry. The assembly of the first working drafts of the entire human genetic code announced at the White House in June 2000[2] is likely to have an enormous impact on medicine by enabling development of the following:

- New genetic diagnostic products,
- A new class of genetically defined drugs of improved specificity of function,
- New cures for monogenic and polygenic diseases,
- A better understanding of how drugs can be targeted (pharmacogenomics), and
- New techniques for repairing and regenerating damaged tissues and organs.

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[1]Biotechnology Industry Organization. 2000. "What Is Biotechnology?" Washington, D.C., May 10. Available online at <http://www.bio.org/aboutbio/guide2000/whatis.html>.

[2]Weiss, Rick, and Justin Gillis. 2000. "Teams Finish Mapping Human DNA." *Washington Post*, June 27, p. A01.

In addition, it is probable that tomorrow's health care will emphasize the prediction and prevention of disease as well as interventional treatments and the maintenance of health and well-being based on knowledge of individuals' genetic characteristics and understanding of their predisposition to disease and the risk factors that affect its staging.

Modern molecular genetics, combined with robust statistical and epidemiological methodologies, is being applied to discover the relationships between gene expression and the environment and the influence of gene expression on the onset and progression of disease. With the proliferation of information at the molecular level, chromosomal aberrations are being uncovered in large numbers. For example, a single nucleotide polymorphism, detected through variations in the sequence for a disease-associated gene, may have functional significance in the body and affect an individual's susceptibility or predisposition to the associated disease. Information from polymorphisms also allows scientists to map a gene's location on a chromosome. The integration of chromosome structure data, pharmacological and epidemiological data, and clinical trial response data is required for precise analyses of chromosomal function and aberrations. Such integration is an enormous future task for science, requiring vast computing power and advances in data linkage, mining, and imaging.

Data processing skills relevant to biological data (i.e., bioinformatics) have thus become crucial to health care and the success of the pharmaceutical and biotechnology industry. An immediate challenge for genomics is to correlate gene structure and assembly with gene function and purpose. Much effort will be devoted to defining the genetic components in regulatory pathways responsible for controlling gene expression and to characterizing the biological functions of the proteins that genes encode. This will entail, among other things, a convergence of expertise in such fields as molecular biology, (patho)physiology, protein chemistry, and bioinformatics.

A.3 BIOINFORMATICS AND IT TOOLS FOR BIOTECHNOLOGY

An emerging and increasingly important nexus between biology, biotechnology, and information technology is bioinformatics. Genomics is generating large quantitites of new, high-quality information about complex biological organisms. In addition, computational biology, which uses simulation and computational techniques to define and analyze biological events at the level of the whole organism and, increasingly, at the molecular level, is becoming a central part of biomedical science. To assist their research and help with analyses of the results, biotechnologists rely increasingly on sophisticated IT systems with a range of capabilities.

Bioinformatics focuses on the requirement to analyze, archive, and annotate the vast amounts of data contained in the great diversity of genomic and proteomic datasets.[3] It is a key factor in the progress of biotechnology research and its application to the development of useful products, including gene-defined medicines and diagnostic tools for assessing disease and its etiology.

Robust and scalable computer resources and technologies are needed to formulate and manage datasets placed in large repositories (libraries) of sequence, microarray, gene expression, and clone data. A challenge for IT is to link these heterogeneous datasets and databases in a coherent and navigable form. Furthermore, the volume and diversity of genomic data require that new tools be developed for data analysis.[4] Data mining and knowledge discovery require the application of often-new algorithms for clustering tens of thousands of independent data points automatically to enable the discovery of trends and patterns in large databases of unstructured information and thus help to identify novel relationships. Data mining can automate the identification, extraction, and normalization of information from unstructured text such as technical papers or genetic sequence datasets. One application of data extraction—the automatic population of a database of protein structure and function that is generated by an automated search of the scientific literature—has been technically validated at the National Library of Medicine using the NLM's text processing capabilities (Metamap). In addition to data extraction applications, text processing can be used to cluster and summarize large document sets, although new capabilities in natural language processing and text processing are required.

Also needed are means to facilitate the integration of gene-based data from a wide variety of private and public data sources such as tissue banks, epidemiological databases, and clinical trials so that scientists and clinicians can develop, for example, a comprehensive picture of the progression of a particular disease.

Biotechnologists also have an increasing need to organize and search the scientific literature. Indeed, many biotechnology and biomedical workers can spend large portions of their working time searching for

[3]Bioinformatics is not synonymous with biomedical computing or medical information sciences. Bioinformatics focuses on a computational approach to handling data and is arguably a subspecialty of biomedical computing, which may also include biomedical imaging, information retrieval and analysis for medical decision making, and so on.

[4]Baldi, Pierre, and Søren Brunak. 1998. *Bioinformatics: The Machine Learning Approach.* Cambridge, Mass.: MIT Press.

scientific information. A related issue is that, because the volume of information is increasing so rapidly, the time from discovery to publication is forcing editors and researchers to rethink the traditional methods of publishing in printed journals so that publication times can be reduced. New electronic methods are being discussed.

Other advances in IT related to biotechnology include the development of models that simulate cell processes and the linkage of visual and digital images of physiological and genetic processes. In addition, security and privacy technologies are receiving more attention as confidential personal and commercial data are collected, stored, transmitted, and used in the development and marketing of new products.

A.4 IMPACT OF BIOTECHNOLOGY ON THE ECONOMY

A recent report points out that the biotechnology industry has already had a significant impact on the U.S. economy, having doubled in size between 1993 and 1999.[5] According to the report, the biotechnology industry was responsible in 1999 for the following:

- *437,400 U.S. jobs*. Of these, 150,800 were generated directly by biotechnology companies and 286,600 were generated by companies supplying inputs to the industry or by companies providing goods and services to biotechnology employees.
- *$47 billion in revenue*. Biotechnology companies produced revenues of $20 billion, and companies supplying inputs or selling goods and services to biotechnology employees produced revenues of $27 billion.
- *$11 billion in R&D spending*.

A.4.1 Biotechnology in Drugs, Medical Diagnostics, Agriculture, Environmental Management, and Manufacturing

Biotechnology is a global industry. The United States, Europe, and—to a lesser extent—Australia and Asia provide much of the science and innovation required to develop effective products and processes. Biotechnology spans human and animal health care, agriculture, the industrial manufacture of proteins, and management of the environment. In each of these broad areas, modern biotechnology methods and techniques

[5] Ernst & Young Consulting and Quantitative Analysis. 2000. *The Economic Contributions of the Biotechnology Industry to the U.S. Economy*. Washington, D.C.: Biotechnology Industry Organization.

are leading to new classes of products and enabling processes. For example, in human health care, biotechnology companies are developing, in addition to recombinant therapeutic proteins for drug and diagnostic use, drugs based on genetic information, methods to create patient biosignatures for diagnostic purposes, new manufacturing processes using cells as production factories, and cell and gene therapies.

Health care, including drugs, vaccines, diagnostics, and related products, is the focus of about 55 percent of the biotechnology industry, and employees in such health-related companies account for more than 65 percent of the employees in U.S. biotechnology companies.

A.4.2 Number of Companies and Their Valuation

In 1999, the U.S. biotechnology industry included 327 public companies with 106,000 employees and had total revenues of $15 billion and a total net loss of $2.7 billion (Table A.1). Many of the companies provide larger biotechnology and pharmaceutical firms with support in genomics, combinatorial chemistry, high-throughput screening, and bioinformatics. Although several have positive cash flows, only about two dozen are currently profitable. Private and public companies in the U.S. biotechnology industry in 1999 together totaled 1,283 and had 153,000 employees, total revenues of $18.6 billion, and a total net loss of $5.1 billion.

By contrast, Merck—a large, mature pharmaceutical company—had 53,800 employees in 1998, total revenues of $24 billion, and a net income of $4.6 billion (see Table A.1).

A.4.3 Relationship to the Pharmaceutical Industry

The biotechnology industry has strong connections to the much larger pharmaceutical industry, which provides capital in return for access to new drug technologies, thus playing a role similar to that of venture capitalists in the IT industry. Close technical and business collaboration between the biotechnology and pharmaceutical industries has led in recent years to a melding of employee skills and competencies across the two. Today's pharmaceutical industry is characterized by work teams, techniques, and processes that are often indistinguishable from those in the biotechnology industry. It appears that over time, biotechnology will increasingly become an enabling technology for pharmaceutical as well as agricultural products companies, which will have a greater need for in-house biotechnology competency as corporate alliances mature.[6] Esti-

[6]Mark D. Dibner, president, Institute for Biotechnology Information, private communication, June 2000.

