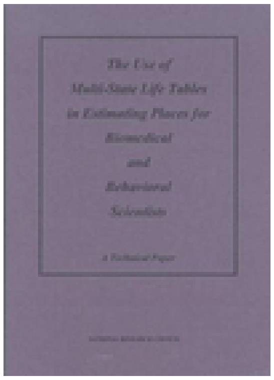

The Use of Multi-State Life Tables in Estimating Places for Biomedical and Behavioral Scientists: A Technical Paper

Committee on National Needs for Biomedical and Behavioral Research Personnel, National Research Council

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A TECHNICAL PAPER

Committee on National Needs for Biomedical and Behavioral Research Personnel
Panel on Estimation Procedures
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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COMMITTEE ON NATIONAL NEEDS FOR BIOMEDICAL AND BEHAVIORAL RESEARCH PERSONNEL

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The paper that follows is a technical paper commissioned by the Committee on National Needs for Biomedical and Behavioral Research Personnel. It is being published well after the report of the full committee, in part, because it is an exploration of a technique that should be considered by future committees, as opposed to a technique that was used in the 1994 report. The Panel wishes to thank Alan Fechter, Jeffrey Kallan, Charlotte Kuh, and Pamela Lohof for their assistance in compiling the statistics, editing, and drafting the report.

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Demographic Models

INTRODUCTION

In 1994, the Committee on National Needs for Biomedical and Behavioral Research Personnel published *Meeting the Nation's Needs for Biomedical and Behavioral Scientists* for the National Institutes of Health (NIH). This was the tenth volume in a series responding to the request by the Congress that the Secretary of Health and Human Services arrange a continuing study of the national need for biomedical and behavioral scientists, to be conducted by the National Research Council (NRC). This volume addressed, as had previous volumes, the nation's future need for biomedical and behavioral research scientists and the role the National Research Service Awards (NRSA) program can play in meeting those needs.

In addition to guidance about the future demand for researchers relative to the current supply, NIH also directed the NRC to review the mathematical projection models of supply and demand used by previous NRC study committees and to establish their adequacy in addressing "national needs" issues in the 1990s. To review these supply and demand models, the committee convened a Panel on Estimation Procedures. The panel carried out an analysis that was used by the committee in preparing its report to NIH. In addition, the panel, the work of which continued beyond that of the committee, undertook further studies that provide the basis for this report.

The panel found that most of the models employed by previous study committees were inadequate and recommended that these models not be used in the future as the basis for developing recommendations. In particular, the panel was skeptical about the possibility of generating useful forecasts of "demand"—defined as employment.

Forecasts of demand for scientific personnel used in the previous reports for NIH were based on functions relating employed scientists to student enrollments and size of funds available for research. They assumed that student-faculty ratios were affected only by biomedical R&D expenditures and that the number of dollars required to support one scientist was fixed. However, student-faculty ratios also depend on other factors, such as salaries of faculty, which in turn reflect market conditions. The relationship between research dollars and Ph.D.s employed also depends on many other factors, such as the cost of non-faculty researchers, facilities and equipment, other inputs to the research process, and the technology of this process, none of which have been included in the models. In addition, the models were employed to project demand forward only five years. Yet these demand forecasts are being used to assess the adequacy of a supply of doctoral and post-doctoral trainees whose education may span a far longer period.

Similarly, the panel was uncomfortable with the approach taken by previous studies to assess job openings created by turnover. Turnover rates based on net (rather than gross) flows were estimated using cross-sectional (rather than time series) data. The validity of such an estimation technique as a basis for forecasting requires that the components of these single-year rates be stable over time. No effort was made to validate this assumption.[1]

Having rejected the previously used models, the panel explored the feasibility of developing projections of the size and characteristics of the future workforce of biomedical and behavioral scientists employing demographic techniques through the use of a life-table model. The data upon which a life-table model is based are the known characteristics of an existing population. In this case, characteristics of interest include age, employment sector, and employment status. Changes are projected in these characteristics based on the life history of the members of the population. Rates of transition (from employed to unemployed by age group or death by age group, for example) are calculated and applied to the behavior of the population in future years. Rates of entry to the system are also an important element of the model. With these techniques, the model can be used to answer the following questions:

- What will the characteristics of the labor force be in five years?
- What will the retirement rate be in the near future?
- How many new openings will there be if the behavior of the population in the future is the same as it was in the past?

Although life-table models can be used to obtain estimates of new openings, it is important to note that they should not be used, mechanically, to perform the task NIH set for the study committee: that is, to estimate future needs for biomedical and behavioral research scientists and the role the National Research Service Awards (NRSA) program can play in meeting those needs. The committee arrived at its recommendations through a process that involved gathering a large amount of both quantitative and qualitative information about future needs for research personnel in different fields in the biomedical and behavioral sciences. In future reports, the panel felt that life-table models could be useful in estimating an "other things equal" baseline.[2]

In this exploratory effort, the panel developed a life-table model using a database that could be used by NIH were it to adopt the model as an aid in formulating its policy decisions with respect to training. A primary objective of this paper is to determine whether the database is adequate to support future modeling efforts and to

[1] A demographic model that employed similar estimation procedures was developed by Xie (1995) to track student commitment to science and engineering careers as they flow through the educational system.

[2] The panel felt, however, that the estimation of such a baseline would be more helpful than earlier work that yielded estimates based on models that were both overly simple and reliant on strong, hidden assumptions.

recommend steps to be undertaken in the future to develop successfully such a model.

This report begins by providing an overview of demographic modeling, including the strengths and weaknesses of this technique. Then the elements of the model are developed (e.g., workforce inflows and outflows are defined) and the data set used for estimation of the model—the Survey of Doctorate Recipients (SDR)—is described. Next, the calculation of transition rates for various life changes (e.g., retirement, changing profession) is described. At this point, the model is used to make retroactive projections that are tested against real data from the SDR. Finally, the panel presents recommendations for further work that is needed to develop the model so that it can be used to project the needs for biomedical and behavioral scientists.

