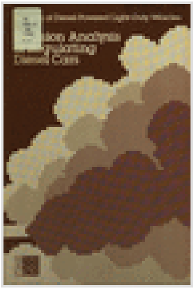

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Impacts of Diesel-Powered Light-Duty Vehicles

Decision Analysis of Regulating Diesel Cars

Report to the

Diesel Impacts Study Committee

Assembly of Engineering

National Research Council

by

William W. Hogan

Energy and Environmental Policy Center
John F. Kennedy School of Government
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National Academy Press
Washington, D.C. 1982

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PREFACE

In May 1979 the National Research Council began a comprehensive study of the human health effects and public policy issues associated with the prospective increase in the use of diesel-powered light-duty vehicles in the United States. The study was requested by the White House Office of Science and Technology Policy and supported by the U.S. Environmental Protection Agency, the U.S. Department of Energy, and the U.S. Department of Transportation.

The purpose of the study was to inform those government bodies, along with the U.S. Congress, the automotive industry, and the American public, about the current state of knowledge and understanding of diesel engine emissions and their control and to provide an authoritative and balanced examination of the risks and implications of the anticipated growth in the number of lightweight diesel vehicles. According to the projections of the nation's largest automobile manufacturer, General Motors, diesel engines are likely to power some 18 percent of the passenger cars, vans, and small trucks it produces in the year 1985 and as much as 25 percent by the end of the century. All things considered, government authorities responsible for regulations to protect the health and safety of the public need the best scientific, technical, and economic data and analyses on which to base their policy decisions about diesel engines.

Accordingly, the National Research Council organized the Diesel Impacts Study Committee in the Assembly of Engineering, which operated in conjunction with the Assembly of Life Sciences for aspects of the study dealing with the possible adverse health effects of diesel engine emissions. The committee consisted of 20 members drawn from diverse disciplines and backgrounds--medical research, health care, environmental protection, chemical and mechanical engineering, political science, economics, banking, and business management. Because the scope of the study involved a complex range of questions and problems, the committee established four panels to examine, respectively, the issues involving technology, environment, human health, and public policy. Each of the four panels was made up of specialists from the relevant subject of concern, as well as some members of the committee.

In performing their separate tasks the panels sometimes called on experts to assist in elucidating special matters and explicating certain problems. Thus, the Analytic Panel, established to assist in the committee's review of public policy issues, asked William W. Hogan, Professor in the John F. Kennedy School of Government at Harvard University, to discuss the construction of a decision analysis for diesel vehicle regulation. The resulting work of Professor Hogan was used in the documentation of the Analytic Panel as well as in the preparation of the committee's final report, Diesel Cars: Benefits, Risks, and Public Policy. To provide a wider dissemination of the complete report by Professor Hogan, the committee requested the National Research Council to issue his document as a supporting paper.

The National Research Council customarily publishes only the final reports of its committees--and then only after the report has been reviewed by a group other than its authors, according to procedures laid down by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. Because such a large volume of information and analyses was assembled for consideration by the committee, and because the diversity and scope of that information was important for the final report, the reports of the Technology Panel and the Health Effects Panel are being published after "peer review" in accord with approved procedures. In addition, three other reports by associated authors are being issued as supporting papers. Each of these has been used by the committee in developing its findings, though this supporting paper has not undergone the critical review process customary within the National Research Council.

Some conclusions implied in this report may be at variance with the conclusions of the committee's report. The findings reported in this document are those of the author and are not necessarily endorsed by the committee or the National Research Council.

ACKNOWLEDGMENTS

The author gratefully acknowledges the contributions of the members of the Diesel Impacts Study Committee, chaired by Henry Rowen, and the Analytic Panel, chaired by Fred Hoffman. Gene Peters provided programming assistance in preparing the decision analysis model. The Transportation Systems Center of the U.S. Department of Transportation contributed to the early model development through a seminar at Harvard University. The author alone is responsible for oversights and errors in this report.

CONTENTS

INTRODUCTION

The purpose of this paper is to examine a decision analysis approach to the selection of the best timing and level for regulating diesel engine emissions from passenger cars and small trucks. The U.S. Environmental Protection Agency (EPA) has begun to implement a program to limit diesel particulate emissions from light-duty vehicles to 0.6 g/mi for model years 1982 through 1984 and 0.2 g/mi for the model year 1985 and thereafter. It is possible that as late as 1983, the EPA could relax or tighten the requirements for the model year 1985 and beyond. Two factors dominate the EPA deliberations--the magnitude of particulate-related health effects and the cost and availability of control technology. Major advances in understanding the health effects of diesel exhaust and in developing reliable, effective, and durable emission control devices before 1985 might enable the EPA to change its regulations for that model year or thereafter. Advances made subsequent to 1985 might also be cause for revision of the regulation affecting model years 1990 and beyond.

Concurrent with the program on particulate emissions, the EPA is establishing standards for the emission of nitrogen oxides (NO_x). The current standard for emission of NO_x is 1.5 grams per mile, to be reduced to 1 g/mi for model years 1985 and beyond. Further reductions in NO_x emissions, to as low as 0.4 g/mi, are under consideration, but according to present technological forecasts this could be achieved for light-duty diesel vehicles no earlier than 1990.

The trade-offs between particulate and NO_x standards, the cost of control technology, and the health effects will be complicated by several factors. Diesel engines may contribute significantly to improving the average fuel efficiency of the auto fleet while meeting the consumer demand for a range of car sizes--though consumer demand in its many aspects is uncertain. In addition, the EPA regulatory decision will be affected by expectations of the scale of industry investment in diesel engine manufacture; thus, industry investment must be affected, in turn, by the degree of regulation.

An in-depth examination of the details of any one of these subjects would require a major study. The Diesel Impacts Study Committee was organized by the National Research Council to perform a survey of all the potential impacts of diesel emissions and diesel regulation. As part of its survey, the committee took as its task the synthesis and integration of several separate evaluations of health and environmental effects, technology, and economics to illuminate the choice of the optimum level of emission regulation, given the unavoidable uncertainty surrounding the factors that impinge on the decision.

In order to simplify the decision problem, this paper focuses on the choices in 1985 and the choices that could be available in 1990. There are at least two approaches to analyzing the decisions. In the first approach, one could analyze a series of scenarios of possible futures. Such scenarios necessarily ignore the interaction between decisions and uncertainty by assuming that we must decide once and for all the future level of emission standards and the evolution of the diesel auto market. But by selecting scenarios that approximate plausible "worst" case decisions, one can examine the problem in detail to estimate the maximum "regret" associated with early decisions. In the easiest world for the decision maker, the "worst" case scenarios suggest a dominant solution in the sense that the same regulatory decision is optimal for all reasonable outcomes of future events. In this fortunate circumstance, the scenario analysis provides all the information needed to make a decision.

Often, of course, scenario analysis, while providing insight into the nature of the problem and the importance of the various uncertainties, is ambiguous about the best decision; the best choice may depend on the nature of the future events. Such situations call for an alternative approach in which the choices are organized into a formal decision analysis. The decision analysis provides an opportunity to collect information and condition decisions on the outcome of future events. Using a model of the automobile market and calculating summary estimates of economic costs and health and environmental impacts, the decision analysis can serve as a framework to structure the interaction between diesel impact events and regulatory decisions and to produce estimates of the value of information or the costs of being wrong.

The Diesel Impacts Study Committee performed both a scenario analysis and a decision analysis to the investigation of diesel regulatory decisions. A comparison of the two approaches revealed the consistency of results with the appropriate selection of scenarios. The committee's Analytic Panel, therefore, relied on the simpler scenario comparison to illustrate the implications of alternative regulatory choices.* The present paper summarizes the companion decision analysis.†

Although simplified compared with the actual situation, this decision analysis requires a significant number of data that are difficult to obtain. In some cases these "data" are judgments about the likelihood of future events; in others, they are estimates of health and technological parameters that are highly uncertain. The paper draws upon several sources for the data, wherever possible using the work of the many groups supporting the Diesel Impacts Study Committee. Application of the decision analysis framework is illustrated by solving a few selected decision problems and conducting sensitivity analysis based on the many judgmental parameters.