TABLE A.1 U.S. Biotechnology Companies in 1999 Compared with a Large Pharmaceutical Firm in 1998 (billion dollars)

	Public Biotech Companies (1999)	All Biotech Companies (1999)	Merck (1998)
Revenues	15.2	18.6	24.0
R&D expenses	6.2	9.9	1.7
Net income (loss)	(2.7)	(5.1)	4.6
Market capitalization	91.2	97.0	162.0
Number of Employees	106,000	153,000	53,800

SOURCE: Ernst & Young. 2000. *Biotech 99: Bridging the Gap.* Biotechnology Industry Annual Report, pp. 4 and 7. Available online at <http://www.ey.com/global/vault.nsf/International/Biotech99:BridgingTheGap/$file/biotech99.pdf>.

mates suggest that the number of biotechnology employees within the pharmaceutical industry has more than doubled over the past 5 years.

While the pharmaceutical industry has provided much of the financial underpinning for biotechnology companies, venture capital, government grants, and financing from the public markets have also been major factors in the success of the biotechnology industry. Another factor has been employee participation in equity sharing and its contribution to individual wealth generated by public offerings of company stock.

A.4.4 Global Competition: The United States and Europe

The U.S. biotechnology industry leads or is competitive with the rest of the world in terms of its size and the development of innovative products and processes. It can be argued that much of its success derives from early investment by venture capital funds, government, and the pharmaceutical industry in high-risk, cutting-edge science. During the past few years, venture capital funds have made additional investments in Europe's biotechnology industry as academics and governments there adopt a more entrepreneurial approach to the exploitation of basic scientific findings.

In 1996, the U.S. biotechnology industry was at least four times larger than the European biotechnology industry in terms of revenues, R&D expenses, and number of employees but only twice as large in terms of the number of companies (Table A.2).

The U.S. strategy of focusing on the creation of new products and processes has thus far provided a competitive edge over the Japanese strategy of licensing existing products, focusing on production technolo-

TABLE A.2 A Comparison Between the European and the U.S. Biotechnology Industries, 1996

	Europe	United States
Companies	716	1,287
Employees	27,500	118,000
R&D expenses, billion ecu	1.5	6.3
Revenues, billion ecu	1.7	11.7

SOURCE: Animal Cell Technology Industrial Platform (ACTIP) position paper on key figures of the European biotechnology industry, available online at <www.actip.org/manuals/keyfigures.html>. The ACTIP is an informal forum of European companies with activities in animal cell technology.

gies, and investing modestly in basic research.[7] Information published in 1998 estimated the worth of the Japanese biotechnology market at about ¥1,083 billion (about $9 billion).[8]

A.5 WORKFORCE ISSUES

A.5.1 Growth in the Workforce

In 1999, the number of people working in the biotechnology industry in the United States was estimated to be 153,000, a 9 percent increase over the preceding year.[9] Total employment now is estimated at approximately 172,000. Employment has been growing at between 9 and 17 percent per year over the past 4 years and is expected (conservatively) to increase annually by 8.5 percent for the next decade. Over the next 4 years, the number of commercially available products is likely to double from the current total of about 110. In addition, there are 1,100 to 1,800 products in the pipeline—both preclinical and clinical. Of these, about 400 are in the late phases of clinical trials, and it is estimated that about a third of them could become viable and successful commercial products.[10]

[7]Callan, Benedicte. 1996. "Why Production Technology Is Not a Measure of Competitiveness in the Biotechnologies," BRIE Working Paper 86. Berkeley, Calif.: University of California. Available online at <http://brie.berkeley.edu/~briewww/pubs/wp/wp86.html>.

[8]BioIndustry Association. 1998. "*Biotechnology in Japan–Review*," prepared by Euro Japan Marketing Limited (Tokyo), April.

[9]Ernst & Young. 2000. *Biotech 99: Bridging the Gap.* Biotechnology Industry Annual Report, Palo Alto, Calif. Available online at <http://www.ey.com/global/vault.nsf/International/Biotech99:BridgingTheGap/ $file/biotech99.pdf>.

[10]Steve Dahms, San Diego State University, interview March 8, 2000.

A.5.2 Training and Education

The range of expertise needed to develop biotechnology products or processes includes molecular and cell biology, bioengineering, testing, pharmacology, toxicology, process scale-up, clinical research and development, formulation science, regulatory affairs, and manufacturing. Increasingly, the scientific base of biotechnology rests on genetic information developed through the activities of genomics and proteomics, aided by bioinformatics. A strong—and growing—scientific base drives product development in biotechnology. (By contrast, the scientific underpinnings of information technology products are sparser, in the sense that science per se does not drive the solution of user problems.) Perhaps as a result, the general biotechnology workforce responsible for product development requires a higher level of education than does the analogous IT workforce (e.g., biotechnology employs a greater proportion of Ph.D.s). In most cases, biotechnologists must have years of training in experimental work.

At least half of biotechnology industry employees hold scientific and technical positions and are involved in R&D or production.[11] Of these, a typical categorization might be as follows: 19 percent have a Ph.D., 17 percent have an M.S., 50 percent have a B.S., and 14 percent are pre-baccalaureate or community college educated.[12] For the smaller, more research-intensive companies, the proportion of employees with scientific and technical skills may be even higher. For example, 85 percent of the staff of Geron, a 100-employee company, have scientific and technical positions, and more than half have advanced degrees.[13] At Millennium Pharmaceuticals, a company with approximately 1,500 employees, 95 percent of the staff have college degrees, with 60 percent holding advanced degrees, half of which are at the M.D. or Ph.D. level.

Beyond their training in basic science, professionals in the biotechnology workforce require considerable in-house training and education to develop the ability to work on project teams. Furthermore, close interdisciplinary teamwork necessitates a working knowledge of other (sub)disciplines. As a rule, new recruits into the industry do not have such a range of experience.

These comments notwithstanding, formal subbaccalaureate education is also an important source of skills for biotechnology workers (Box A.1).

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[11]Dibner, Mark D. 1999. "Career Alternatives for Scientists." *Nature Biotechnology* 17(8):825.

[12]Steve Dahms, San Diego State University, interview March 8, 2000.

[13]Based on testimony presented at the meeting of the Committee on Workforce Needs in Information Technology, September 22-24, 1999, Santa Clara, Calif.

BOX A.1
Community College Programs in Biotechnology

Biotechnology courses at community colleges fulfill several needs. They provide hands-on experience for those with the relevant scientific qualifications, opportunities for career change (often for people with B.S. degrees), and practical skills for individuals who want to go immediately into industry or move to a 4-year college. Anecdotal information suggests that individuals who complete these programs do not have much difficulty finding jobs in the biotechnology industry, which—if broadly true—implies that they do not experience the difficulties in job hunting perceived by retrained IT workers.

Bio-Link is a National Science Foundation Advanced Technological Education (ATE) Center whose charge is to support new programs and faculty development in community colleges, as well as linkages between community colleges and high schools and between community colleges and 4-year colleges. Bio-Link's national center is at the City College of San Francisco, located at the University of California at San Francisco. Bio-Link also has six regional centers: Seattle Central Community College, in Washington state; San Diego City College, in California; Austin Community College, in Texas; Madison Area Technical College, in Wisconsin; Alamance Community College, in North Carolina; and New Hampshire Community Technical College.

Collaborative networking efforts under the auspices of Bio-Link and similar programs include collaborations such as the following:

- *High school and community college*. A partnership between San Diego High School and San Diego City College resulted in a 3-year biotechnology course in the vocational program at the high school. Year 1 covered DNA; year 2, proteins; and year 3, a research project and an industrial internship. Laboratory space is provided by the college.
- *Community college and both high schools and 4-year colleges*. Austin Community College (ACC) seeks to create a pipeline from high school through the community college to the 4-year college. ACC has helped two high schools set up biotechnology courses by providing equipment and training the teachers. An Industry Board from the local biotechnology industry provides input to ACC on the organization of the biotechnology courses, the material covered, when the courses are held, and so on.
- *Community college and 4-year college.* The Massachusetts Bay Community College operates three biotechnology courses—general biotechnology, marine biotechnology, and forensic DNA science. These courses prepare students for careers as research technicians and for the pursuit of advanced degrees. Eighty percent of the graduates work toward higher degrees, and the rest go directly into industry.
- *4-year college and community college.* The Department of Biological Sciences at the Rochester Institute of Technology seeks students from community colleges and has articulation agreements with the New Hampshire Community Technical College, the City College of San Francisco, and the Finger Lakes Community College, in Canandaigua, New York. Students from these colleges can enter the junior year at Rochester Institute of Technology if their GPA is at least 2.75, if they are students in good standing, and if they are supported by the program director.

A.5.3 Foreign Worker Participation

The biotechnology industry, like the IT industry, has used H-1B visas to recruit staff in areas of skill shortages (see above). According to data collected by Steve Dahms, of San Diego State University, the use of H-1B visa holders is much higher in Southern California's biotechnology industry than first thought. Of the 25,000 employees who work in San Diego area biotechnology and biopharmaceutical companies, approximately 6.4 percent are H-1B visa holders. (One research-intensive biotechnology company, Millennium Pharmaceuticals, reported that 17 percent of its workforce is composed of foreign nonimmigrant workers and that about 3 percent of its staff are permanent residents whom Millennium has sponsored to achieve residency status.) For comparison, among IT workers in the San Diego area 650 out of 10,200 employees at Qualcomm and 321 out of 9,800 employees at SAIC are H-1B visa holders.