Demographic Modeling: An Overview

Demography involves the study of the structure and dynamics of human populations or subpopulations, focusing on their size and composition and how they change over time. The changes result from flows into and out of these populations, reflecting births, deaths, and migration. The composition of a population or subpopulation will change when there are disproportionate flows of people with a particular set of characteristics. Although these models were originally developed to forecast population growth and size, they can also be used to model change in other populations of interest. Models of the labor force are an example. If the labor force is considered to be a population and the propensity of a sub-population to enter that population changes, the result will be a change in the share of the population whose propensity has changed. More specifically, the proportion of the labor force that is female (a sub-population) will increase if a disproportionately large number of new entrants to the labor force (the equivalent of births) are female, other factors held equal.

One of the simplest demographic models, a "cohort-survival" model, involves projecting the effects of mortality on the size and composition of a given cohort.[3] For example, the size of the cohort at time t, P_t at the next time, P_{t+1}, is projected by multiplying the base population by a "survival rate," 1 -d_t, where dt is the proportion of that cohort expected to die during period t:

$$(1)\quad P_{t+1} = (1 - d_t)P_t$$

This type of model is called a "decrement" model because the cohort can only decline over time.

Any measurable process that involves a time pattern of attrition from or accession to a particular state (e.g., in the above example attrition from life) can be analyzed using "life tables"—a statistical device that helps present in an elegant and convenient way the information in a sequence of age- or duration-specific rates. Life tables can be used to generate projections of the size and characteristics of future populations based on some initial base populations. In the simple example above, where the projection is made over a single period for a single cohort, the life-table contains two elements: P_t and 1 - d_t.

The model can be made more complex by considering multiple periods and/or multiple cohorts. To project for multiple periods, the model must make some assumption about the death rate. Frequently, it is assumed that this rate will remain stable over time. In this case, the life table used to project the future size of the

[3] A cohort is a group of people who experienced a referenced event (e.g., birth, marriage, receipt of a Ph.D., etc.) at a common calendar time (Xie 1995, 60).

cohort after *n* years, P_{t+n}, would include only one survival rate, $1 - d_t$. The equation used to project the cohort to period t+n would be

$$(2)\quad P_{t+n} = (1 - d_t)^n P_t$$

The alternative assumption—that death rates will rise, fall, or vary in some irregular way—will require more than one survival rate in the life table. In this case, the life table would include a set of *n* survival rates.

To project for more than one cohort, the model must have death rates for each cohort being examined. For example, one might wish to project both the future size and age composition of the male and female population in period t+n. To do so the model would require survival rates for both males and females. In this case, there would be two life tables—one for each gender. Each table would include a set of survival rates for each age group, as well as a set of numbers representing the size of the initial population for each age group.

One can further complicate the cohort-survival model outlined above by adding inflows and other outflows. For example, to project the future size of the "biomedical workforce,"[4] inflows would include (1) the number of new Ph.D.s entering the workforce, (2) the number of reentrants to the workforce, and (3) the number who have emigrated to this workforce from other fields or other countries. Outflows would include (1) the number who leave because of death or retirement or other nonworkforce states (e.g., unemployment or nonlabor force activity), and (2) those who leave to jobs in other fields or other countries. These models are typically called "increment-decrement" models because, given both inflows and outflows, the population can either increase or decline, depending on whether inflows exceed or fall short of outflows.

Life tables for these models would include estimates of rates of inflow and outflow. Such tables are generally referred to as "multi-state life tables" because they incorporate many modes of entry and exit from the cohort, as well as movements between states within the cohort. These rates are then applied to an initial distribution of the population of interest across the states to generate a forecast or projection.

[4] The "biomedical workforce" is defined as those Ph.D.s who are employed as biomedical scientists. Comparable definitions of the workforce apply to other fields.

Modeling the Biomedical/Behavioral Workforce: Strengths and Limitations

Although demographic models and associated life tables are typically applied to total populations, the panel examined the applicability of these techniques to a particular subset of the population—those employed in biomedical or behavioral sciences (hereafter referred to as the biomedical or behavioral workforce[5]). These models have both strengths and limitations. Among the possible strengths of such models is their ability to project salient characteristics as well as the size of these workforces. Attributes such as their distribution by age, gender, and type of work activity (e.g., research vs. nonresearch) have policy significance.

The models are capable of addressing the following issues:

- How many new entrants would be required to support a given rate of workforce growth?
- How many members of these workforces can be expected to retire over the next five years?
- How will alternative inflows of new Ph.D.s affect the age distribution of these workforces?
- How long will members of these workforces remain in research careers?

Accurate projections can be generated by these models if the following occur:

- All transitions are made analytically explicit—either by assumption or with estimated values.
- The estimates of the base workforce and the transition rates are derived from a representative sample.
- The estimated transition rates are either stable or vary over time in some predictable way.

These types of models can probably produce more accurate short-term projections than alternative models because most of the future workforce already exists as part of the base period workforce, and information about that workforce is used as a basis for estimation of the model parameters. For a population in which there is relatively little turnover, errors arising from the projections will be small.[6] In

[5] Throughout the rest of the paper, the term "biomedical/behavioral workforce" is used to refer to those Ph.D.s who are employed as biomedical or behavioral scientists.

[6] The magnitude of such errors will vary directly with the size of projected flows relative to the size of the workforce. It will also vary directly with the interval of the projection period.

addition, important flow parameters (e.g., death and retirement rates) are expected to be reasonably stable. This strengthens the expectation of reliable results.

Among the limitations of these models is their reliance on longitudinal databases for estimation of the flows. Such databases are expensive to compile; hence they are relatively scarce. Moreover, such databases are vulnerable to possible response and selectivity biases, which could bias parameters derived from them. For example, if people who change fields are less likely to answer the questionnaire than those who remain in a field, a field mobility parameter estimated from the sample will be smaller than the true parameter. Further, the degree of reliable disaggregation such databases will allow will be limited by their sample sizes. This means that fields that display disparate behavior may be lumped together, and important aspects of behavior for separate fields may be missed. In addition, parameter estimates may vary due to changes in the composition of the heterogeneous sample, even though they might be stable for a particular field taken separately.