The following section provides an overview of the structure of the basic decision problem. The simulation of the automobile market is central to the evaluation of future outcomes. Therefore, this presentation briefly describes the automobile market model with an illustration of its output. This is followed by an example specification of the decision problem and analysis, using the nominal data. The final section presents an interpretation of key lessons that might persist even after refinements of the data.

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*See chapter 7, National Research Council (1981). Diesel Cars: Benefits, Risks, and Public Policy. Report of the Diesel Impacts Study Committee. Washington, D.C.: National Academy Press.

†For an introduction to the subject of decision analysis, see Howard Raiffa (1968). Decision Analysis. Reading, Mass.: Addison-Wesley.

THE DECISION PROBLEM

The problem can be characterized by building a "decision tree" anchored to three critical dates--1981, 1985, and 1990. The decision tree displays a stylized version of the possible paths by which the future might unfold. It assumes that between the decision points selected key uncertainties will be resolved or information gained about how these are likely to be resolved in the future. Further, at each decision point, relevent decision makers will have the information about the resolution of past uncertainties, but they are assumed to have only probability estimates of how future uncertainties will be resolved. Given this information and these expectations, the decision makers make the optimal choice as characterized by the decision tree as well as their objective function. The choices depend upon the outcome of the automobile market estimates from the model described in the following section.

The validity of the model and the completeness of the data for such a decision analysis are always problematic. Although many techniques are available for eliciting subjective probabilities, there is no objective test of the validity of such estimates. In cases such as the automobile market model, the discussion depends upon amalgamations of more detailed models, but the aggregation process is *ad hoc* and selective. The resulting model, dealing with structural change in the automobile industry, is qualitatively essential for this analysis, though a rigorous validation effort would go well beyond the committee's time and resources. In other instances, such as with the health effects data, the gaps are so pervasive that the problem is not one of aggregation but rather one of ambitious extrapolation or subjective estimation by analogy.

Apparently these difficulties in validation are not unique to the models and data described here. The problems apply to any comprehensive analysis of regulatory decision making. The formal decision analysis only makes the assumptions explicit and provides a method for incorporating the estimates of the degree of uncertainty into the evaluation of the choices.

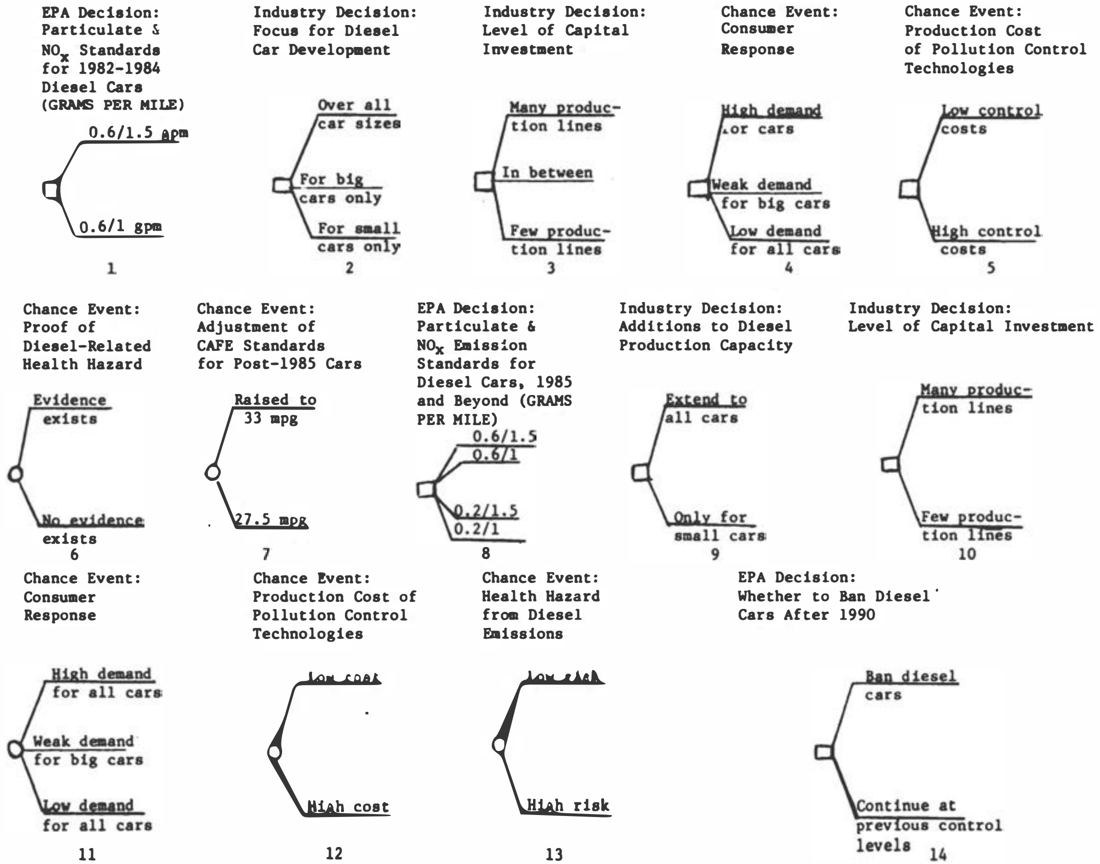
The sources of the data and models, therefore, range from documentable outside references to subjective judgments collected through interactions with the Diesel Impacts Study Committee, its panels and consultants, and other researchers. The resulting nominal data base was used for the analysis presented here. Selected sensitivity studies were then used to explore areas where critical uncertainties might have an effect on the decisions. The results of these sensitivity studies were reinforced in the parallel scenario analyses; hence, the decision analysis terminated with this exploratory effort. The next logical steps, the formal elicitation of subjective probabilities and the construction of a representative utility function, were judged unlikely to provide new insights worthy of the substantial cost of the additional effort. If necessary, the present model could be used as a starting point for a more exacting study.

DECISION TREE

The generic structure of the decision tree is illustrated in Figure 1 for an automobile market with three classes of cars (small, medium, and large) and two engine types (gasoline and diesel). In the notation of Figure 1, squares represent decisions and circles represent uncertain events. The decisions and events include:

(1) EPA Regulatory Decision. The first decision will set the NO_x standard for model years 1982-1984. With particulate standards set at 0.6 g/mi, the two alternatives are to continue the NO_x standard or to relax the standard to 1 g/mi. (In the nominal data base, we have no available information on the trade-off between NO_x and particulate standards; hence, in the selected decision trees examined later, we look only at conditions that have 1.5 g/mi of NO_x emissions.)

FIGURE 1


EPA Decision: Particulate & NO_x Standards for 1982-1984 Diesel Cars (GRAMS PER MILE)
0.6/1.5 gpm
0.6/1 gpm
1
Industry Decision: Focus for Diesel Car Development
Over all car sizes
For big cars only
For small cars only
2
Industry Decision: Level of Capital Investment
Many production lines
In between
Few production lines
3
Chance Event: Consumer Response
High demand for cars
Weak demand for big cars
Low demand for all cars
4
Chance Event: Production Cost of Pollution Control Technologies
Low control costs
High control costs
5
Chance Event: Proof of Diesel-Related Health Hazard
Evidence exists
No evidence exists
6
Chance Event: Adjustment of CAFE Standards for Post-1985 Cars
Raised to 33 mpg
27.5 mpg
7
EPA Decision: Particulate & NO_x Emission Standards for Diesel Cars, 1985 and Beyond (GRAMS PER MILE)
0.6/1.5
0.6/1
0.2/1.5
0.2/1
8
Industry Decision: Additions to Diesel Production Capacity
Extend to all cars
Only for small cars
9
Industry Decision: Level of Capital Investment
Many production lines
Few production lines
10
Chance Event: Consumer Response
High demand for all cars
Weak demand for big cars
Low demand for all cars
11
Chance Event: Production Cost of Pollution Control Technologies
Low cost
High cost
12
Chance Event: Health Hazard from Diesel Emissions
Low risk
High risk
13
EPA Decision: Whether to Ban Diesel Cars After 1990
Ban diesel cars
Continue at previous control levels
14

(2) Industry Development Decision. The industry must decide on the emphasis for the development of diesel cars. If a diesel is primarily for preserving the large car option while meeting corporate average fuel efficiency standards, then the industry might emphasize big diesel cars. In the nominal data, the diesel production capacity is spread equally on the upper branch among the three size classes; on the middle branch 60 percent of the capacity is for big cars, with the remaining 40 percent shared equally by medium and small cars; and on the bottom branch 60 percent of the capacity is for small cars, with the remaining 40 percent capacity split between medium- and large-size cars.