A.5.4 Age of Workers and Hiring Needs

According to National Science Foundation SESTAT data (data from surveys on science and engineering personnel), the mean age of those with bachelor's or higher degrees working in the private biotechnology industry (excluding those in academia and in government) is about 37.4 years, comparable to the mean age of the U.S. workforce at large.

Given the life cycle of many biotechnology products (especially those that must clear various regulatory hurdles such as those imposed by the FDA), biotechnology employers place a high value on experienced workers who understand the drug development process and are also experienced managers. As a rule, such workers develop their experience on the job and tend to have spent many years in the industry. In the areas of the United States where the biotechnology industry is most heavily concentrated—in the Northeast (the Boston to North Carolina corridor) and California (San Francisco, San Diego)—employer competition for employees is described as being very keen.

Despite an oversupply of life sciences Ph.D.s,[14] the biotechnology industry is having difficulty finding Ph.D.-level specialists in analytical chemistry, instrumentation, organic synthesis, clinical biostatistics, bioinformatics, production quality assurance, and regulatory affairs.[15] Man-

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[14]National Research Council. 1998. *Trends in the Early Careers of Life Scientists*. Washington, D.C.: National Academy Press.

[15]Steve Dahms, San Diego State University, interview on March 8, 2000, and testimony at the meeting of the Committee on Workforce Needs in Information Technology, September 22-24, 1999, Santa Clara, Calif.

agers with good skills in project definition and management are also in short supply. And, because of the long product cycles and heavy regulatory burden imposed on pharmaceuticals, individuals with experience in the later stages of drug development are highly prized.

A particularly challenging area is bioinformatics. The wealth of biotechnology-related data continues to expand, along with the need to analyze and understand it, and specialists in bioinformatics—arguably a subspecialty in IT work—are now in great demand relative to supply. Other efforts that will increase the need for managing large amounts of information include rational drug design and the conduct of genotype-profiled clinical trials. Such efforts will shorten development and testing times and facilitate targeting of drug delivery more precisely to the people that would benefit. There is no sign that the demand for bioinformatics specialists is abating.[16] Indeed, the demand will continue to grow rapidly, given estimates that as many as 40 percent of the biotechnology companies that survive will be selling information rather than products.[17]

A.5.5 Additional Opportunities and Challenges

In the late 1990s Harold Varmus, then director of the National Institutes of Health, asked his advisory committee "to assess the challenges and opportunities presented to the National Institutes of Health by the convergence of [biomedicine and IT]."[18] The result was a mid-1999 set of recommendations for "national programs of excellence in biomedical computing," including cross-disciplinary education and training as well as institutional support for cross-disciplinary research.

In the newer fields of computational biology, genomics, and bioinformatics, several distinct challenges confront the biotechnology workforce. First, users of genetic sequence data and databases, image repositories, and laboratory cell data are generally not highly trained informaticians. They have studied biology and molecular biology and generally require instruction in how to use IT tools. Second, knowledge-based expert systems are in demand to support clinicians in their decision

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[16]Paula Stephan, "Bioinformatics: Emerging Opportunities and Emerging Gaps," presented at the Government-Industry Partnerships in Biotechnology and Computing Conference, sponsored by the Board on Science, Technology, and Economic Policy, National Research Council, Washington, D.C., October 25-26, 1999.

[17]Steve Dahms, testimony at the meeting of the Committee on Workforce Needs in Information Technology, September 22-24, 1999, Santa Clara, Calif.

[18]Working Group on Biomedical Computing, Advisory Committee to the Director. 1999. "The Biomedical Information Science and Technology Initiative." National Institutes of Health, June 3.

making and to help them make effective use of scientific knowledge. Training that links biologists and computer scientists is critical to meeting these needs. New authoring tools are required to allow researchers, clinicians, and educators to work with complex data without having to learn complex information models or structures. The educational needs of those who have not studied genetics or used genetic principles in their work will be magnified as more clinicians begin to prevent, detect, diagnose, and treat diseases on an individualized basis.

As biotechnology products become more common in the marketplace, individuals qualified for sales and marketing will see additional employment opportunities; such positions are not likely to require postgraduate education in the life sciences. Nevertheless, the industry and its products are driven by scientific discovery, and scientific reasoning and experience are vital to the discovery process in biotechnology. In IT, by contrast, individuals without college degrees can often create and develop successful products.

A.6 SIMILARITIES IN AND DIFFERENCES BETWEEN THE BIOTECHNOLOGY AND IT INDUSTRIES

The biotechnology industry is similar to the IT industry in a number of key dimensions. Both are leaders in scientific innovation. Both enjoy a close relationship among their venture capital, industrial, academic, and government components. Advances in each industry are driven by R&D (e.g., cloning in biotechnology, object-oriented programming in IT), although the biotechnology industry spends a greater proportion of its revenues on R&D than does the IT industry. Both industries are relatively young in comparison with physics and most engineering fields, so they share the advantages and disadvantages of relative youth. Both are entrepreneurially driven, with great importance attached to the availability of venture capital at the front end of the process and the hope for substantial market capitalization. And both industries place a very high premium on speed, as evidenced by IT in its concern over “time to market” and biotechnology in its concern to be “first to invent” and “first to patent,” as well as to lead in time to market.

There are also key differences. Compared to IT product development, product development in biotechnology is more risky, more costly, and generally more time consuming. Unlike the IT industry, the biotechnology industry is highly regulated: for example, the FDA regulates drugs, foods, cosmetics, diagnostics, medical devices, and animal and human food additives, and the USDA regulates animal vaccines, plant pests and derivatives, and transgenic plants and animals. While biotechnology spans the development of products with very short life cycles (e.g., genomics information that is sent business to business) and products with long life cycles (e.g., medicines), for most products, the time to market can be very long (several years). Also, because of the high degree of attrition in developing a clinical product, the success rate for the biotechnology industry is about one in ten, and the averaged cost of bringing a successful therapeutic product to the market represents an investment of around $500 million.

The capital investment needed to pursue biotechnology, especially in the initial stages, is much higher than that for much of the IT industry (chip fabrication aside). Additionally, biotechnology has a much longer history of protecting its innovative efforts by creating barriers to entry (proprietary position/relationships and, especially with the pharmaceutical industry, patents) than does the IT industry, although the IT industry is rapidly turning to patents to protect its innovations as well.

There are interesting cross-plays between the biotechnology and IT sectors. IBM has estimated that drug companies are spending $1.2 billion to $1.8 billion externally on R&D software and IT equipment. As pharmacogenomics and molecular medicine expand, and as clinics and providers move into individualized medicine, the IT opportunity expands alongside them. IBM has announced that its *Gene Blue* project—the company aims to build a computer 500 times more powerful than the fastest computers used today—will attempt to solve the complex problem of protein folding, a key challenge in understanding protein function.

Also, in response to the needs of the biotechnology industry, several new companies are using the Internet to create new markets for bioinformatics and are offering easy-to-use versions of complex software to life scientists rather than to bioinformaticians per se.

Appendix B

Estimating the Size of the IT Workforce

Analysts who have recently examined the size of the IT workforce have developed a wide range of estimates that have varied from just under 2 million to nearly 10 million. These different estimates can be explained but not precisely reconciled.

Estimates of the IT workforce depend, first, on the definition of "IT worker" used. For example, estimating the number of Category 1 IT workers would yield a result (Table B.1) very different from that obtained by estimating the combined total of Category 1 and Category 2 workers (Table B.2). Similarly, estimating the number of individuals in software occupations would be a different exercise from estimating the number of individuals in both software and hardware occupations. Second, estimates depend on the data set used in the analysis and on the occupational categories in that data set used as a proxy for IT workers as defined by the analysts. Finally, estimates depend on whether the analyst focuses on the number of individuals employed, the number of individuals in the labor force (employed plus unemployed who are seeking work), or the number of positions a firm has (filled or vacant).

B.1 ESTIMATING THE CATEGORY 1 IT WORKFORCE

As Table B.1 shows, analysts have derived estimates for the number of Category 1 IT workers ranging from fewer than 2 million to more than 3 million. These estimates are not directly comparable because of the differing definitions and data sets used.