Another possible limitation arises from the assumption usually made by such models that their estimates of transition rates are given and not sensitive to market conditions and/or other factors that could affect flows into, out of, and within these workforces.[7] If transition rates are influenced by factors not included in the description of the demographic system, projections using them are likely to prove inaccurate. Demographic models can, however, provide "baseline" analyses that reflect the demographic characteristics of the population being modelled. Adjustment to market conditions can then be incorporated in the demographic model. For example, salaries, which adjust to excess supply or demand, will affect transition rates. If the magnitude of this effect is estimated, transition rates that are assumed fixed in the demographic model can then be made endogenous in a model that incorporates this adjustment to market conditions.

Despite the limitations of demographic models, the committee felt that it could illuminate a number of aspects of adjustment in the biomedical/behavioral workforce that were muddied or improperly specified in the earlier models constructed for NIH.

[7] With sufficient data, it might be possible to estimate how transition rates depend on market conditions.

Applying the Model to the Biomedical and Behavioral Science Workforce

In this workforce analysis, each individual is classified as being in one of three possible states:

- Employed in the biomedical or behavioral workforce
- Employed, but in the nonbiomedical or nonbehavioral workforce
- Not employed[8]

Multi-state life tables are used to model the flows and the distribution of the workforce among these states.

The basic model used to generate projections of the workforce was a standard demographic model in which the future workforce in period t+1 (WF_t+1) was defined as the current (or base) workforce in period t (WF_t) plus gross inflows experienced between period t and period t+1(INF_t) minus comparable gross outflows (OUT_t):

$$(3)\quad WF_{t+1} = WF_t + INF_t - OUT_t$$

Gross inflows between periods t and t+1 include new entrants to the workforce (NE_t), mobility from other fields ($MOBIN_t$), immigration from abroad (IMM_t), and mobility from outside the workforce (WIN_t). Gross outflows between periods t and t+1 include deaths (D_t), retirements (R_t), mobility to other fields ($MOBOUT_t$), emigration to other countries (EMI_t), and those who leave the workforce for reasons other than death or retirement ($WOUT_t$).[9]

Because satisfactory data were not available, IMM_t and EMI_t were omitted from the model. Although it is possible that these omissions offset each other, the panel believes, on balance, that they produce an understatement of NE_t immigration; hence the model probably understates the rates of growth and the sizes of the workforces.[10] WIN_t and $WOUT_t$ are also not included.

[8] "Not employed" includes respondents who report they are either not employed and looking for work (i.e., unemployed) or not employed and not looking for work (i.e., retired, disabled, etc.).

[9] In the model that is estimated below, neither WIN_t nor $WOUT_t$ were included, although they should be if the model is to be used for projections

[10] See Appendix A for a more detailed examination of the zero immigration assumption.

To approximate likelihoods or rates, the model generally expresses these flows as fractions of some relevant stock variable (e.g., the workforce).[11] For example, among the outflows the likelihood of a member of the workforce dying (or death rate (d_t)) was defined as the ratio of D_t to WF_t. Comparable definitions were used for retirement rates (r_t) and rates of mobility to other fields ($mobout_t$).[12] Only one inflow variable—mobility from other fields ($mobin_t$)—was expressed as a likelihood or transition rate. The stock used to deflate this inflow was the workforce of scientists and engineers in other fields (NON_t) (e.g., nonbiomedical or nonbehavioral). New entrants (NE_t) was treated as an endogenous variable, determined by the model, and was not deflated by a stock variable.

Given the assumptions about immigration and emigration, and given the transformations of numbers to rates, the workforce model can be summarized by the following equation:

$$(4)\quad WF_{t+1} = NE_t + (1-d_t-r_t-mobout_t)WF_t + mobin_t NON_t$$

An important issue for determining training needs is the number of new entrants that will be needed to support the workforce (i.e., to replace those who leave and to provide for adequate workforce growth). Equation (4) can be transformed to solve for this number. Solving for NE_t, the equation becomes

$$(5)\quad NE_t = (d_t + r_t + mobout_t)WF_t - mobin_t NON_t + (WF_{t+1} - WF_t)$$

The model assumes that the rates summarized in equation (4) (i.e., d_t, r_t, $mobin_t$, and $mobout_t$) remain constant.[13]

The model presented above shows the calculation of the number of new entrants under the assumption that there is only one cohort, or, equivalently, that the entire population is the same age. In actual application, in a population consisting of a number of cohorts, NE_t is calculated for each cohort and summed to get new entrants for the entire system.[14]

[11] An implication of this assumption is that the transition rates are assumed to be independent of the size of the pool from which these transitions occur.

[12] Transition rates are denoted by lower case and quantities by upper case.

[13] In more technical terms, the model assumes that the transition rates are characterized by a zero-order Markov process.

[14] It is also possible to make the model even more complex by adding an endogenous "fertility" component. In this sort of a model, some fraction of the biomedical workforce enters the professoriate. These professors reproduce themselves by training new Ph.D.s. Their fertility may depend on research funding and the need for graduate student teaching and research. Fertility may also depend on length of time in the professoriate. Regrettable few data are available to permit enrichment of the empirical model in this way.

The Data

With the exception of death rates, the data used to estimate the transition rates were derived from the information collected by the SDR, a longitudinal sample survey undertaken biennially since 1973. From 1973 through 1989, the sample included (1) individuals who earned their doctorates in a science or engineering field from U.S. institutions, (2) U.S.-earned doctorates in education and professional fields, and (3) any doctorates employed in 1973 as scientists or engineers with foreign-earned Ph.D.s. These individuals were to be kept in the sampling frame for 42 years from the time they were first sampled.[15]

The sample used to generate the estimates included only those respondents who reported valid information in two adjacent surveys on employment status, occupation, birth year,[16] and U.S. employment location in both the initial and the terminal year of the biennial period.[17] The proportions were calculated by age of the survey respondent beginning with age category 28-29 and proceeding in two-year intervals through age category 68-69; the final category was age 70 and above.