(3) Industry Capacity Decision. After choosing the emphasis of diesel development, the industry must select the scale of operations for early production. The case for the nominal data assumes a production capacity for diesels as high as 1.5 million cars per year, with many production lines, 1 million cars per year at the in-between level, but only 500,000 cars per year if there are few production lines.

(4) Consumer Demand. The decisions by the industry must be made well before the corporate executives know the level of consumer demand for cars during the 1982-1984 model years. This uncertainty appears in the model at node 4, by considering three levels of possible demand: a low demand for all cars, which is set according to the baseline forecase; a weak demand for big cars, where the 10 percent increase in demand occurs only for medium and small cars; and a high level of demand for all cars, with a 10 percent higher demand than the low demand case. The baseline forecast for gasoline car demand used in the nominal data is the 1976 sales report of gasoline engine cars noted by Stucker and his colleagues (1980)--3.4 million small cars, 2.9 million medium cars, and 2.3 million large cars. An additional 25 percent of each category is assumed as the base demand for diesels if user costs give approximately a 5 percent advantage to diesels. Deviations of the fleet mix from this benchmark will be determined using the elasticities in the automobile model discussed below. Because of the capacity constraint, however, diesel sales prices will be higher in 1982-1984; the user cost advantage will thus favor gasoline-powered cars, and diesel sales penetration will be determined by production capacity.

(5) Control Costs. Costs for control technologies available for 1982-1984 model years might be high or

low. This analysis considers two regulatory cases and two different kinds of costs. In Table 1 the low and high outcomes are indicated for small, medium, and large cars for both the increase in annual operating costs and production costs associated with each assumed control technology case.

(6) Health Evidence. Although more information on the health effects of diesel engines will become available, it is possible that the state of information in 1985 will not be significantly better than it is today. This uncertainty is reflected by the two branches at node 6. The upper branch represents the case with evidence of health effects; on the lower branch, no such evidence exists. These branches will condition the probability assumptions for a later uncertainty regarding the scale of the health effects; if the outcome at node 6 yields evidence of health risks, the later probabilities will lean toward the high health risk. On the lower branch,

TABLE 1
DIESEL CONTROL TECHNOLOGY PARAMETERS[a]
(0.2 g/mi particulate level)

	Increased Operating Cost[b] ($1980)		Increased Production Cost ($1980)	
Car Size	Low	High	Low	High
Small	80	360	100	450
Medium	120	480	150	600
Large	160	600	200	750

[a] Increased costs over control at 0.6 gpm, which is included in the baseline data. These costs increments are for 1985 model year and assume technological progress sufficient to achieve a 20 percent reduction in these costs by 1990. Data described in Memorandum from Donald Dewees to the Diesel Impacts Study Committee's Analytic Panel; Diesel Pollution Control Technology and Costs, October 2, 1980; as amended in letter to W. Hogan, dated October 20, 1980.

[b] Undiscounted total over the life of the car, excluding fuel costs.

the probabilities of health risks will be weighted more heavily toward the low health effect.

(7) Efficiency Standards. The availability of diesel engines and the continuing scarcity of liquid fuels raise the possibility that Corporate Average Fuel Economy (CAFE) standards will be further tightened in later years. This uncertainty is modeled at node 7 by assuming different CAFE standard outcomes as a chance event. The upper branch illustrates an assumption that the Department of Transportation will choose a trajectory aimed at achieving a new car fleet average of 33 mpg by 1990. The lower branch represents the current trajectory to 27.5 mpg in 1985 and keeping that standard thereafter.

(8) EPA Regulatory Decision. In time for the 1985 and subsequent model years, and after the resolution of uncertainties about human health effects and control technology costs, the EPA could reconsider its decision regarding both particulate and NO_x standards. For the sake of the generic decision tree, the model shows four possible outcomes at node 8. These represent two levels each for particulate and NO_x emission standards. The standards will interact with the control cost assumptions to determine the economic costs of providing any desired fleet mix.

(9) Industry Development Decision. After the EPA makes its decisions for the 1985 model year, the industry must consider its decision regarding the emphasis for capacity development. Node 9 repeats the same structure of decision represented in node 2; nominal data for node 9 use the same relative mixes as on the branches defined for node 2.

(10) Industry Capacity Investment. As at node 3, after deciding on the focus of new capacity development, the industry must determine the scale of investment. The capacity level for the three branches for this epoch (node 10) are 2 million cars per year with many production lines, 1.2 million cars per year with the in-between level, and 750,000 cars per year if there are only a few production lines.

(11) Consumer Response. The uncertainty associated with the demand for cars between 1982 and 1984 repeats in node 11. The same rules apply to the nominal data: gasoline car demand is as it was in 1976, and there would be an additional 25 percent demand for diesels if diesels enjoyed a 5 percent cost advantage.

(12) Control Technology. The uncertainty in node 5 repeats in node 12 to reflect both the possible change in standards and possible progress in technology. Again the choice of technology affects the operating costs of the car, the cost of producing the car, and the fuel efficiency of diesel cars. Table 1 summarizes the data for the nominal assumptions.

(13) Health Hazard. The assumption is made here that by the end of the 1980's any health hazard associated with diesel engines can be conclusively determined from new research information. The two possibilities modeled at node 13 are low-risk and high-risk outcomes. The relative risks are based on subjective estimates discussed later. In order to quantify trade-offs between the economic costs of control, the changes in the fleet mix, and the health effects, the health hazards have to be converted to a comparable economic value. Final resolution of the estimate of health effects is not in sight. However, the nominal calculations assume the existence of a cost externality for large gasoline cars. Given this externality, the comparison with diesel cars and cars of different sizes reduces to an evaluation of the relative hazard of each type of car compared with large gasoline cars. From these nominal data and the sensitivity runs for the health externality, the trade-off can be calculated between economic and health benefits.

(14) EPA Regulatory Decision. For model years 1990 and beyond, the resolution of uncertainty about health effects will present enough information to establish the final standards for particulates and NO_x emissions. This final decision is reflected at node 14, which uses the simple assumption that EPA either makes regulations to ban new diesels or continues at the previously established control levels. The nominal calculations assume that banning is equivalent to producing 300,000 diesel cars per year of each size class.

These 14 decision and chance nodes provide the framework for summarizing the major choices and uncertainties that emerged in the committee's discussions of the effects of diesel sales and the EPA regulatory decision. The early choices depend upon the later uncertainties, and left open is the opportunity to improve future decisions, depending on the outcome of future events.

When the decisions and chance outcomes are set for each branch of the decision tree--i.e., for each scenario--the effects can be accumulated and averaged.

By "rolling back" the tree, the effect of early decisions can be determined. With variations in the parameters and the subjective probabilities, this decision tree provides a tool for conducting sensitivity analysis. Such analysis isolates those factors that dominate early decisions on diesel regulation and development.

AUTOMOBILE MARKET MODEL

At several points on this tree, one must simulate choices in the domestic automobile market. Ideally, analysts would simulate the market for each year, taking into account all past events and future uncertainties. In practice, this analysis is simplified by simulating the market only for representative years of the three major decision epochs--1982-1984, 1985-1990, and 1990-2000.

Furthermore, future uncertainties are here assumed not to affect the outcome for the simulation years other than in the choice of the model's parameters. In other words, costs, technology, and standards are assumed to be fixed at the time of car purchase. With the possible exception of future changes in fuel costs, which might affect purchase decisions, these simplifying assumptions should do no harm to the analysis. We are in effect modeling car buyers as though they use the fuel price at the time of purchase as their estimate of fuel prices over the life of the car.