TABLE B.1 Comparing Recent Estimates of the Size of the Category 1, or "Core," IT Workforce

Federal Agency/Analyst/ Organization	Description of Groups Included in Estimate	Estimate of IT Workforce
Capers Jones, Software Productivity Research (1999)	1998 software occupation groups	2,034,000
U.S. Department of Commerce, *Digital Workforce* (1999)	1998 Current Population Survey (CPS): computer systems analysts and scientists, computer programmers (all)	2,084,000
Ellis and Lowell, "Core Occupations in the U.S. Information Technology Workforce" (1999)	1998 CPS: computer systems analysts and scientists, computer programmers (all)	2,084,000
NRC staff analysis	1998 Occupational Employment Survey (OES): estimate of Category 1 occupations	1,649,210
	1998 and 1999 CPS: computer systems analysts and scientists, computer programmers (employed)	1,985,166 (in 1998) 2,092,866 (in 1999)
	1998 and 1999 CPS: computer systems analysts and scientists, computer programmers, computer engineers, computer science teachers (employed)	2,363,309 (in 1998) 2,477,779 (in 1999)
Information Technology Association of America, *Help Wanted* (1998)	Number of positions in core IT occupations: programmers, systems analysts, computer engineers, and scientists	3,354,000

SOURCES: Jones, Capers, 1999, "The Euro, Y2K, and the US Software Shortage," *IEEE Software* 16(May/June):55-61; Ellis, Richard, and B. Lindsay Lowell, 1999, "Core Occupations of the U.S. Information Technology Workforce," *IT Workforce Data Project: Report 1* (New York: United Engineering Foundation, January), available online at <http://www.uefoundation.org/itworkfp.html>); Department of Commerce, 1999, *The Digital Workforce: Building Infotech Skills at the Speed of Innovation* (Washington, D.C.: Department of Commerce, June), pp. 21-31; Information Technology Association of America and Virginia Tech, 1998, *Help Wanted: 1998: A Call for Collaborative Action for the New Millennium* (Arlington, Va.: ITAA).

TABLE B.2 Estimating the Size of the Total (Category 1 + Category 2) IT Workforce

Federal Agency/ Analyst/ Organization	Description of Groups Included in Estimate	Estimate of IT Workforce: Category 1	Estimate of IT Workforce: Categories 1 and 2
Capers Jones, Software Productivity Research (1999)	1998 software occupation groups	2,034,000	
	1998 software occupations, including support occupations		2,383,500
U.S. Department of Commerce			
Digital Workforce (1999)	1998 Current Population Survey (CPS): computer systems analysts and scientists, computer programmers (all)	2,084,000	
Digital Economy 2000 (2000)	1998 Occupational Employment Survey (OES): Estimate of a "middle range" of all IT workers		5,300,000
Information Technology Association of America			
Help Wanted (1998)	Estimate of number employed in "core" IT occupations: programmers, systems analysts, computer engineers/scientists	3,354,000	
Bridging the Gap (2000)	Estimate of Category 1 and Category 2 positions in private, for-profit firms based on NWCET skills standards		10,009,503
NRC staff analysis, 1998 Occupational Employment Survey	Category 1 occupations	1,649,210	
	Category 1 occupations plus computer support specialists and computer programmer aides		2,170,780
	All Category 1 and Category 2 occupations based on *Digital Economy 2000* (2000) (see Table B.6)		5,308,000

continued

TABLE B.2 continued

Federal Agency/ Analyst/ Organization	Description of Groups Included in Estimate	Estimate of IT Workforce	
		Category 1	Categories 1 and 2
NRC staff analysis, 1999 Current Population Survey	Computer engineers, computer system analysts and scientists, computer programmers, computer science teachers: employed, bachelor's degree or above	1,637,244	
	Computer engineers, computer system analysts and scientists, computer programmers, computer science teachers: employed, all education levels	2,477,779	
	All Category 1 and Category 2 occupations (see Table B.5)		3,445,297

SOURCES: Jones, Capers, 1999, "The Euro, Y2K, and the US Software Shortage," *IEEE Software* 16(May/June):55-61; Department of Commerce, 1999, *The Digital Workforce: Building Infotech Skills at the Speed of Innovation* (Washington, D.C.: U.S. Government Printing Office, June), pp. 21-31; Department of Commerce, 2000, *Digital Economy 2000* (Washington, D.C.: U.S. Government Printing Office, June); Information Technology Association of America and Virginia Tech, 1998, *Help Wanted: 1998: A Call for Collaborative Action for the New Millennium* (Arlington, Va.: ITAA); Information Technology Association of America, 2000, *Bridging the Gap: Information Technology Skills for a New Millennium* (Arlington, Va.: ITAA, April); Department of Labor, Bureau of Labor Statistics, Occupational Employment Survey, 1998, and Current Population Survey, 1999, special tabulations.

Capers Jones, based on data from his firm, Software Productivity Research (SPR), estimated a population of slightly more than 2 million IT workers employed in software occupations.[1] His narrow focus on software reflected his intent to examine the effect of the Euro conversion and the Y2K bug on the need for software programmers. His estimate, developed by extrapolating the characteristics of SPR's client group to the national population, must be seen as a rough indication at best of the population of software workers. Other estimates, described below, include both software and hardware occupations.

[1]Jones, Capers. 1999. "The Euro, Y2K, and the US Software Shortage," *IEEE Software* 16(May/June):55-61.

The Department of Commerce, Ellis and Lowell, and the Information Technology Association of America (ITAA) all used a broader definition of "core IT occupations"—"the study, design, development, implementation, support or management of computer-based information systems," as described by ITAA and echoed by Ellis and Lowell.[2] However, each of the three studies used different occupations and data sets. The Commerce Department and Ellis and Lowell counted programmers, systems analysts, and computer scientists in the Current Population Survey (CPS), a monthly survey of households conducted by the U.S. Census Bureau for the Bureau of Labor Statistics. ITAA looked at these occupational groups plus computer engineers in a survey developed and fielded by ITAA. Because of these differences, the three studies arrived at different estimates of the same population (see Table B.1).

Because the Department of Commerce and Ellis and Lowell used the same definition of an IT worker, the same data set (the CPS), and the same occupational categories, they arrived at the same result: 2,084,000 individuals whose occupations were "computer systems analysts and scientists" and "computer programmers."[3] Had the Commerce Department and Ellis and Lowell restricted their analysis to just those *employed* in these occupational groups, rather than *all* workers (employed or unemployed), their estimate would have been slightly lower, at 1,985,166 in 1998, as shown in Table B.1. (This number grew to 2,092,866 in March 1999.)

Many complications arise in using the CPS to estimate the size of the IT workforce. CPS occupational categories and job titles were developed for the 1990 Census. Given the growth and change in information technology in the decade since, these old occupational categories do not begin to address the many new dimensions of IT development, networking, support, and applications. Thus, Census coders must map many new occupations onto old occupational categories, leaving considerable ambiguity as to who is being counted in what occupational groups. A couple of examples illustrate:

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[2]Ellis, Richard, and B. Lindsay Lowell, 1999, "Core Occupations of the U.S. Information Technology Workforce," *IT Workforce Data Project: Report 1* (New York: United Engineering Foundation, January), available online at <http://www.uefoundation.org/itworkfp.html>; Department of Commerce, 1999, *The Digital Workforce: Building Infotech Skills at the Speed of Innovation* (Washington, D.C.: U.S. Government Printing Office, June), pp. 21-31; Information Technology Association of America and Virginia Tech, 1998, *Help Wanted: 1998: A Call for Collaborative Action for the New Millennium* (Arlington, Va.: ITAA).

[3]Ellis and Lowell derived the estimate of 2,084,000 using the CPS average for the first three quarters of 1998. Using the most recent results available to them in November 1998, they arrived at a figure of 2,217,000.

• First, some non-Category-1 IT workers may be counted among Category 1 workers. For example, it is not clear which occupational group Census coders place help-desk staff into. Some help-desk staff may be categorized as "computer programmers," but others may be coded into an occupation that may or may not be readily identifiable as computer-related. If they are categorized as programmers, then not all individuals in the estimate of the Category 1 IT workforce are strictly Category 1 workers.

• Second, depending on the categories used as proxies for the Category 1 workforce, one may derive an estimate that either does not include some Category 1 IT workers or may include as part of Category 1 some individuals who are not IT workers at all. The Census counts computer engineers, who are Category 1 IT workers, as electrical and electronic engineers, an occupational group that includes non-IT workers. To ignore electrical and electronic engineers, estimated at 663,882 in 1998, is to omit from the estimated number of Category 1 IT workers some (computer engineers) who are clearly Category 1 workers. To include them all is to potentially include some non-IT workers in Category 1.

Using the CPS, NRC staff developed an alternative estimate of the Category 1 workforce that helps account for some of the shortcomings in that data set. This estimate uses the definition of Category 1 developed and used by ITAA and Ellis and Lowell. It includes computer systems analysts and scientists, computer programmers, and computer science teachers—all discrete occupational categories in the CPS. It also includes computer engineers, which is not a discrete category but one which can be estimated roughly based on ratios from other data sources.