TRANSITION RATES

To estimate transition rates for the biomedical and behavioral workforces, the data were aggregated into three distinct six-year periods: 1973-1979, 1979-1985, and 1985-1991. This provided a sample size that would be large enough to produce reasonably reliable estimates. It also provided some initial data that would allow

[15] The sampling strategy changed significantly in 1991 when the sampling frame was limited to those who (1) had earned a doctorate in science or engineering from a U.S. institution, (2) were either U.S. citizens or non-U.S. citizens who did not indicate at the time they were awarded their degree that they had firm plans to leave the United States in the following year, and (3) were below the age of 76 (NSF 1994).

[16] Birth year was needed to calculate transitions and workforce statistics by age.

[17] Nonrespondents include both those who did not respond at all to the survey and those who responded to the survey but did not provide the information necessary to describe the transition. Adjustment was made for the former nonrespondents by weighting the individual sample members by the inverse of the nonresponse rate (in addition to weighting by the inverse of the sampling rate). No adjustment was made for the latter nonrespondents. Details on sampling and nonresponse weighting may be found in *Characteristics of the Doctoral Scientists and Engineers in the United States, 1989* (NSF 1991).

the panel to evaluate the assumption that transition rates were stable.[18]

Retirements

Since during the course of a career an individual could have more than one transition to a retirement state, each transition was treated as a separate observation in the retirement rate calculations. To calculate the proportion of retiring biomedical or behavioral scientists, average age-specific retirement rates for combined six-year periods of time were used as model parameters. These rates were calculated by first summing the total number of persons retiring in three separate pairs of survey cycles. For example, survey years 1973 and 1975 represent one pair of survey cycles; persons employed in 1973 but retired in 1975 were counted as "retired" in this pair of survey cycles. Survey years 1973-1975, 1975-1977, and 1977-1979 represent three pairs of survey cycles. The total number of persons retiring in three pairs of survey cycles was then divided by the total number of persons in the workforce during the earlier year of each pair of survey cycles (e.g., 1973 in the 1973-1975 pair of survey cycles). In computing these retirement rates, the data were aggregated over both the biomedical and behavioral science workforces to enhance sample sizes. This aggregation assumes that age-specific retirement rates do not differ significantly between these two workforces.

Field Mobility

Field mobility was defined as movement out of or into the field of biomedical or behavioral science. As with retirement rates, the mobility rates were based on the observed proportion of personnel moving out of or into a field over a two-year period. In the case of biomedical out-migration, for example, the rate was defined as the proportion of persons moving from the biomedical workforce state to a nonbiomedical workforce state between two survey cycles. The biomedical in-migration rate was defined as the proportion of persons moving from the nonbiomedical workforce to the biomedical workforce over a two-year period. As noted earlier, the base (or denominator) of these proportions was not the same for the two types of mobility. For outflows it was the field-specific workforce; for inflows it was the nonbiomedical or nonbehavioral workforce.

The methods used to calculate the mobility rates by age category for the two-year periods and for combined periods of time were the same as those described for retirement rates. Similarly, the methods used to calculate mobility rates for the behavioral workforce were the same as those described for the biomedical workforce.

The model includes four disjoint workforces: biomedical, nonbiomedical, behavioral, and nonbehavioral.[19] The number flowing into the biomedical (or behavioral) workforce is constrained by the model to be equal to the number flowing out

[18] A more complex model would estimate how the transition probabilities change as a function of variables that are projected or predicted.

[19] By nonbiomedical or nonbehavioral, we mean those who are trained as biomedical (or behavioral) scientists but are not employed as biomedical (or behavioral) scientists.

of the nonbiomedical (or nonbehavioral) workforce.

Deaths

The methodology used by the SDR to estimate the number of deaths was considered to be inaccurate as it was produced by a sample that was too small to be considered reliable. Therefore, death rates were estimated from data for TIAA policyholders used in a recent study of faculty labor markets.[20] The age-specific death rates were based on five-year rates from the mid-1980s.[21]

New Entrants

"New entrants" were defined in the model as individuals who either had entered the workforce for the first time or had reentered the workforce after a period of time in the nonworkforce state. The number was not estimated from existing data sources. Instead it was solved for by the model. The estimate represented the number needed to support a given projected rate of workforce growth.[22] These new entrants were distributed by age based on SDR data from two pairs of adjacent surveys as shown in Appendix B.[23]

Summary of Flow Data

The estimated transition rates generated from the SDR and the TIAA data are summarized by type of transition and period of analysis in Table 1.[24] When averaged over all age groups within a period, these estimated rates look reasonable and do not display large amounts of variation. Most of the observed variation reflects interperiod differences in the age distribution of the workforce. Age-specific mortality and retirement rates, as well as in-migration and out-migration rates, are shown in Appendix C. Overall rates are shown in Table 1 for the three cohorts.

The average mortality rate is about 1 percent in the biomedical workforce and

[20] See Bowen and Sosa, 1989, pp. 201-2.

[21] Two-year death rates were calculated based on a memo from Peter Tiemeyer, a consultant to the project, dated September 1993. Tiemeyer calculated death rates by sex, adjusting the five-year rates found in Bowen and Sosa. The Bowen and Sosa rates were generated by TIAA for the mid-1980s. For the workforce below the age of 70, Tiemeyer's male and female rates were combined to produce a rough approximation of the aggregate rates by weighting the male rates by two-thirds and the female rates by one-third. The estimated death rate for the workforce aged 70 and over was derived as an "educated guess."

[22] The number includes replacement needs (defined as the number who transition out minus the number who transition in from other workforces) and incremental needs (defined as the number required to support a given rate of workforce growth).

[23] For the 1973-1979 parameters, the estimate of the age distribution of new entrants was generated by the data reported on the 1975-1979 surveys; for the 1979-1985 and 1985-1991 periods, the age distributions were estimated from the 1981-1985 and 1987-1991 surveys, respectively. The age distributions are described in Appendix B.

[24] Detailed tables are included in Appendix C.