If the _existing_ automobile fleet size and usage patterns will be only slightly affected by decisions about the regulation of _new_ diesel cars, then the analysis of the health, energy, environmental, and economic effects of our decisions can concentrate on the market for new cars. By assuming independence of usage patterns and future events, all future costs and impacts associated with each type of car can be calculated at the time of sale. Therefore, to calculate the health, energy, environmental, and economic effects, we need a model of new car sales that distinguishes car sizes and fuel types and accounts for changes in sales prices, fuel costs, efficiencies, production costs, and production capacities, yet reflects fleetwide fuel economy constraints imposed by the CAFE standards.

Stucker _et al_. have developed a model with nearly all of these properties for a fleet of gasoline cars. In the Diesel Impact Study Committee's examination, Stucker's model was adapted principally by introducing diesel cars in competition with gasoline cars and by allowing for substitution among size classes. The result is an aggregated model that can be viewed as a summary of more detailed models of the automobile industry. In principle, all of the parameters of this model could emerge by fitting them to the results of the detailed models. This was done for the demand models; most of the remaining parameters were taken from Stucker _et al_. or the analysis supporting the committee's assessment.

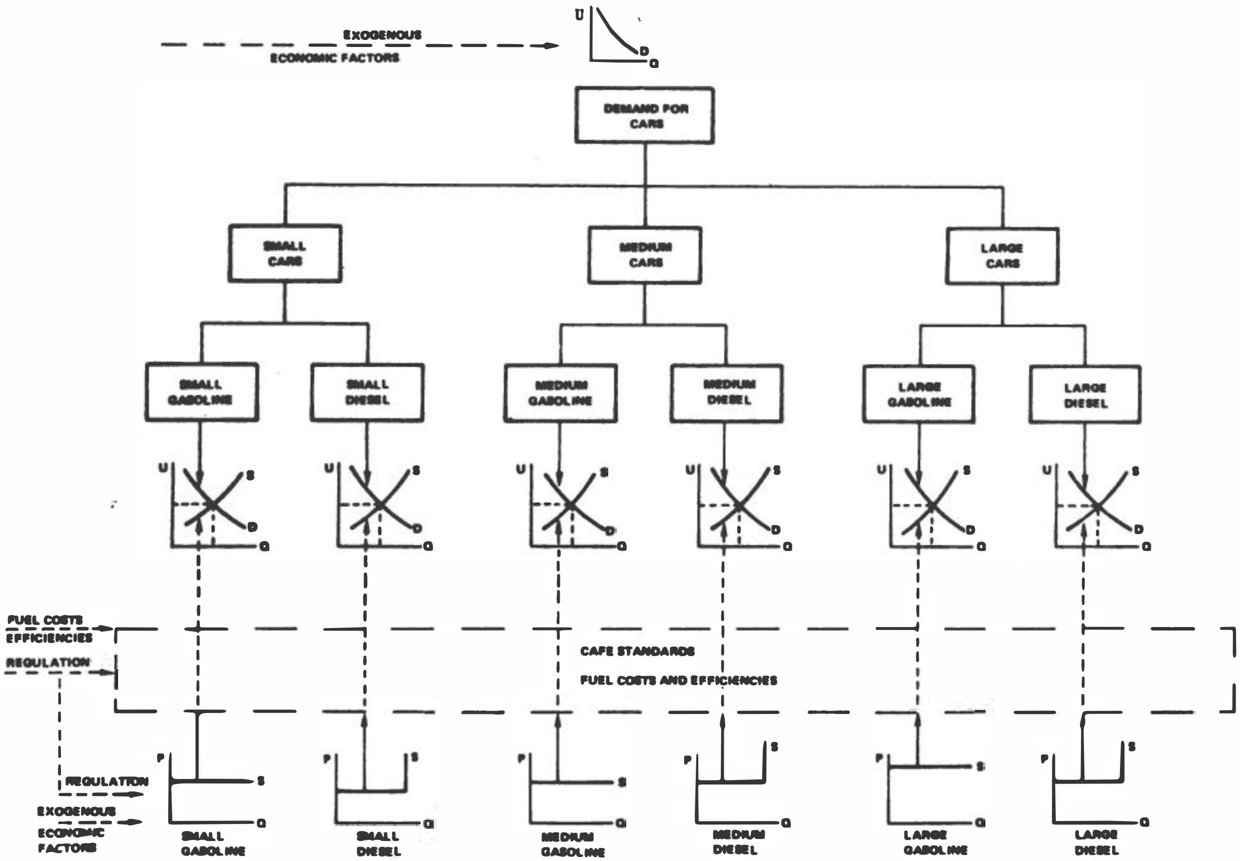
An important assumption is the choice of market theory embodied in the model. Stucker _et al_. have examined the two extremes of effective competition and complete monopoly. Because their model parameters were selected separately for competitive and monopoly situations, to reproduce 1976 outcomes, their choice of market theory had a great bearing on the implicit demand elasticities but little effect on the results, and they concentrated on the monopoly case. Because the case developed for the committee's study uses a single set of demand elasticities based on an independent econometric analysis of consumer behavior, the choice of market theory becomes important. The true automobile market is far more complex than the extremes of either competition or monopoly. However, a sophisticated description of one of many possible oligopolistic models is beyond the scope of this analysis. Moreover, it was judged to be unlikely to affect the insights of the analysis. Since the distinction between imported and domestic passenger cars is ignored, and we are dealing with the world response to U.S. conditions, there is support for the competitive approximation. Furthermore, the demand elasticities of the automobile model are inconsistent with a pure monopoly model. Therefore, for this analysis it is assumed that the mix and level of automobile sales, subject to CAFE standards and short-run capacity constraints, conform to the competitive solution.

The resulting automobile model is a partial equilibrium system of several equations that must be solved simultaneously. Figure 2 presents a schematic of the model. At the top, economic conditions and other exogenous factors establish an aggregate demand for cars as a function of user cost,

$$QA = \alpha_0 UA^{\alpha_1} \qquad (1)$$

where QA is the quantity, UA the user cost, and α_0, α_1 are parameters to be set.

FIGURE 2 AUTOMOBILE MARKET MODEL



There are three automobile size class k (k = small, medium, large). Sales for size class k are denoted as QB^k with user cost UB^k. Allowance for substitution among size classes is provided by specifying a translog cost function for the aggregation of user costs,*

$$\ell n\ UA = \beta_{00} + \sum_k \beta_{k0} \ell n\ UB^k + 1/2 \sum_{kj}\sum \beta_{kj}\ \ell n\ UB^k\ \ell n\ UB^j \tag{2}$$

with the β parameters to be determined by a separate analysis of demand.

The competitive value share s^k, for each size class, is the logarithmic derivative of the cost function,

$$s^k = \beta_{k0} + \sum_j \beta_{kj}\ \ell n\ UB^j \tag{3}$$

With this share equation the quantity demanded can be calculated for each size class,

$$QB^k = \frac{s^k UA \cdot QA}{UB^k} \tag{4}$$

Within each size class there are competing demands for diesel and gasoline engine cars. Our model for the substitution between engine types uses a constant elasticity of substitution. This gives the user cost aggregation

$$UB^k = \left(\sum_i \theta_i^k U_i^{k\,1-\sigma_k}\right)^{\frac{1}{1-\sigma_k}} \tag{5}$$

where U_i^k is the user cost of car type i in size case k and σ_k is the elasticity of substitution for size class k. As before, the shares for each type can be found by differentiating,

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*For a discussion of the translog approximation to a general cost function, see Diewert, W.E. (1974). "Applications of Duality Theory," in M.D. Intuligator and D.A. Hendrich (eds). Frontiers in Quantitative Economics, Vol. III. Elsevier, North-Holland.