Although "computer engineers" is not a discrete occupational group within the CPS, it is a discrete group in the Occupational Employment Survey (OES), and it is disaggregated even further—into computer engineering-hardware and computer engineering-software—in the National Science Foundation's SESTAT system (a system of surveys on science and engineering personnel). As shown in Table B.3, all three of these data sets indicate that the total population of electrical, electronic, and computer engineers ranges from about 630,000 to 690,000. As estimated by the OES and the SESTAT, computer engineers account for 47.8 and 52.6 percent, respectively, of this total population. Because the SESTAT data set more fully disaggregates the computer engineering occupation into software and hardware, the committee assumed that the 52.6 percent figure is probably more accurate.

To estimate the number of computer engineers counted in the CPS, the committee multiplied the CPS total for employed electrical and electronic engineers (692,987; Table B.4) by 0.526 and added the result

TABLE B.3 Estimate of the Population of Electrical, Electronic, and Computer Engineers in Government Data Sets, most recent years

Data Set	Electrical/ Electronic Engineers	Computer Engineers, Hardware	Computer Engineers, Software	Total	Computer Engineers as Percent of Total
1997 CPS		692,988		692,988	Not applicable
1998 OES	328,410	300,830		629,240	47.8
1997 SESTAT	317,478	47,368	304,613	669,459	52.6

TABLE B.4 Current Population Survey (CPS) Estimate of Employment and Unemployment in Computer and Computer-related Occupations, 1999

Occupation	Employed	Unemployed	Total
Electrical and electronic engineers	692,987	9,138	702,126
Computer systems analysts and scientists	1,453,072	25,683	1,478,755
Computer programmer	639,794	11,679	651,472
Computer science teachers	20,402	0	20,402
Subtotal—Category 1	2,806,255	46,500	2,852,755
Technical writer	78,201	570	78,771
Computer operators	340,011	10,822	350,833
Peripheral equipment operators	8,164	0	8,164
Data processing equipment repairers	335,777	13,375	349,152
Electrical and electronic technicians	460,899	7,910	471,094
Subtotal—selected support occupations	1,223,051	32,678	1,258,014
Total	4,029,306	79,178	4,110,769

SOURCE: U.S. Department of Labor, Bureau of Labor Statistics, Current Population Survey, 1999, special tabulation.

(364,511) to the CPS estimate of the number of employed computer systems analysts and scientists, computer programmers, and computer science teachers. Table B.5 shows the result—an estimate of the employed Category 1 IT workforce as totaling 2,477,779.

Table B.1 shows that the Occupational Employment Survey, another U.S. government data source, provides an estimate of the Category 1 workforce. The OES, a survey of public and private employers conducted

TABLE B.5 NRC Estimates of Employed and Unemployed Workers in Computer and Computer-related Occupations, 1999

Occupation	Employed	Unemployed	Total
Computer engineers[a]	364,511	4,807	369,318
Computer systems analysts and scientists	1,453,072	25,683	1,478,755
Computer programmer	639,794	11,679	651,472
Computer science teachers	20,402	0	20,402
Subtotal—Category 1	2,477,779	42,169	2,519,947
Computer technical writer[a]	41,134	300	41,434
Computer operators	340,011	10,822	350,833
Peripheral equipment operators	8,164	0	8,164
Data processing equipment repairers	335,777	13,375	349,152
Computer technicians[a]	242,433	4,161	247,795
Subtotal—selected support occupations	967,518	28,658	997,378
Total	3,445,297	70,827	3,517,325

NOTE: Based on the Current Population Survey with adjustments for computer engineers, computer technical writers, and computer technicians.

[a]Computer engineers were estimated as 52.6 percent of the CPS category of electrical and electronic engineers, which includes computer engineers. The same percentage was used to estimate the number of computer technical writers among technical writers and the number of computer technicians among electrical and electronic technicians.

SOURCE: U.S. Department of Labor, Bureau of Labor Statistics, Current Population Survey, 1999, special tabulation.

by the Bureau of Labor Statistics, estimated a total of 1,649,210 Category 1 IT workers in 1998. These individuals were employed as computer engineers, systems analysts, database administrators, programmers, computer science teachers, and all other computer scientists.[4]

[4]The committee believes it is likely that the OES figure underestimates the size of the IT workforce. The OES data for a given year are drawn from a rolling sample of firms surveyed over a 3-year period. That is, the sample is divided by three, with one-third of all firms in a given industry surveyed each year. For 1998, then, data include survey results based on the 1996, 1997, and 1998 surveys. This approach would tend to produce an underestimate in a given year for any rapidly growing field such as IT. For example, if a constant per-year growth rate of 14.5 percent is assumed for this period, as in the CPS, data from 1996 should be adjusted by 31 percent and data from 1997 by 14.5 percent. Thus, the figure for IT occupations in 1998 might be adjusted upward by as much as 15 percent, to approximately 2,250,000.

These Category 1 estimates from government data sources are substantially lower than the ITAA estimate of 3,354,00 (see Table B.1), based on querying a sample of companies nationwide about their number of programmer, systems analyst, and computer engineer/scientist positions. Because of the ITAA question's ambiguity—"About how many [programmer, systems analyst, computer scientist or computer engineer] positions do you have in your entire company?"—it is not clear whether respondents gave the number of filled positions or the total number of positions, filled or vacant. Based on other questions in its survey, ITAA estimated vacancies for these positions at 346,000, which may or may not be included in the figure of 3,354,000.

However it is interpreted, the ITAA estimate may serve as an upper bound on the number of Category 1 workers, although it is important to note that the estimate is based on responses from 532 firms out of a sample of 1,493 (survey response rate of 36 percent). By contrast, the OES had a sample size of more than 400,000 establishments in each of the years 1996, 1997, and 1998, for a total sample size of more than 1.2 million establishments on which to base its 1998 estimates.

B.2 ESTIMATING THE LARGER IT WORKFORCE

While estimates of the number of Category 1 workers vary substantially, estimates of the combined number of Category 1 and Category 2 workers vary still more. The myriad ways in which IT has penetrated our economy, society, and workplace complicate setting bounds on the Category 2 workforce. Most would agree that Category 2 includes technical support specialists, such as help-desk staff, PC support specialists, and technical writers. Should it include individuals who work in such diverse occupations as telephone operator, cable installer, business analyst, desktop publisher, digital animator, or one of the many more occupations involving IT infrastructure and use?

Table B.2 summarizes estimates (from several sources) of both Category 1 workers and the total of Category 1 plus Category 2 workers. The variations in the estimates are substantial, both in the base (i.e., Category 1, as described above) and in the ratio of Category 2 to Category 1 workers.

As noted above, the Category 1 estimates developed by Capers Jones were focused narrowly on software occupations. Similarly, Jones defined Category 2 workers as including a limited range of support occupations (sales and marketing specialist, customer support representative, systems administrator, software librarian, and various process improvement, planning, and cost estimating specialists). These support occupations increased his estimate of the IT workforce by just 17 percent, from 2.03 million to 2.38 million.

The CPS can also be used to estimate the number of workers employed in selected support occupations. At least five occupations in the CPS—technical writer, computer operator, peripheral equipment operator, data processing equipment repairer, and electrical and electronic technician—can be readily identified as including a substantial number of IT workers. If all of the individuals in these categories were included in the estimate of the IT workforce, the total would grow by more than 1.2 million (see Table B.4). But assuming, based on the rationale described above, that about 52.6 percent of all technical writers and electrical and electronic technicians are actually engaged in IT work, it can be estimated that about 967,518 employees work in IT-related support occupations. When this set is added to the number of Category 1 IT workers estimated by the NRC (2,477,779), the result is an increase of 39 percent, for an overall employed IT workforce of 3,445,297 (see Table B.5).

There are yet other CPS occupational categories that potentially include IT workers, depending on an analyst's definition. For example, computer artists are coded as "photographers" and computer graphics illustrators are coded as "painters, sculptors, craft-artists, and artist-printmakers." Similarly, computer systems administrators are coded as "managers and administrators, not elsewhere classified" and computer publishers-editing are coded as "editors and reporters." It is impossible to estimate what percentage of workers in these categories and other categories qualify as IT workers. Accordingly, it is not possible, by using the CPS, to derive an accurate estimate of the "total IT workforce" or of the ratio of Category 2 to Category 1 workers.

If a limited range of computer support occupations—computer support specialist and programmer aide—is added to the OES estimate of Category 1 workers (Table B.6), the estimated size of the IT workforce grows by 32 percent, from 1.65 million to 2.17 million. Other estimates based on the OES have included an even broader range of occupations as defining Category 2 employment. In 2000, the Department of Commerce used the OES to derive a "middle range" estimate of Category 1 and Category 2 workers of about 5.3 million.[5]

In Table B.6, NRC staff have derived an estimate of the IT workforce using the occupational categories listed in the Commerce Department's *Digital Economy 2000* report as applied to OES data. The range of OES occupations used by the Commerce Department to derive the broader estimate includes such diverse categories as engineering, mathematical, and natural sciences managers; electrical and electronic engineers; com-

[5]U.S. Department of Commerce. 2000. *Digital Economy 2000.* Washington, D.C.: U.S. Government Printing Office, June, p. 46. In 1999, the Department of Commerce, in *Digital Workforce*, used the CPS to estimate a core IT workforce of about 2.1 million.