TABLE 1 Estimated Transition Ratesa by Type, Field, and Time Period

		ESTIMATED RATES[b]	
Type and Field	1973-1979	1979-1985	1985-1991
MORTALITY			
Biomedical	1.01	1.03	1.08
Behavioral	1.43	1.14	1.20
RETIREMENT	1,38	1.79	2.67
MOBILITY			
TO OTHER FIELDS			
Biomedical	3.91	3.33	3.62
Behavioral	2.27	2.35	2.44
FROM OTHER FIELDS			
Biomedical	0.89	0.58	0.86
Behavioral	0.27	0.23	0.33

[a] Estimated rates are expressed per 100 workforce members per two-year period.
[b] Estimated rates are weighted averages of age-specific rates.

ranges between 1.2 and 1.5 percent in the behavioral workforce. Retirement rates show a clear upward trend and range from 1.4 to 2.7 percent. Mobility rates to other fields are in the 3 percent range in the biomedical workforce, and they are in the 2 percent range in the behavioral workforce. Mobility rates from other fields range from 0.6 to 0.9 percent in the nonbiomedical workforce and from 0.2 to 0.3 percent in the nonbehavioral workforce.[25] There was initial concern about the stability of these estimates over time since this is one of the critical assumptions underlying the model. Another concern was about the adequacy of the SDR sample for producing reliable estimates. The empirical analysis summarized below addresses these issues.

STABILITY OF ESTIMATES

For each of the transitions, the data reveal a considerable amount of stability over time. It is reassuring to find the variability among time periods was only a fraction of the variability among age groups at a given period of time. This suggests that if we know the age distribution of the population, we can make projections with

[25] It is not surprising to note that the means and standard errors of the mobility rates from nonbiomedical and nonbehavioral fields are substantially smaller than those for the other fields since they were generated from samples that were substantially larger than those of the biomedical and behavioral workforces.

some assurance that the process generating the transition rates is not changing, but only the size of the cohorts that are moving through those ages.[26] Table 2 summarizes the variability among age groups. The difference between high and low estimates (i.e., the range of estimates) is 9.9 percentage points for death rates (in contrast to the interperiod difference of 0.1 percentage points summarized in Table 1). The range exceeds 26 percentage points for retirement rates (in contrast to the interperiod difference of 1.4 percentage points summarized in Table 1). It exceeds 8 and 7 percentage points for mobility rates to other fields from the biomedical and behavioral workforces, respectively (in contrast to interperiod differences of 0.3 and 0.1 percentage points summarized in Table 1). And it exceeds 2 and 0.7 percentage points for mobility rates from other fields to the biomedical and behavioral workforce (in contrast to interperiod differences of 0.3 and 0.1 percentage points summarized in Table 1).

PRECISION OF ESTIMATES

In addition to displaying a reasonable amount of stability over time, the rates seem to be reasonably precise. A commonly used statistical indicator of precision is the "standard error" of the estimate. This indicator is inversely related to precision (i.e., estimates with a small standard error are more precise than those with a larger Standard error). The "coefficient of variation"—the ratio of the standard error to the mean of the estimate—summarizes the relative variability of an estimate. This may be a more meaningful indicator of precision since it is adjusted for the size of the estimate. Again, an inverse relationship exists between the size of the coefficient and the precision of the estimate; an estimate with a small coefficient of variation is more precise than a large coefficient.

The coefficients of the estimated age-specific, period-specific transition rates derived from the SDR are summarized in Appendix D.[27] The distribution of these coefficients reveals that the estimates are reasonably precise and that the estimates for the biomedical workforce were more precise than those for the behavioral workforce. When aggregated over both workforces, over two-thirds were 0.3 or less. This means that these rates were more than three times the size of their standard errors, and that more than one-half of the coefficients for both workforces were less than 0.2, meaning that these rates were at least five times the size of their standard errors.

[26] The large range in retirement rates makes intuitive sense since almost no one retires from the younger cohorts (a very low age-specific rate), while virtually everyone retires from the oldest cohorts (a high age-specific rate).

[27] The panel was unable to estimate the standard errors of the mortality rates derived from TIAA. However, since they are based on actuarial experience, it is presumed that they are quite reliable.

TABLE 2 Estimated Range[a] of Transition Rates by Type, Field, and Time Period

	ESTIMATED RANGE (in percentage points)		
Type and Field	1973-1979	1979-1985	1985-1991
MORTALITY	9.90	9.90	9.90
RETIREMENT	35.45	30.79	33.99
MOBILITY			
TO OTHER FIELDS			
Biomedical	17.62	13.89	9.44
Behavioral	12.22	6.73	6.53
FROM OTHER FIELDS			
Biomedical	2.67	2.26	2.29
Behavioral	4.02	0.99	0. 73

[a] Range is defined as the difference between the high and the low age-specific transition rate.

Initial Results

Using the age-specific death, retirement, and field migration rates, the model described earlier and its associated life tables were used to estimate the average annual flow of personnel into and out of the biomedical and behavioral sciences workforces and, based on these, to calculate the annual number of new entrants. A defined growth rate was applied to calculate a target workforce, and a comparison of the estimated workforce (after all relevant inflows and outflows had been computed) with the target workforce provided the number of new entrants needed to sustain that growth rate. Recall, however, that the model assumes zero immigration (of doctorates with degrees from foreign institutions) and zero emigration and does not include flows to or from the "out of workforce" state. These assumptions bias downward the estimated workforce and its rate of growth.[28]

ACCURACY OF THE MODEL

The accuracy of the model in projecting the number of new entrants needed was assessed by applying it to biennial data for the period 1980-1981 to 1988-1989. The model was used to produce biennial "forecasts" of the number of new entrants, the total workforce, and the median age of the workforce. The base period used to generate these forecasts was 1978-1979. Due to the omission of immigration data and of data on flows in and out of the workforce, as well as the assumption of constancy for transition rates, the committee did not expect to achieve especially accurate results. Rather, the assessment presented in this section is shown as an exemplar of ways in which a model could be assessed were it to include the omitted data and were the transition rates to be modeled more richly.