(6) $$s_i^k = \theta_i^k \left(\frac{UB^k}{U_i^k}\right)^{\sigma_k - 1}$$

And the quantity Q_i^k of each type and size of car is

(7) $$Q_i^k = \frac{s^k UB^k \cdot QB^k}{U_i^k} = QB^k \theta_i^k \left(\frac{UB^k}{U_i^k}\right)^{\sigma_k}$$

The user cost for each size and type of car is a function of the prices of the car P_i^k, the price of fuel PF_i, the efficiency E_i^k, and various operating costs and interest rate parameters. The form of the approximation developed by Stucker _et al_. can be adapted to

(8) $$U_i^k = \gamma_{0_i}^k + \gamma_1 P_i^k + \gamma_2 PF_i/E_i^k + \gamma_3^k (PF_i/E_i^k)^2$$

where the parameters γ will be drawn from the data on costs of operation.*

Stucker _et al_. have distinguished between fixed and variable production costs. Lacking data for diesel cars, this distinction was dropped for the analysis by the Disel Impacts Study Committee, which assumes for the sake of this model that all production costs are variable, up to a capacity limit,

(9) $$C_i^k = b_i^k Q_i^k$$

where C^k is the total cost and b_i^k is the cost per unit.

The mandatory efficiency standards provide for a fine on each car sold for each mile per gallon that the fleet

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*For the derivation of the user cost equation, see the appendix. User costs are expressed here in terms of present values as compared to annualized values in the basic model of Stucker _et al_.

average E fails to meet the CAFE standard M. With tax rate T, the fine F is

$$\text{(10)} \qquad F = T(M - E)Q, \text{ for } E \leq M$$
$$= 0, \qquad \text{for } E > M$$

Here the total quantity of cars is just the sum

$$\text{(11)} \qquad Q = \sum_k \sum_i Q_i^k$$

and the fleet average efficiency is

$$\text{(12)} \qquad E = \left(\sum_k \sum_i \frac{Q_i^k}{E_i^k} \right)^{-1} Q$$

(Note that Equation 12 assumes implicitly that all corporations are the same, so that the corporate fleet standard applies to the total fleet.)

The production capacity for each type of car is assumed to be determined exogenously,

$$\text{(13)} \qquad Q_i^k \leq \bar{Q}_i^k$$

and will be an important element of the decision tree.

Equations (1) through (13) define the model; the sales prices P_i^k that clear the competitive market can be sought, assuming that car efficiencies and fuel prices are exogenous. Because the CAFE fine is not tax deductible, it is inflated to reflect the corporate tax rate δ. In searching for the competitive prices, the model uses penalty functions to describe constraints. Because the demand functions are integrable by assumption, this competitive solution is equivalent to determining

$$\text{(14)} \qquad \underset{Q_i^k}{\text{Max}} \quad \sum_k \sum_i \left\{ \int_0^{Q_i^k} P_i^k - C_i^k \right\} - F/(1-\delta)$$
$$- \sum_k \sum_i \lambda_{i0} \, \text{Max} \left(0, Q_i^k - \bar{Q}_i^k\right)^{\lambda_{i1}^k}$$

subject to (1) through (10). The first-order conditions include:*

$$(15)\quad 0 = P_i^k - b_i^k - \frac{\partial F}{\partial Q_i^k} / (1-\delta) - \lambda_{i0}^k \lambda_{i1}^k \text{ Max } (0, Q_i^k - \bar{Q}_i^k)^{\lambda_{i1}^k - 1}$$

Hence, the final definition of a solution for the automobile market is a simultaneous solution of (1)-(10) and (15). This solution results from applying a quasi-Newton method in a search over P_k/P_i^{kl}.

Given a solution to this model, one can calculate the consumer and producer surplus. For the consumer surplus, integrate the demand equation in (1). For the producer surplus, assume that the production costs, the efficiency fine, the fuel costs, and the operating cost components of the user's cost are real resource costs internalized by the industry; the rents created by the capacity constraints and the marginal fine make up a surplus to be

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*The function F is not differentiable. To solve this problem calls for a two-phased approach. First, calculate the competitive solution in the absence of the CAFE fine and restriction. If the solution satisfies the CAFE restriction, the calculation is done; if not, assume the fine applies over the whole region (which makes F differentiable) and add to (14) the additional penalty

$$-\lambda_{E0} \text{Max } (0, E-M)^{\lambda_{E1}}$$

or to (15) the additional term

$$-\lambda_{E0} \lambda_{E1} \text{ Max } (0, E-M)^{\lambda_{E1}-1}$$

This problem is differentiable and this second pass of the quasi-Newton algorithm solves the original problem. The quasi-Newton method uses a diagonal estimate of the second derivative of (14) to obtain a Newton estimate of the solution to (15). This Newton estimate established the direction for a conventional line search and a "feasible directions" algorithm for seeking the competitive solution. It takes an average of 10 to 15 Newton steps to obtain acceptable convergence.

included in benefits. Hence, the total consumer plus producer surplus V is

$$V = \frac{\alpha_0}{\alpha_1 + 1}\left(\overline{UA}^{\alpha_1+1} + \alpha_1 UA^{\alpha_1+1}\right) - UA \cdot QA + \sum_k\sum_i P_i^k Q_i^k - \sum_k\sum_i C_i^k - F/(1-\delta) \tag{16}$$

where UA is an arbitrarily high user cost at which auto demand is assumed to drop to zero. (The term UA is only a convenience, since the analysis emphasizes changes in V only.)

The terms used in this model include:

C_i^k = Production costs
F = CAFE fine
δ = Income tax rate
QA = Aggregate demand for generic cars
UA = Aggregate user cost for generic cars
QB^k = Demand for cars of size class k
UB^k = User cost for cars of size class k
Q_i^k = Demand for cars (k = small, medium, large
i = gasoline, diesel)
U_i^k = User cost of cars of type i in class k
P_i^k = Sales price of cars of type i in class k
E_i^k = Efficiency of cars of type i in class k (exogenous)*
PF_i = Price of fuel (exogenous)
T = CAFE tax rate (exogenous)
V = Consumer-producer surplus
M = CAFE standard (exogenous)
Q = Total number of cars; and
E = Average fuel efficiency of fleet.

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*The use of exogenous efficiencies is an important deviation from the model of Stucker <u>et</u> <u>al</u>., who included an endogenous adjustment of model efficiencies. The Diesel Impacts Study Committee elected to examine this as an sensitivity variable, which may understate the response of the market to changes in M or T.

The various branches on the decision tree set the parameters for the automobile market model. The different outcomes for control costs, for example, translate into different values for γ^k_{0i} and b^k_i, yielding different solutions for the automobile sales mix. By systematically moving through the decision tree, one can calculate the possible outcomes for the automobile market and evaluate the various costs and benefits of alternative regulatory decisions.

Welfare Functions

There are two basic welfare functions that define the costs and benefits and guide the choices at the decision nodes. The first summary measure is the private benefit function that captures all the economic benefits appropriable by the private sector. Assuming that the automobile industry approximates the competitive market outcome, this private benefit function determines the choices at the industry decision nodes.

The private benefit function is simply the consumer and producer surpluses as defined above, minus a penalty for unrecouped capital costs whenever the market solution fails to utilize the full diesel capacity:

$$\text{PRB} = \text{V} - \text{PEN}, \tag{17}$$

where PRB is the private benefit, V is the consumer-producer surplus, and PEN is the unrecouped capital cost.*

The public benefit function includes all the private costs plus the costs of all the externalities associated with the operation of automobiles. In our calculations, these externalities are reduced to two types: for health and environmental effects and for an oil import premium. For the health and environmental effects, the externality cost is decomposed into two parts. First, we obtained judgmental estimates of the relative risk, R^k_i, of each type of car compared to large gasoline cars. Second, we assigned an externality cost, H, to large gasoline cars. Hence, the externality cost, EXT, is

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*Note that in this formation the excess capacity does not lower the market prices below b^k_i.

$$EXT = H \sum_i \sum_k R_i^k Q_i^k$$

For the import premium, assume a social cost of oil imports, W, above the price paid in the market. The total import premium cost, PREM, is then

$$PREM = W \frac{Q}{E}(10,000) \left(\frac{1-r^{n+1}}{1-r}\right)$$

assuming 10,000 miles a year per car over the life n and a discount factor of r. In the nominal data for this analysis, W is set equal to $10/bbl.

Hence, the public benefit function, PUB, is

(18) $$PUB = PRB - EXT - PREM$$

This public benefit function determines the overall measure of social cost and benefit. PUB is used to determine the best choices at the regulatory decision nodes.