TABLE B.6 NRC Staff Estimate of Employment in Computer and Computer-related Occupations

Occupation	Employment
CATEGORY 1 OCCUPATIONS	
Computer Engineers	300,830
Systems Analysts, Electronic Data Processing	552,530
Data Base Administrators	89,680
Computer Programmers	573,850
Programmers, Numerical Tool and Process Control	8,980
Computer Science Teachers, Postsecondary	24,470
All Other Computer Scientists	98,870
Subtotal: Category 1	1,649,210
COMPUTER SUPPORT OCCUPATIONS	
Computer Support Specialists	455,950
Computer Programmer Aides	65,620
Subtotal: Support Occupations	521,570
OTHER OCCUPATIONS	
Electrical and Electronic Engineers	328,410
Engineering, Mathematical, and Natural Sciences Managers	345,790
Technical Writers and Editors	49,180
Electrical and Electronic Engineering Technicians and Technologists	299,020
Broadcast Technicians	37,240
Billing, Posting, and Calculating Machine Operators	88,600
Duplicating, Mail, and Other Office Machine Operators	189,120
Computer Operators, Except Peripheral Equipment	198,920
Peripheral EDP Equipment Operators	25,130
Data Entry Keyers	416,520
Communications Equipment Operators	280,780
Central Office and PBX Installers and Repairers	41,950
Telegraph and Teletype Installers and Maintainers	1,030
Telephone and Cable Television Line Installers and Repairers	193,850
Data Processing Equipment Repairers	61,680
Electronics Repairers, Commercial and Industrial Equipment	66,360
Electrical Power-Line Installers and Repairers	97,000
Other Electrical and Electronic Equipment Mechanics, Installers, and Repairers	109,470
Electronic Semiconductor Processors	63,110
Electromechanical Equipment Assemblers, Precision	55,370
Electrical and Electronic Equipment Assemblers, Precision	188,700
Total (Category 1, Support, and Other)	5,308,010

NOTE: Based on occupational categories designated by the Department of Commerce, using the Occupational Employment Survey, 1998, in its *Digital Economy 2000*.
SOURCE: U.S. Department of Labor, Bureau of Labor Statistics, Occupational Employment Survey, 1998, special tabulations.

puter support specialists, electrical and electronic engineering technicians and broadcast technicians; various communications equipment and office machine operators; and a variety of assemblers, installers, and repairers of electronic and communications equipment. The addition of many of these occupations has the virtue of including individuals who manufacture, install, repair, and operate the hardware that is critical to the functioning of IT and, especially, telecommunications. However, while the OES categorization of IT-related jobs is more differentiated than that of the CPS, it still lacks currency and sufficiently fine granularity to match the range of today's IT jobs. Thus, the OES categories include many individuals who are not likely to be IT workers in the strictest sense, and they omit many who work in other dimensions of information technology, such as networking and applications. An estimate based on the Commerce Department occupation list, as applied to the OES, must, then, also be seen as rough at best.

At a minimum, though, these estimates from the CPS and OES suggest at least a lower bound on the size of the Category 1 IT workforce, the size of the total IT workforce, and the ratio of Category 2 to Category 1 workers. These surveys point to a Category 1 workforce in 1998 and 1999 of 1.65 million to 2.5 million and an overall IT workforce in the range of 3.45 million to 5.30 million. They suggest a ratio of Category 2 to Category 1 workers of at least 1:1.

The ITAA's surveys, by contrast, provide an upper bound on these estimates. As discussed above, ITAA estimated the number of employed individuals in core IT occupations in 1998 at more than 3 million. Based on its most recent survey, reported in *Bridging the Gap,* the ITAA estimated a larger total IT workforce of just over 10 million positions based on skill standards and occupational groupings developed by the Northwest Center for Emerging Technologies (NWCET).[6] Together, these estimates provide an upper bound on the estimate of Category 1 workers (3.35 million), the total IT workforce (10.0 million), and the ratio of Category 2 to Category 1 workers (about 2:1).

Despite the ITAA's care in elaborating some definitions in its survey—distinguishing IT from non-IT firms and classifiying skills based on the NWCET skills standards—the actual question used in estimating the size of the IT workforce is rather vague. According to *Bridging the Gap,* Appendix VI, IT hiring managers were asked, "How many people in IT-related positions does your company employ?" The report states that "the response of these IT managers was predominantly focused on IT development and support activity," but how such a focus was achieved—

[6]Information Technology Association of America (ITAA). 2000. *Bridging the Gap: Information Technology Skills for a New Millennium.* Arlington, Va.: ITAA, April.

through follow-up questions or a clearer definition of "IT-related position"—is not specified. The ordering of the question on workforce size in the questionnaire is also unspecified but may have had an appreciable impact on the final estimate; a respondent who has already undergone a battery of questions related to the NWCET skill set may be able to provide a more accurate estimate (and have a clearer idea of what "IT-related position" means) than a respondent asked a vague question at the start of the questionnaire. Thus, the question used by ITAA to develop its IT workforce estimate of 10 million may have been overly broad. The committee also notes that several other aspects of the 2000 ITAA survey, such as the representativeness of the sampling frame, how the final sample was constructed, and the response rate, raise concerns about the reliability of its estimate.

B.3 CONCLUSION

Because they are based on different data sets and count different populations, it is impossible to reconcile the varying estimates of the size of the IT workforce produced by various analysts drawing on U.S. government or private data sources. Nevertheless, it is the judgment of the committee that the size of the Category 1 workforce is very likely now, or soon will be, in the range of 2.5 million or more. It is also the judgment of the committee that the size of the Category 2 workforce is at least equal to that of the Category 1 workforce, and may well be larger. Thus, the size of the overall IT workforce is at least 5.0 million, with approximately 2.5 million Category 1 workers and a number of Category 2 workers that is at least as large. To its credit, the most recent ITAA survey explicitly includes a wide variety of Category 2 workers who are not captured systematically in any government data. The committee urges federal data collection efforts to obtain estimates based on similar occupational categories so that policymakers may have up-to-date data based on large-scale government surveys on which to base policy decisions.

Appendix C

Study Committee Biographies

Alan G. Merten, *Chair,* became president of George Mason University on July 1, 1996. George Mason University, located in northern Virginia and within the Washington, D.C., metropolitan area, is a doctorate-granting institution with an enrollment of over 24,000 students. Dr. Merten was previously the dean and professor of information systems at the Johnson Graduate School of Management of Cornell University. He was dean of the College of Business Administration at the University of Florida and associate dean for executive education and computing services at the University of Michigan. Dr. Merten has an undergraduate degree in mathematics from the University of Wisconsin, a master's degree in computer science from Stanford University, and a Ph.D. degree in computer science from Wisconsin. He has held academic appointments in both engineering and business, and academic and business positions in Hungary and France. Dr. Merten is a member of the board of directors of the Center for Innovative Technology. He serves on the board of directors of the Greater Washington Board of Trade, INOVA Health System, three information technology companies, and a mutual trust fund. Dr. Merten was a member of the Governor's Blue Ribbon Commission on Higher Education and served as program chairman of the 1998 World Congress on Information Technology, held at George Mason University.

Burt Barnow, *Vice Chair*, is associate director for research and principal research scientist at the Institute for Policy Studies of Johns Hopkins University. Much of his work focuses on the operation of labor markets and evaluating social programs. He teaches the evaluation course in the Institute's graduate public policy program and a course in labor economics for the Department of Economics. His current research includes an evaluation of the welfare-to-work program, a project to help states design programs to enhance job retention and advancement for welfare recipients, and an evaluation of New Hampshire's welfare reforms. Dr. Barnow received a Ph.D. in economics from the University of Wisconsin in Madison and a B.S. in economics from the Massachusetts Institute of Technology. Before coming to Johns Hopkins, he was vice president of a consulting firm in Washington, D.C. He served 9 years in the Department of Labor, most recently as director of the Office of Research and Evaluation for the Employment and Training Administration.