The average annual growth rate used to forecast new entrants for the biomedical sciences workforce was 4.2 percent, while the growth rate used to forecast the behavioral sciences was 4.0 percent. These rates are based on actual SDR growth rates for these workforces between 1980 and 1989. Observed average retirement and field migration rates for the three biennial periods covering 1973-1979 and the observed average age distribution of new entrants for the two biennial periods covering 1975-1979 were used as model parameters.[29]

[28] For a more detailed discussion of this issue, see Xie, p. 9, and Appendix A.

[29] While using data from the 1977-1979 survey cycle pair would have produced estimates based on experience closest to the forecasting period, an average of several pairs of survey cycles was used to increase the sample size.

The forecast data were then compared with the actual data for each two-year period from 1980-1981 through 1988-1989. Given the use of actual growth rates for the period 1979-1989, it is not surprising to find that forecasts of the workforce derived from the model closely track the observed data for both the biomedical and behavioral science workforces. The model forecasts an increase of roughly 25 thousand, from 63 thousand to 88 thousand, for the biomedical workforce. The actual increase was 23 thousand. Similarly, for the behavioral science workforce the model predicts a growth of 19 thousand, and the actual increase was 17 thousand.

The findings are not as impressive for the forecasts of required new entrants. The model vastly underestimated the number needed for the biomedical workforce in 1980-1981, but it tracked reasonably well for the remainder of the period. The average absolute value of the relative forecast error is slightly less than 10 percent.

In the behavioral sciences, the observed number of new entrants increased between 1980 and 1985 and then decreased between 1986 and 1989, while the forecast number increased steadily over the entire period. This resulted in a strong trend in the forecast error, which understates needs by about 10 percent in 1980-1981 and eventually overstates needs by 27 percent in 1988-1989. The average absolute value of the relative forecast error was almost 13 percent. The discrepancy reflects, in part, a difference between the actual and forecast workforce growth rates. The model used the average workforce growth rate for the entire 1980-1989 period. The actual growth rate within the 1980-1989 period varied: it was higher in the first half of the decade than it was in the second half.

The strong trend in forecast errors for new entrants to the behavioral science workforce generated a similar trend in forecast errors for the median age of that workforce. The model consistently understates this age, and the gap between actual and forecast values grows over time. For the biomedical science workforce, the forecasts of median age were very similar to the observed median ages.

The relatively poor performance of the model for the behavioral sciences for a period of slowing growth is instructive. These models are useful in estimating demand that is inherent in the demographic structure of the system (for example, demand changes caused by an uneven distribution of ages that results in variation in retirements). They cannot, however, accurately forecast changes that result from factors not included in the model. Since such factors (e.g., economic conditions) can never be completely taken into account, these models provide, at best, a baseline from which to project the demand for new entrants, given assumptions about changes in overall demand. Where these models are useful is in exploring the sensitivity of demand for new entrants, given assumptions about workforce demand and the mobility characteristics of the workforce.

Summary, Conclusions, and Recommendations

SUMMARY

The possibility of using demographic models and techniques to project the size and characteristics of the future biomedical and behavioral workforce (and/or the number of new entrants required to support these workforces) was explored. These models and techniques are feasible if the following occur:

- The longitudinal database used to estimate the parameters of the model is adequate.
- The parameters derived from analysis of such a database are stable or vary in some predictable manner.

CONCLUSIONS

The SDR is a reasonably adequate data base for estimating model parameters. The sample sizes are adequate, the estimated parameters are reasonably precise, and response bias does not appear to be a major problem.[30] In addition, the parameters derived from the SDR data are reasonably stable over time.

The major flaw in the database is that it does not adequately account for immigration—specially of biomedical or behavioral scientists who earned their degree from foreign institutions. These scientists constitute a nontrivial share of these workforces. It may be possible to supplement SDR data with other data collected by NSF and the Immigration and Naturalization Service to remedy this deficiency.

An additional shortcoming of the empirical analysis may lie in the taxonomy of these fields. In particular, the fields included as part of biomedical and behavioral sciences appear to be too heterogeneous, yet parameter estimates based on small SDR sample sizes for subfields will likely be unreliable. Further study should include a look at feasible disaggregation. Finally, an analytic flaw in these models is that they fail to address the role of market feedback. This shortcoming is not unique to these models, but it is a generic problem in practically all such simulation models.

RECOMMENDATIONS

The findings from this initial exploration of demographic models and techniques is encouraging, and, based on them, the panel believes that further effort to refine and extend these models and

[30] SDR sample sizes are probably not large enough to estimate parameters for underrepresented minorities, although they are large enough to estimate parameters separately by gender.

techniques would be productive. In the ideal world, an obvious next step would be to update the parameters of the model based on more recent SDR data (1993). Unfortunately, this will not be possible because of radical changes that were made in the 1993 survey instrument, creating problems for comparisons with earlier years, although work is under way to assess the extent to which this lack of comparability presents problems.

Despite this barrier, efforts to refine the taxonomy, improve the estimation of immigration, and deal more adequately with the estimation of reentrants to the workforce can be expected to improve the performance of these models. Finally, the sensitivity of the estimated transitions to differences in gender needs to be explored.

In addition, efforts to expand the model ought to be undertaken. In particular, the effects of market feedback on the transition rates ought to be incorporated into the model. Both an assessment of the feasibility of transforming the transition estimates from parameters to functions that relate them to indicators of market conditions and efforts to expand the sensitivity of model outcomes to alternative market scenarios and variables need to be undertaken.

Life-table estimates can inform science policy by exploring the implications of very different rates of change in variables of interest (e.g. net migration, Ph.D. production, R&D funding), but they can only give a very rough estimate, especially if the data on which they are based are problematic or lack comparability over time. They are, however, one useful approach to the construction of estimates of future need for biomedical research personnel.