In this analysis the automobile market model is solved three times for each branch (i.e., each scenario) on the decision tree. The solution for 1983 represents the period 1982-1984; 1987 represents the period 1985-1990; and 1995 represents the period 1990-2000. The two objective functions are discounted to reduce everything to a present value in 1980 at a discount rate of 5 percent.

EXAMPLE OF AUTOMOBILE MODEL OUTPUT

As an example of the output of the automobile model, one might examine the results for the year 1995 under two different assumptions regarding the regulation of diesel emissions. Table 3 presents price, user cost, and sales quantity output for two different branches, differing in the choice at the last decision, node 14. The choices at the first thirteen nodes are (1), (1), (1), (3), (2), (1), (2), (3), (1), (1), (1), (2), and (2), respectively. Hence, we have two scenarios at node 14 and an opportunity for sensitivity analysis.

In one case at node 14, diesel production is limited to no more than 300,000 units of each type. In the other case, diesel production is unlimited at the nominal variable cost. Table 3 shows that prohibiting diesels has little effect on the total number of cars sold, but significantly changes the mix of cars in the new fleet and the relative prices needed to clear the market, with the price of large diesels increasing from $9,050 to $11,230 and other size classes following a similar pattern. This reflects, among other factors, the importance of the substitution elasticities across different automobile models.

The change in mix produces a reduction in discounted private economic net benefits, from $1,370 billion with unlimited diesel to $1,365 billion with diesels banned. (Note that the absolute value of the benefits is arbitrary because of the integration convention used herein for consumer surplus. Only the relative differences are determined by the mode.)

The private economic benefits are the consumer and producer surpluses that can be captured by individuals in the marketplace. In addition, there are externality costs, such as the health effects and the social premium on imported oil. Private and public benefits were calculated for each case, using a $5,000 per car health and environmental externality cost, at the relative risks in the nominal data, and a $10 per barrel import premium. Although the reduction in benefits is now lessened, the change is not enough in this case to warrant the choice of banning the diesel engine.

In a second example, also shown in Table 2, the resolution of the CAFE standard is changed from 27.5 mpg to 33 mpg by 1990. Whereas at 27.5 mpg the CAFE standard was not binding, at 33 mpg the fine is inadequate to compel full compliance with the standard, shifting instead the mix of the fleet and making the fuel-efficient diesel cars more valuable. Comparison of the "ban" versus unlimited diesel case confirms that the diesel option is greater than the tighter the CAFE standard.

SELECTED DECISION TREE

The use of a simple model with an explicit decision tree offers several aids for the study of a diesel regulation problem. First, as with any formal model, the explicit statement of the data and relationships helps make the assumptions transparent and subject to scrutiny. Second, such an organized approach allows examination of many

TABLE 2 AUTOMOBILE MARKET OUTPUT SAMPLE 1955 CASE[a]

		CAFE = 27.5 MPG						CAFE = 33.0 MPG					
		Unlimited Diesel			"Ban" Diesel			Unlimited Diesel			"Ban" Diesel		
		Price	Qty.	User Cost	Price	Qty.	User Cost	Price	Qty.	User Cost	Price	Qty.	User Cost
GASOLINE	S	5.50	4.01	13.47	5.50	4.37	13.47	5.29	4.27	13.27	5.32	4.76	13.29
	M	6.50	3.42	16.33	6.50	3.67	16.33	6.78	3.23	16.61	6.77	3.55	16.60
	L	7.50	2.47	18.95	7.50	2.62	18.95	8.17	2.20	19.62	8.10	2.41	19.55
DIESEL	S	6.61	0.65	14.10	9.00	0.31	16.49	5.84	0.86	13.33	9.01	0.31	16.50
	M	7.90	0.58	17.07	10.77	0.31	19.95	7.49	0.66	16.66	10.94	0.31	20.11
	L	9.05	0.43	19.76	11.23	0.31	21.95	8.98	0.45	19.69	11.45	0.31	22.17
Total Quantity		11.55			11.58			11.66			11.65		
Fleet Efficiency		31.30mpg			30.83mpg			31.88mpg			31.17mpg		
Private Economic Benefit		$1370.Billion			$1365.Billion			$1364.Billion			$1357.Billion		
Private & Public Benefit		981.			977.			969.			964.		

[a] Solution for model years 1990 and beyond. Automobile quantities are 10^6 units, prices are in 10^3 dollars. All dollar values are 1980 real. Economic and externality benefits are present values. Model data at nominal values

different scenarios and incorporation of the effects of the large number of uncertainties that complicate early decisions.

Third, the decision analysis captures and displays the opportunities inherent in the sequential interaction between decisions and the collection of information. For instance, it is not necessary to decide now the level of particulate emission standard that will apply to light-duty vehicles for all time. If, later, particulates are (not) found to be a serious health risk, the standards can be tightened (relaxed) with relatively little loss during the interim.

Only a relatively few diesel-powered cars will be built over the next few years, so exposure to their emissions will be at a low level. And, if necessary, much of the early investment in diesel production capacity can be converted, at a cost, to other uses.* The standard set during the period of information collection can be the best choice possible today, given the present uncertainties and recognizing the opportunity to make other choices later when the nature of the uncertainties changes.

For the nominal data of this analysis, with no information on the trade-offs between particulate and NO_x regulation, the most interesting decision is the establishment of the level of particulate control. By 1985, after collecting information about industry's early investment decisions, control costs, future CAFE standards, and preliminary evidence of health risks, the EPA must establish particulate standards that will apply for the model years 1985 and beyond (of course, the public might choose to severely limit the number of diesels sold if the health evidence in some future year indicates a serious danger). In order to illustrate the decision analysis, focus is placed on establishing emission standards, as this decision might be made under a number of different conditions.

For this purpose, the decision problem is simplified by removing some of the alternatives in the description of the generic decision tree. The simplified decision tree appears in Figure 3. It ignores the complication of a tighter NO_x standard at node 1, and at nodes 2 and 3

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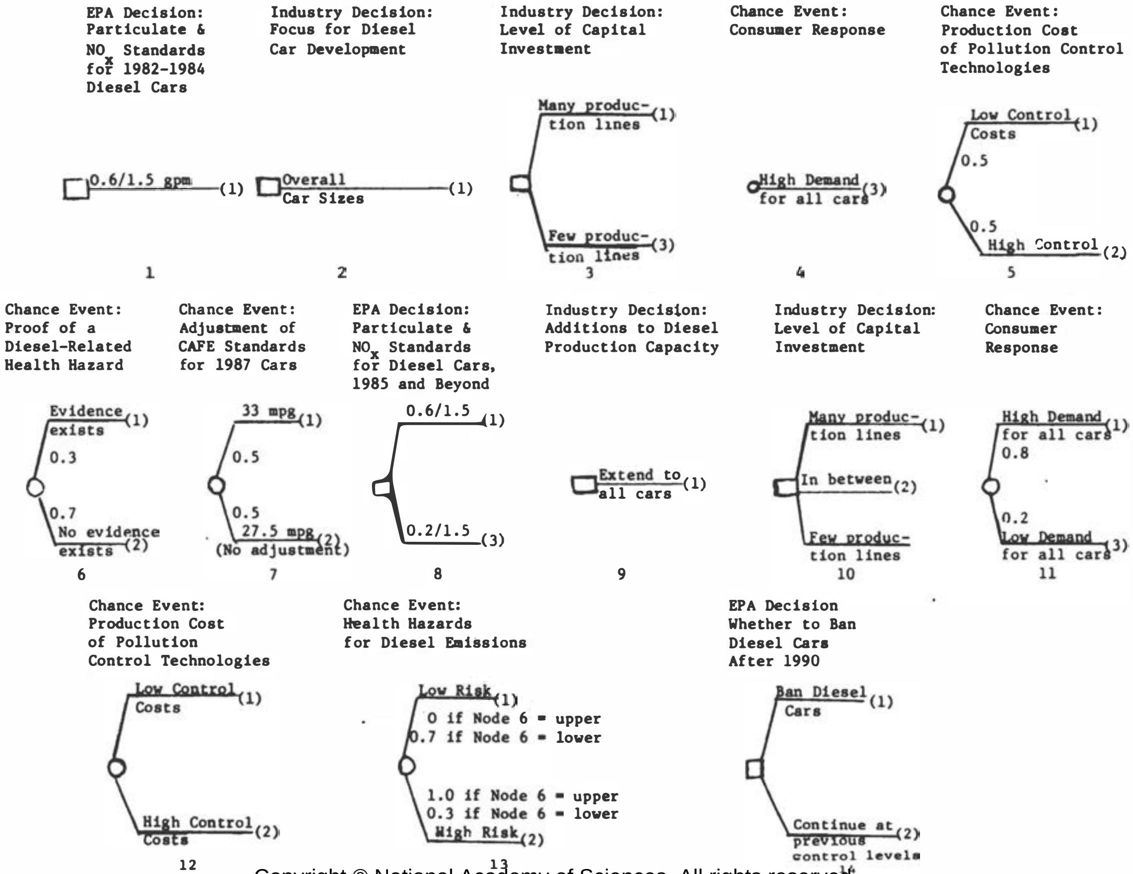
*Of course, this definition of the private benefit function assumes the extreme case of scrapping unused diesel capacity.