Eileen Appelbaum is the research director at the Economic Policy Institute in Washington, D.C., where she has been employed since 1991. Formerly she was professor of economics at Temple University and spent several summers as a guest research fellow in the Labor Markets and Employment section of the Wissenschaftszentrum Berlin (WZB). In 1995 Dr. Appelbaum was elected to the Executive Board of the Industrial Relations Research Association and in 1996 was appointed to a 4-year term on the Advisory Council of the WZB. She has acted as consultant to the Office of Technology Assessment (OTA) of the U.S. Congress on several volumes, including *Programmable Automation Technologies in Manufacturing* (1985) and *Trade in Services* (1988), and is coeditor of *Labor Market Adjustments to Structural Change and Technological Progress* (1990). More recently she served on an OTA panel that reviewed modernization plans of the Social Security Administration. She has studied and written about employee participation and is coauthor of *Job Saving Strategies: Worker Buyouts and QWL* (1988); *The New American Workplace* (1994); and *Manufacturing Advantage: Why High Performance Work Systems Pay Off* (2000), on high-performance work systems in the United States. She has published numerous articles on employment and labor market issues and on developments in the service sector of the economy. She has also published extensively on the labor market experiences of women, including the effects of technology on women's jobs and the reasons for the expansion of part-time and contingent work arrangements in the United States. She is the author of *Back to Work: Determinants of Women's Successful Reentry* (1981). Her current research focuses on organizations and employment. Current projects include studies of high-performance work systems and an international comparison of working time arrangements in companies in the industrialized economies. Recent articles on these topics have appeared in *Industrial Relations*, *British Journal of Industrial Relations*, *Inter-*

national Labour Review, and *Labour and Society*. Dr. Appelbaum received her Ph.D. in economics from the University of Pennsylvania in 1973.

Sarah Kuhn is an associate professor in the Department of Regional Economic and Social Development at the University of Massachusetts at Lowell. Her research area is the use and design of information technology, using social science methods to study work processes, and the impact of computer technology in the workplace. These interests have led her also to study the processes by which information technology is designed and technical specialists are educated. She received her Ph.D. in 1987 from the Massachusetts Institute of Technology's Department of Urban Studies and Planning, and she has worked with labor unions on technology-related concerns and with community groups on community development issues. Dr. Kuhn will be a fellow at Radcliffe Institute for Advanced Study at Harvard during the 2000-2001 academic year.

Joel Moses is an institute professor at the Massachusetts Institute of Technology as well as professor of computer science and engineering and professor of engineering systems. He was previously provost at MIT, dean of engineering, and head of the Electrical Engineering and Computer Science Department. He received a B.A. (1962) and an M.A. (1963) from Columbia University and a Ph.D. (mathematics, 1967) from MIT. He led the development of the MACSYMA system for formula manipulation. Other areas of interest include organization of large complex systems, software production, knowledge-based systems, and symbolic manipulation. Dr. Moses is a fellow of the IEEE and AAAS, as well as a member of the National Academy of Engineering (NAE) and the American Academy of Arts and Sciences. He is a member of NAE's Committee on Engineering Education and a member of the advisory boards of Columbia University, Hebrew University, and the University of Michigan's Engineering School. He is also a member of the board of Analog Devices Inc.

Patricia Murray is vice president and director of human resources for Intel Corporation. She is responsible for ensuring that on a global basis the corporation hires, develops, and retains the best and the brightest employees in the industry. She is also responsible for providing world-class technology-based support and service to Intel's more than 70,000 employees around the world. Ms. Murray first joined Intel in 1990, as an attorney on the company's Human Resources legal staff. She was promoted to manager of the Human Resources legal staff in 1992, a position she held until her promotion to vice president and director of Human Resources in 1996. She has been a corporate vice president since 1997. Prior to joining Intel, Ms. Murray was an attorney at the law firm of

Morrison and Foerster in Palo Alto, California, where she specialized in employment litigation and counseling. Prior to her legal career, she was also in the medical profession as an ICU nurse and nursing administrator at the University of Michigan Hospitals. Ms. Murray has a B.A from Michigan State University, a B.S. from Saint Louis University, and a J.D. from the University of Michigan (1986).

James L. Outtz has been an industrial and organizational psychologist in private practice for more than 20 years. His area of specialization is employment selection. Dr. Outtz received his doctorate in industrial/organizational psychology from the University of Maryland in 1976. He is a fellow in the Society for Industrial and Organizational Psychology. An active member of professional organizations, he served for 3 years as a member of the National Research Council's Board on Testing and Assessment and for 2 years on the Committee on Psychological Tests and Assessment of the American Psychological Association. He has published works on a variety of topics, including implementing fair selection strategies, the effect of testing media on validity and subgroup performance, and the use of test score banding as a referral method. Dr. Outtz is a nationally recognized expert in the area of employment selection. The focus of his work reflects a strong interest in the factors that influence the effect of employment tests and other selection devices on racial and ethnic minorities.

Roy Radner has been a Stern School professor of business at New York University since 1996. He teaches microeconomics, including the economics of information and organization. His research interests include decentralization of information, decisions, and incentives in large firms; bounded rationality and the managerial theory of the firm; demand and supply in higher education; and strategic analysis of global warming. A few of his selected publications are "Hierarchy: The Economics of Managing," *Journal of Economic Literature*, Vol. 30, 1992; *Economic Theory of Teams* (with J. Marschak), Yale University Press, 1972; *Demand and Supply in U.S. Higher Education* (with L.S. Miller), Carnegie Commission on Higher Education and McGraw-Hill, New York, 1975; and "Economic Survival," in D.P. Jacobs et al., *Frontiers of Research in Economic Theory*, Cambridge University Press, Cambridge, 1998, pp. 183-209. Dr. Radner has a Ph.D. in mathematical statistics from the University of Chicago (1956) and an M.S. and a B.S. in mathematics (1951 and 1950, respectively). He is also a member of the National Academy of Sciences.

Cecilia E. Rouse is associate professor of economics and public affairs and research associate of the Industrial Relations Section at Princeton University. She is also a faculty research associate in the National Bureau of Economic Research Labor Studies Program, as well as a member of the National Science Foundation Advisory Panel for the Doctorate Data and of the National Charter School Advisory Committee. Dr. Rouse currently has a Mellon Foundation Grant to study the roles of community colleges in postsecondary education. She also currently has grants from foundations such as Annie E. Casey, Smith Richardson, and Spencer to evaluate Florida's new school voucher program. She has published research on the effects of workplace education on earnings, turnover, and job performance; the underrepresentation of women in economics; labor market returns to postsecondary education; the achievement effects of the Milwaukee Parental Choice program; and the existence of discrimination in symphony orchestras. She has a Ph.D. in economics from Harvard University.

Ira Rubinstein is associate general counsel at Microsoft. Previously, he was an associate at MacDonald, Hoague, and Bayless in Seattle. Mr. Rubinstein received his J.D. in 1985 from Yale Law School. He received his M.A. in 1978 in philosophy from SUNY at Stony Brook and his B.A. in 1974 from Clark University, in Worcester, Massachusetts. Mr. Rubinstein is an expert on legal dimensions of electronic commerce and employment issues in the software industry. He was a member of both the U.S. delegation to the Ad Hoc Group of Experts on Cryptography Policy in Paris and the Carnegie Endowment for International Peace, International Migration Policy Program, Study Group on Labor Certification, and he currently serves on the President's Export Council, Subcommittee on Encryption, and on the Board of Trustees of the American Immigration Law Foundation.

Peter Saflund is the associate director of the Northwest Center for Emerging Technologies, whose mission is to advance information technology (IT) education by advancing the quality, quantity, and diversity of the IT workforce. Mr. Saflund was a key player in a recent Center effort to develop skill standards, curriculum, online and traditional courseware, and development models for IT education. He has been a tenured full-time professor of electronics engineering, an associate dean of science technology programs, and technology officer for Puget Sound community and technical colleges. He also has over 20 years of experience in industry, holding engineering and management positions in several major high-technology companies, including Harris Corporation and General Electric, and has owned his own business specializing in voice and data. Mr. Saflund has completed doctoral coursework in community college leadership at Oregon State University. He holds a master's degree in education with a concentration in curriculum and development and holds undergraduate degrees in engineering and education.

Jan Schultz is an experienced executive, software entrepreneur, and software designer. He has had extensive experience in all aspects of software analysis, design, and development, as well as extensive business planning and execution experience. He has started two software businesses and one computer consulting business and has done pioneering medical informatics work in the University of Vermont's Department of Medicine. He is the director of reuse and the team leader of the Reuse Group at IDX Corporation. Mr. Schultz's background includes, most recently, being senior vice president for engineering, president, and founder of StepSoft Inc. Prior to forming StepSoft, he was the director of information services and a member of the executive staff at the University of Vermont Health Center, where he managed operations, application support, the help desk, and production. Mr. Schultz was principal and owner of JRS Computer Consultants in Burlington. He provided product design and implementation in the medical and financial service software industries. He was also principal systems engineer and a founder of Second Foundation Inc., a spin-off from PROMIS Laboratory. While at Second Foundation, he designed and implemented an object-oriented database management system tailored to manage electronic medical records. He also designed and implemented a 4GL with a C-like syntax to operate in the UNIX environment to replace PPL, and he converted 400,000 lines of PPL code to the new language. Mr. Schultz was director of systems development for PROMIS Laboratory and a research associate in the Department of Medicine as well as an assistant professor of computer science in the Engineering, Mathematics and Business Administration College of the University of Vermont. He planned, coordinated, and implemented the evolution of the PROMIS system through four generations of hardware and software. The PROMIS system was a highly interactive, touch-screen system that allowed users to manipulate an electronic medical record within the context of a large body of medical knowledge. He has a B.S. in mathematics and physics and an M.S. in mathematics from the University of Illinois. He developed a very early computer-based teaching machine called Socrates while a graduate student.