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Appendix A

An Examination of the Assumption of Zero Immigration

The assumption of zero immigration was essentially limited to members of this workforce who received their doctorates from foreign universities since the SDR covers a subset of non-U.S. citizens who graduate from U.S. institutions (i.e., those who do not report at the time they receive their degrees that they plan to return to their countries of origin). Data from the National Survey of College Graduates can be used to derive a crude estimate of immigration. In 1993, roughly 11 percent of the doctoral population in fields classified as biomedical science earned their degrees from foreign institutions. The comparable percentage for fields classified as behavioral science was slightly less than 2 percent (NSF 1994).

In addition to the foreign nationals who earned their doctorates abroad, a substantial number of non-U.S. citizens earn their doctorates from American institutions. Between 1963 and 1983, roughly 20 percent of the doctorates in the life sciences from U.S. institutions were awarded to non-U.S. citizens. After 1983 the share increased steadily; it rose to 28 percent in 1988 and 35 percent in 1993 (NRC 1995, 21). Although the SDR attempts to capture those who stay in their sampling frame, it fails to capture (1) those who indicate at the time they receive their degrees that they plan to return to their native countries but remain in the U.S., and (2) those who actually return to their native countries after receiving their degrees but who subsequently come back to the U.S.

A recent study estimates that roughly 40 to 45 percent of the foreign nationals who earned doctorates in the life sciences from U.S. institutions in 1984 and 1987-1988 were working in the United States in 1992 (Finn and Pennington 1994). These data suggest that roughly 10 percent of the life science workforce might be non-U.S. citizens who received their doctorates from American institutions. This is reasonably consistent with the estimate generated by the National Science Foundation from the National Survey of College Graduates. Data reported on this survey indicate that in 1993 about 11 percent of the Ph.D.s in biomedical fields had received their degrees from American institutions.

A comparable estimate was not generated for the behavioral sciences because they were not broken out separately in the Finn/Pennington study. Instead, they were included in the aggregates for the social sciences. It seems likely, however, that non-U.S. citizens who earned doctorates in the behavioral sciences will constitute a smaller fraction of the behavioral science workforce. This conjecture is supported reasonably well by data from the National Survey of College Graduates that indicate that about 8 percent of the doctorates in behavioral science fields were foreign citizens who received their degrees from American institutions.

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Appendix B

TABLE B-1 Age Distribution of New Entrants, 1973-1979

		FIELD OF SCIENCE		
Age	Biomedical	Nonbiomedical	Behavioral	Nonbehavioral
<29	0.251	0.194	0.228	0.2
29-30	0.267	0.226	0.215	0.237
31-32	0.183	0.189	0.189	0.188
33-34	0.118	0.122	0.102	0.125
35-36	0.076	0.082	0.075	0.082
37-38	0.039	0.054	0.049	0.052
39-40	0.021	0.034	0.033	0.031
41-42	0.012	0.024	0.025	0.021
43-44	0.013	0.017	0.018	0.016
45-46	0.006	0.017	0.018	0.014
47-48	0.006	0.013	0.009	0.012
49-50	0.002	0.007	0.012	0.005
51-52	0.002	0.01	0.01	0.006
53-54	0.002	0.005	0.003	0.005
55-56	0	0.002	0.003	0.002
57-58	0	0.002	0.004	0.001
59-60	0	0.001	0.002	0.001
>60	0.001	0.001	0.003	0.002

SOURCE: Survey of Doctorate Recipients (1975-1979).

TABLE B-2 Age Distribution of New Entrants, 1979-1985

		FIELD OF SCIENCE		
Age	Biomedical	Nonbiomedical	Behavioral	Nonbehavioral
<29	0.195	0.154	0.142	0.162
29-30	0.29	0.204	0.197	0.222
31-32	0.211	0.179	0.174	0.182
33-34	0.12	0.153	0.167	0.147
35-36	0.07	0.094	0.084	0.089
37-38	0.043	0.07	0.078	0.064
39-40	0.022	0.043	0.047	0.039
41-42	0.019	0.029	0.025	0.027
43-44	0.008	0.019	0.027	0.017
45-46	0.007	0.013	0.011	0.012
47-48	0.004	0.011	0.012	0.01
49-50	0.005	0.008	0.014	0.007
51-52	0.003	0.006	0.006	0.006
53-54	0.001	0.003	0.003	0.003
55-56	0.002	0.005	0.004	0.004
57-58	0.001	0.005	0.005	0.004
59-60	0	0.002	0.003	0.002
>60	0.001	0.001	0.003	0.001

Source: Survey of Doctorate Recipients (1981-1985).

TABLE B-3 Age Distribution of New Entrants, 1985-1991

		FIELD OF SCIENCE		
Age	Biomedical	Nonbiomedical	Behavioral	Nonbehavioral
<29	0.116	0.115	0.074	0.123
29-30	0.268	0.18	0.133	0.209
31-32	0.207	0.178	0.166	0.187
33-34	0.131	0.14	0.138	0.138
35-36	0.092	0.106	0.133	0.098
37-38	0.07	0.079	0.093	0.075
39-40	0.04	0.06	0.06	0.056
41-42	0.028	0.042	0.068	0.034
43-44	0.018	0.029	0.043	0.024
45-46	0.01	0.022	0.033	0.017
47-48	0.009	0.013	0.017	0.011
49-50	0.004	0.009	0.012	0,008
51-52	0.003	0.007	0.009	0.005
53-54	0	0.006	0.007	0.004
55-56	0.002	0.003	0.004	0.003
57-58	0.001	0.003	0.002	0.002
59-60	0.003	0. 003	0.002	0.003
>60	0	0.003	0.002	0.003

SOURCE: Survey of Doctorate Recipients (1987-1991).