FIGURE 3


EPA Decision: Particulate & NO_x Standards for 1982-1984 Diesel Cars
0.6/1.5 gpm (1)
1
Industry Decision: Focus for Diesel Car Development
Overall Car Sizes (1)
2
Industry Decision: Level of Capital Investment
Many production lines (1)
Few production lines (3)
3
Chance Event: Consumer Response
High Demand for all cars (3)
4
Chance Event: Production Cost of Pollution Control Technologies
Low Control Costs (1)
0.5
0.5
High Control (2)
5
Chance Event: Proof of a Diesel-Related Health Hazard
Evidence exists (1)
0.3
0.7
No evidence exists (2)
6
Chance Event: Adjustment of CAFE Standards for 1987 Cars
33 mpg (1)
0.5
0.5
27.5 mpg (2)
(No adjustment)
7
EPA Decision: Particulate & NO_x Standards for Diesel Cars, 1985 and Beyond
0.6/1.5 (1)
0.2/1.5 (3)
8
Industry Decision: Additions to Diesel Production Capacity
Extend to all cars (1)
9
Industry Decision: Level of Capital Investment
Many production lines (1)
In between (2)
Few production lines
10
Chance Event: Consumer Response
High Demand for all cars (1)
0.8
0.2
Low Demand for all cars (3)
11
Chance Event: Production Cost of Pollution Control Technologies
Low Control Costs (1)
High Control Costs (2)
12
Chance Event: Health Hazards for Diesel Emissions
Low Risk (1)
0 if Node 6 = upper
0.7 if Node 6 = lower
1.0 if Node 6 = upper
0.3 if Node 6 = lower
High Risk (2)
13
EPA Decision Whether to Ban Diesel Cars After 1990
Ban Diesel Cars (1)
Continue at previous control levels (2)
14

the industry choice is narrowed to the selection of the scale of an early capacity investment spread over all car types. At node 4, the analysis restricts attention to the branch with low demand may be made for the 1982-1984 model years. At node 5, assume an equal chance that the control costs are low or high. At node 6, different judgments about the effects of uncertainty are introduced; the illustration assumes a 0.3 chance of discovering evidence pointing to a high health risk from diesel emissions. At node 7, it considers an equal chance that the CAFE standard will be increased to 33 mpg or remain at 27.5 mpg.

For node 8, only the difference in the particulate standard is examined. Based on early sensitivity runs, node 9 allows dieselization of cars in all production lines. The decision at node 10 for capacity to put in place in 1985 remains as in the generic tree. At node 11, both the industry and EPA face a common uncertainty about the level of demand, with a 0.8 chance of high demand for all cars and a 0.2 chance the demand for cars will be low. At node 12, the analysis assumes an equal chance that control costs will be low or high.

At node 13 in the simplified tree, the probability of the severity of the health risk depends upon the outcome at node 6. If earlier evidence of a health risk arises, the high health hazard is assumed to be realized with certainty. But if no evidence was obtained before 1985, then this analysis assumes only a 0.3 chance of the high health risk. Finally, at node 14, the stylized choice is shown of continuing the 1985 current level of regulation or effectively banning the diesel engine.

This simplified tree captures some of the most important interactions between the decisions and the uncertainties. Even this reduced problem generates more than 1,100 scenarios requiring nearly 1,500 separate solutions of the automobile market model.* Hence, this selected tree illustrates the information available from organizing many choices in a decision analysis.

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*The simplified tree produces 1,152 scenarios and requires 1,540 runs of the auto model. The full generic tree contains 373,248 scenarios or branches and 466,668 solutions of the model. Further simplification of the market model, sampling of uncertain branches, and the use of approximations of benefits may be required to solve the full tree.

RESULTS WITH SIMPLIFIED TREE

The simplified tree was used to illustrate the type of information available with the decision analysis. A key difficulty in the use of the decision tree centers on specifying the environmental and health cost externality. As discussed in the appendix, the analysis reflects judgmental estimates of the risk of each size and type of car relative to large gasoline cars. However, the Diesel Impacts Study Committee did not specify the externality cost for large gasoline cars. In fact, there is no consensus on the proper value for this externality cost, but it might be possible to place bounds on the reasonable values to be used in policymaking.

For this purpose, the decision analysis can be used to demonstrate the sensitivity of the key regulatory choices to changes in the externality cost. For low externality cost estimates the best regulatory choice will be for relaxed controls in all cases. For sufficiently high externality cost estimates, the best regulatory choice will be for tight controls. Between these extremes will be a range of externality cost estimates where the best regulatory choice, for relaxed or tight controls, depends upon the uncertain outcome of such matters as the evidence on health effects, the costs of controls, or the level of demand for diesels. Sensitivity tests of this analysis explored these ranges to bound the magnitudes of externality costs needed to affect regulatory decisions.

The public and private net benefits define the objective functions for the two types of decision makers. Private decision makers, simulating the competitive market outcome, are assumed to maximize private, appropriable economic net benefits of consumer and producer surpluses minus any CAFE fine. Public decision makers are assumed to deduct environmental and import cost externalities from private economic net benefits in selecting the optimal diesel emissions control regulations.

Selected results for the externality cost sensitivity tests appear in Table 3. The cases examine both the level of the assumed externality cost and the freedom to adjust decisions after information is collected. For each of the four possible combinations of early health evidence and the CAFE standard, the table reports the best choice in 1985 for particulate emission standards and the net expected benefits (private and public) for the periods 1985-2000 and 1981-2000.

For example, consider the first case, where it is assumed that there is no externality cost for environmental and health effects. In this situation the evidence on health and environmental effects is irrelevant, the optimal choice will always be for the most relaxed standard, and only the change in CAFE standards can affect the private and public benefits. The loss in private economic benefit associated with tighter CAFE standards would be approximately $20 billion in present value. Taking account of the oil import premium (here assumed to be $10 per barrel), the total public loss at the tighter CAFE standards reduces to $9 billion in present value, but the important premium is not large enough to then make the loss a gain and justify more stringent CAFE standards.

As the assumed health and environmental externality cost increases, the optimal regulatory decisions change and the private and public net benefits decrease. At an externality cost of $7,500 per car, for example, the best 1985 particulate standard depends upon the outcome of the uncertainty regarding early health and environmental evidence. If evidence appears for a severe health risk with diesels, then the stringent 0.2 g/mi standard is best, no matter what the outcome regarding the CAFE standard. But with no adverse health and environmental evidence, the best 1985 particulate standard is the more relaxed case of 0.6 g/mi. Furthermore, the introduction of the larger externality cost leads to fewer diesel-powered cars in the fleet, and slightly increases the economic penalty of going to the higher CAFE standard.

Overall, the changes in future fleet mix caused by the $7,500 per car externality cost reduce the private economic benefits for the 1981-2000 period by $4 billion.