Eric Tomlinson is chief executive officer and cofounder of TheScientificWorld, an e-science Internet company providing high-value information products and business services to the scientific, technical, and medical communities. Previously he was the chief executive officer and president of GeneMedicine, Inc., a publicly traded gene therapy company. He is a visiting professor at the School of Pharmacy of London University and has held several academic appointments. He has B.Pharm., Ph.D., and D.Sc. degrees from London University and an honorary D.Sc. from Liverpool's John Moores University.

Ernst Volgenau is the president and CEO of SRA International Inc., a company that he founded in 1978. SRA provides computer, communications, and management consulting services and software to business and government organizations. Since its founding, SRA has sustained rapid growth and now totals about 1,800 people. Dr. Volgenau has 30 years of experience analyzing, designing, and developing large technological systems of all types. He received a Ph.D. in engineering in 1966 from the University of California at Los Angeles. Dr. Volgenau also holds a master's degree in electrical engineering and is a graduate of the U.S. Naval Academy.

Helen M. Wood is the director of the Office of Satellite Data Processing and Distribution, U.S. National Oceanic and Atmospheric Administration (NOAA). She directs the real-time collection, processing, analysis, and dissemination of data gathered from environmental satellites operated by NOAA and other agencies. This operation aids the protection of lives and property through improved weather and climate forecasting and provides support for U.S. search-and-rescue operations. Ms. Wood is a fellow of the Institute of Electrical and Electronics Engineers (IEEE) and has held numerous positions in computer science and engineering societies, including president of the IEEE Computer Society. She was elected IEEE Engineering Manager of the Year and received the Richard E. Merwin Award for distinguished service to the computing profession. She was awarded the Meritorious Service Award of the American National Standards Institute, the U.S. Department of Commerce Gold Medal, and the Presidential Meritorious Rank Award. She holds a B.S. in mathematics from the University of Maryland and an M.S. in computer science from the American University.

APPENDIX D

Briefers to the Committee

JULY 6-7, 1999
WASHINGTON, D.C.

Stuart Anderson, Senate Judiciary Committee (R)
Bill Aspray, Computing Research Association
Cathleen Barton, SAIC
Peter Denning, George Mason University
Bill Griffith, House Judiciary Committee (R)
Ron Hira, IEEE-USA
Ken Pearlman, Lucent Technologies
Michaela Platzer, American Electronics Association
Sue Ramanathan, Office of Representative Zoe Lofgren (D-CA 16th District)
Mark Regets, National Science Foundation
Neal Rosenthal, Bureau of Labor Statistics
Jim Sanders, ITAA
Charity Wilson, AFL-CIO
Joel Yudken, AFL-CIO

SEPTEMBER 22-24, 1999
SANTA CLARA, CALIFORNIA

Martha Amram, Glazecreek
Avron Barr, Stanford University

Barbara Beck, Cisco Systems
Barry Boehm, University of Southern California
Sharon Bray, Career Action Center
James Brentano, Knowledge Services
Clark Catelain, Broadvision Inc.
Cecilia Conrad, Pomona College, CCST
Peter Crabtree, Peralta Community College
Steve Dahms, San Diego State University
John Engman, CompTia/Jobs+Workforce Development Program
Bill Greenhalgh, Corio Inc.
Denise Gurer, 3Com Corporation, ACM Committee on Women in Computing
Elaine Hamilton, Geron
Jack Irving, CDI Information Technology Services
Carver Johnson, Gymboree
Ed Lazowska, University of Washington and Washington Software
Jennifer Lemas, Gilead Sciences
Norman Matloff, University of California at Davis
Mary Patino, Joint Venture Silicon Valley
Mary Ann Rafferty, Onyx Pharmaceuticals
Marco Rosa, Genelabs
Ed Saliba, Sun Microsystems
Sam Stearns, Oregon State University
Nancy Stewart, IBM
David Wadbrook, Heald College
Deone Zell, California State University at Northridge

DECEMBER 8-10, 1999
BOSTON, MASSACHUSETTS

Ashish Arora, Carnegie Mellon University
Michael Best, University of Massachusetts, Lowell
Coeta Chambers, Intel
David Evans, National Economic Research Associates
Ray Fay, Bell, Boyd and Lloyd
Richard Freeman, Harvard University and National Bureau of Economic Research Inc.
David Lee, Suffolk University
Lisa Lynch, International Economic Affairs, Tufts University
Joyce Malyn-Smith, Education Development Center Inc.
Laurie McCann, AARP Foundation Litigation
Jim Outtz, Outtz and Associates
Joyce Plotkin, Massachusetts Software Council

Marc Rosenblum, U.S. Equal Employment Opportunity Commission
Shani Stickney, Millennium
Suzanne Teegarden, Northeast University Center for Urban and Regional Policy

NOVEMBER 22-23, 1999
NEW YORK CITY
SITE VISIT

Frederick Choi, New York University, Stern School
Dominick Cortellessa, Citicorp
Deborah Coughlin, Computer Associates
Elyse Golob, New York City Economic Development Commission
Lynne Hansen, PriceWaterhouse
Virgil Hollender, Dow Jones
Nguyet Huynh, Lucent Technologies
Joseph Katz, Symbol Technology
Karen Marcune, Bell Atlantic; Steward, CWA Local 1101
John Miano, The Programmer's Guild
Karen Morrell, Deloitte & Touche
Jack Moses, USWEB/CKS
Rodney Nichols, New York Academy of Sciences
Donald Riley, IBM Global Services
Rae Rosen, Federal Reserve Bank of New York
Ann Marie Scheidt, SUNY at Stony Brook
Stephen Unger, Columbia University

DECEMBER 13-15, 1999
AUSTIN, TEXAS
SITE VISIT

Ed Boe, Compaq
David Brant, University of Texas at Austin
Dan Frey, PDS Technical Services
Sam Goodner, Catapult Systems
Jim Gover, Kettering University
Tammy Hasley-Harthcock, Dell
Steve Jackobs, Capital IDEA
Gary Madsen, Round Rock Independent School District
Dan Medlin, LCS Inc.
Michael Midgley, Austin Community College
Gene Nelson, www.BrainSavers.org
Diane O'Neal, Team Tech International Inc.

Sally Pedley, Pedley-Richard Inc.
Allyson Peerman, AMD
Bill Reed, American Engineering Association
Carmen Samora, Society of Hispanic Professional Engineers
Mary Jo Sanna, Computer Science 2000, Tech Prep Consortium
Jeff Smith, IBM
Bell Spencer, SEMATECH
Paul Toprac, PSW Technologies and Austin Software Council

JANUARY 10-11, 2000
BELLEVUE, WASHINGTON
SITE VISIT

Greg Birch, Creative Assets
Mike Blain, Washington Alliance of Technology Workers/CWA (WashTech)
Marcus Courtney, Washington Alliance of Technology Workers/CWA (WashTech)
Alan Hardcastle, Washington State Board for Community and Technical Colleges
Chris Hedrick, Online Learning Network
Ed Lazowska, University of Washington
Susannah Malarkey, Technology Alliance
Paul Sommers, Northwest Policy Center, University of Washington
Dave Szatmary, University of Washington Educational Outreach

FEBRUARY 28-29, 2000
FAIRFAX, VIRGINIA
SITE VISIT

Susan Baker, Northern Virginia Technology Council
James Buckner, HQ Army Materiel Command
Paul Donnelly, Immigration Reform Coalition
Michael Dorio, Lockheed Martin Mission Systems and Maryland High Technology Council Education Advisory Committee and Education Network
Steve Gallison, Professional Outplacement Assistance Center
Susan Gilbert, D.C. Department of Employment Services
Lynne Gilli, Career Technology Education
Jack Golodner, AFL-CIO
Lloyd Griffiths, George Mason University
Steven Hill, Communications Workers of America
Ira Hobbs, Department of Agriculture

Lee Holcomb, NASA
David Hunn, Northern Virginia Regional Partnership
John Keaton, IEEE Computer
Patty Keeton, Howard County Community College
Lindsay Lowell, Institute for the Study of International Migration, Georgetown University
Patricia McGuire, Trinity College
Steve Moore, Cato Institute
Ernest Paskey, Office of Personnel Management
John Reinert, IEEE-USA
Fred Thompson, Department of the Treasury
William Valdez, Department of Energy
Renee Winsky, Maryland Technology Development Corporation

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