Appendix C

Transition Rates

TABLE C-1 Mortality Rates and Retirement Rates, 1973-1991

	MORTALITY RATES	RETIREMENT RATES		
Age	All Periods	1973-1979	1979-1985	1985-1991
28-29	0	0	0	0
30-31	0	0.0003	0	0.0001
32-33	0.0035	0	0	0
34-35	0.0035	0.0003	0	0.0005
36-37	0.0048	0	0.0004	0
38-39	0.0048	0.0001	0.0002	0
40-41	0.0048	0	0	0.0001
42-43	0.0073	0	0.0003	0
44-45	0.0073	0.0003	0.0004	0.0012
46-47	0.0123	0.0004	0.0004	0.0002
48-49	0.0123	0.0012	0.0008	0.0012
50-51	0.0123	0.002	0.0009	0.0022
52-53	0.0199	0.0033	0.0031	0.0039
54-55	0.0199	0.0065	0.0107	0.0093
56-57	0.0285	0.0113	0.0155	0.0291
58-59	0.0285	0.0277	0.0245	0.0484
60-61	0.0285	0.0596	0.0536	0.0929
62-63	0.0416	0.1013	0.1083	0.1544
64-65	0.0416	0.2826	0.2273	0.2452
66-67	0.066	0.2608	0.2041	0.2304
68-69	0.066	0.3545	0.2642	0.325
70 +	0.099	0.3081	0.3079	0.3399

SOURCE: TIAA/CREF (Mortality Rates); Survey of Doctorate Recipients (Retirement Rates).

TABLE C-2 Out-Migration Rates, 1973-1991

OUT-MIGRATION RATES

	BIOMEDICAL			BEHAVIORAL		
Age	1973-1979	1979-1985	1985-1991	1973-1979	1979-1985	1985-1991
28-29	0.147	0.0952	0.1218	0.0435	0.0683	0.0568
30-31	0.0949	0.0688	0.0801	0.0728	0.0727	0.0714
32-33	0.1062	0.1071	0.1035	0.0461	0.0863	0.0493
34-35	0.0976	0.09	0.0819	0.0492	0.0772	0.0891
36-37	0.1144	0.0997	0.1035	0.0571	0.0745	0.0612
38-39	0.1235	0.1052	0.1011	0.0832	0.0701	0.073
40-41	0.1136	0.0872	0.1068	0.0812	0.0962	0.0629
42-43	0.1235	0.1018	0.1115	0.0745	0.0717	0.0552
44-45	0.1393	0.1085	0.1001	0.0661	0.0712	0.0883
46-47	0.0969	0.1196	0.1442	0.0676	0.0702	0.0768
48-49	0.1134	0.0903	0,1219	0.0812	0.0856	0.1086
50-51	0.1358	0.0906	0.1393	0.0648	0.0609	0.0661
52-53	0.1224	0.1013	0.1498	0.0819	0.0601	0.0861
54-55	0.1429	0.0104	0.0887	0.0563	0.0407	0.0798
56-57	0.1264	0.108	0.1178	0.0719	0.0377	0.0841
58-59	0.1556	0.1148	0.0858	0.1078	0.0492	0.0598
60-61	0.1377	0.1301	0.0902	0.0812	0.0585	0.0534
62-63	0.1055	0.1511	0.0992	0,1029	0,0682	0.1024
64-65	0.0738	0.05	0.0698	0.0683	0,0289	0.0433
66-67	0.1366	0.1534	0.1642	0.071	0.0827	0.093
68-69	0.0242	0.1128	0.1573	0.0867	0.0552	0.1034
70 +	0.2204	0.0145	0.1354	0.1657	0.0317	0.0533

NOTE: Numbers are deflated by the appropriate field-specific workforces to derive appropriate rates.
SOURCE: Survey of Doctorate Recipients.

TABLE C-3 In-Migration Rates, 1973-1991

IN-MIGRATION RATES

	BIOMEDICAL			BEHAVIORAL		
Age	1973-1979	1979-1985	1985-1991	1973-1979	1979-1985	1985-1991
28-29	0.028	0.0154	0.0295	0.0086	0.0074	0.008
30-31	0.0355	0.0182	0.0337	0.0067	0.007	0.0076
32-33	0.026	0.0205	0.0252	0.0054	0.0102	0.0129
34-35	0.029	0.0243	0.0275	0.0084	0.0077	0.008
36-37	0.0267	0.0136	0.034	0.0062	0.0078	0.0123
38-39	0.0269	0.021	0.027	0.0075	0.0065	0.0123
40-41	0.0222	0.0182	0.0266	0.0056	0.0055	0.0116
42-43	0.0191	0.016	0.0232	0.0088	0.0076	0.0091
44-45	0.0263	0.0163	0.0319	0.0096	0.0038	0.0081
46-47	0.0282	0.017	0.022	0.0088	0.0083	0.0118
48-49	0.0272	0.0153	0.0276	0.0071	0.0068	0.007
50-51	0.0251	0.0148	0.0231	0.007	0.0079	0.009
52-53	0.0261	0.0138	0.0209	0.0096	0.0123	0.0076
54-55	0.0295	0.0146	0.0232	0.0094	0.0066	0.0068
56-57	0.0315	0.0188	0.0136	0.0077	0.0024	0.0091
58-59	0.025	0.0187	0.0233	0.0155	0.0032	0.0104
60-61	0.0263	0.0155	0.027	0.0146	0.0041	0.0135
62-63	0.0164	0.0138	0.0225	0.0149	0.0061	0.0108
64-65	0.0341	0.0182	0.0216	0.004	0.0055	0.0141
66-67	0.0156	0.0017	0.0231	0.0109	0.0103	0.0115
68-69	0.0217	0.0147	0.0365	0.03	0.0092	0.0071
70 +	0.0088	0.0116	0.0279	0.0442	0.0026	0.0073

NOTE: Numbers are deflated by the appropriate nonbiomedical or nonbehavioral workforces to derive appropriate rates.
SOURCE: Survey of Doctorate Recipients.

Appendix D

TABLE D-1 Frequency Distribution of Coefficients of Variation

	TOTAL (number)	≤ 0.3 (percent)	≤ 0.2 (percent)
MOBILITY RATES			
To other fields			
Biomedical	66	84.9	81.3
Behavioral	66	74.2	45.4
From other fields			
Biomedical	66	75.8	63.6
Behavioral	66	37.8	18.2
TOTAL	264	68.2	51.5

SOURCE: Appendix C.