By doubling the externality cost estimate to $15,000 per car, the same regulatory decisions are optimal in 1985 but the net benefits decrease. The public benefit decreases because the externality cost is higher. Private benefits decrease because the higher externality cost leads to greater probability of diesels being banned in 1990, which lowers the consumer and producer surplus and raises the cost of the tighter CAFE standard. At $15,000 per car the changes in decisions, compared to the case with no externality cost, reduce the private economic benefits by $10 billion.

So far this model of the decision process assumes that the EPA will have the flexibility in 1985 to exploit information gained over the next few years and make a

TABLE 3 DECISION TREE PAYOFFS[a]

Case Assumptions	Early Health/ Environmental Evidence	CAFE Standards	Best 1985 Particulate Standard	EXPECTED NET BENEFITS (Billions 1980$)			
				1985-2000		1981-2000	
				Private	Public	Private	Public
No externality cost	High Risk & No Evidence	33.0 mpg	(Gram per Mile) 0.6 gpm	$2517.	2456.	$3546.	3455
	High Risk & No Evidence	27.5	0.6	2527.	2465		
$5100/car externality cost	High Risk	33.0	0.2	2506.	1497.	3544.	2515.
	"	27.5	0.6	2527.	1524		
	No Evidence	33.0	0.6	2517.	1512.		
	"	27.5	0.6	2527.	1538		
$7500/car externality cost	High Risk	33.0	0.2	2506.	1050.	3542.	2074.
	"	27.5	0.2	2517.	1084.		
	No Evidence	33.0	0.6	2513.	1068.		
	"	27.5	0.6	2527.	1101.		
$15000/car externality cost	High Risk	33.0	0.2	2497.	- 339	3536.	699.
	"	27.5	0.2	2517.	- 288		
	No Evidence	33.0	0.6	2504.	- 315		
	"	27.5	0.6	2524.	- 262		
$15000/car externality cost Early decision on standards	High Risk	33.0	0.2[b]	2497.	- 339	3533.	696.
	"	27.5	0.2[b]	2517.	- 288		
	No Evidence	33.0	0.2[b]	2502.	- 318		
	"	33.0	0.2[b]	2517.	- 266		

Case Assumptions	Early Health/ Environmental Evidence	CAFE Standards	Best 1985 Particulate Standards	1985-2000		1981-2000	
				Private	Public	Private	Public
			(Grams Per Mile)				
$25000/car externality cost	High Risk	33.0	0.2	2497.	-2188	$3534.	-1131
	"	27.5	0.2	2517.	-2133		
	No Evidence	33.0	0.6	2504.	-2153		
	"	27.5	0.2	2517.	-2076		
$50000/car externality cost	High Risk	33.0	0.2	2497.	-6810	3529.	-5702
	"	27.5	0.2	2511.	-6678		
	No Evidence	33.0	0.2	2497.	-6745		
	"	27.5	0.2	2516.	-6606		

[a] The health evidence and CAFE standards are at nodes 6 and 7, where all possible cases were examined to display the optimal choice at node 8 under different outcomes. The earlier decisions and uncertainties do not affect this choice; hence, the results are displayed only for the first branches at nodes 3 and 5. All benefits are present values discounted at 5 percent, and all cases assume a $10/bbl import premium.

[b] Early decision restricts the choice at node 8 to a particulate emission standard of 0.2 gpm.

fresh decision about the control standard for particulate emissions. This idealized view of the decision-making process may not reflect political and institutional realities that could constrain the EPA choice. For example, the early announcement of a stringent standard might make it difficult later to relax the standard even if the evidence were to warrant such a choice. The evidence will surely be highly uncertain, and advocates of the status quo might be able to muster sufficient political support to foreclose the option of 0.6 g/mi. It is important, therefore, to understand the economic costs of such a flexibility loss in decision making. How much would be lost in public and private benefits by choosing now to tighten particulate standards to 0.2 g/mi instead of having the freedom to make the optimal choice in 1985?

This sensitivity run is the next case in Table 3, which preserves the assumed $15,000 per car health and environmental externality costs, but eliminates the 1985 choice of a 0.6 g/mi particulate emission standard. Table 3 shows that this constraint has no effect in those cases where there is evidence of high health and environmental risks. Then the best choice is to adopt the 0.2 g/mi standard, and the loss of flexibility for EPA has no effect on the expected benefits. However, in the circumstance where the health and environmental evidence is ambiguous, and there is still a significant probability that there is no significant risk from diesel emission, the loss in flexibiity forecloses the best 1985 regulatory decision and reduces the expected benefits of both the public and private objective functions. The net present value of the private sector loss increases to $13 billion for the 1981-2000 period. The total public welfare loss compared to the flexible case is $3 billion.

This case also demonstrates an unexpected interaction between the particulate and CAFE standards in a circumstance where no early evidence of health and environmental risks exists. The stringent particulate standard of 0.2 g/mi increases the cost of diesels and, therefore, decreases the number of diesels in the fleet. This slight reduction in the number of diesels is apparently sufficient to reduce the probability that diesels would be banned in 1990. Hence, the private benefits of the stringent standards are reduced less than the public benefits.

Further increases in the assumed externality cost enhance the likelihood that the best 1985 particulate standard will be 0.2 g/mi. At $25,000 per car the high health and environmental risk case always lead to the 0.2 g/mi standard. Furthermore, even if there is still a significant probabilty of a low health risk, if the CAFE standard is low and diesels are thus less important, the best choice is for the more stringent 1985 particulate standard. The expected net loss from the no externality case is now $12 billion in present value.

By the time the externality cost is increased to $50,000 per car, the decision is tipped in 1985 to 0.2 g/mi in every case. The reduction in the expected net private benefit induced by this $50,000 per car externality is a present value of $17 billion, compared with the outcomes in the no externality case.

CONCLUSION

The worst case for a decision maker is choosing when the best choice depends on the outcome of many highly uncertain events. The diesel particulate emission regulation problem would be simple if the costs and benefits of emissions control for all reasonable scenarios always pointed to a single standard. If the health and environmental risks were never large enough to outweigh the costs of control, then a particular emisson standard of 0.6 g/mi would be optimal and there would be no point in further collection of information. Conversely, if the costs of control were easily outweighed by the health and environmental risks, decision makers could move confidently to a tighter standard of 0.2 g/mi.

The decison analysis and the decision tree payoffs provide a framework for investigating a range over which this hoped-for dominance might apply. In the case of no externality cost for adverse health and environmental effects, and a $10 premiun per barrel for imported oil, the optimal particulate standard is *a priori* 0.6 g/mi. But, as the assumed size of the health and environmental externality changes, a situation results in which the best particulate standard to set in 1985 depends upon information that will become available before the time of the decision. At the $7,500 per car externality costs, for instance, the best regulatory choice turns on information gained regarding the health and environmental risks of diesels. How large is $7,500 per car? Is it reasonable to assume that the externality cost could be that great?

The figure seems high but not outlandish. It is between one-third and one-half of the private user cost of a new car. It does not seem beyond reason that this proportion of the total cost of a car would be an externality not seen by the user. Looking at the question another way, take approximately 10 million new cars per year and assign them the *pro rata* share of 50,000 traffic accident fatalities per year; then the $7,500 per car externality translates into $1.5 million per fatality. This is high, but not entirely inconceivable. In addition, if the other health and environmental costs are counted, the fatality costs would be reduced to perhaps $1 million per life. Hence the $7,500 per car externality costs appears to be at the high end of the range of reasonable estimates.* This means that the choice of the best 1985 particulate emission standard will not likely be simplified by a dominance argument.

This point is reinforced by examining the other end of the range of externality costs. It takes an externality cost approaching $50,000 per car to justify the tighter standards under all possible cases. Although the $7,500 per car externality estimate seems to lie within the range of serious discussion, $50,000 per car appears well beyond the bounds that could be supported by a reasonable interpretation of the data. Dominance is not likely to occur at this end of the spectrum. The best choice of particulate standards for diesel cars, therefore, will depend upon the information obtained in the next few years, especially information on the magnitude and likelihood of the health and environmental risks.

Consequently, the most important step for the next few years must be to maintain the flexibility to change the standard, if need be, after new information is collected, and to emphasize efforts to improve the data base for estimating the costs and benefits. Qualitatively, improvements in the data will improve the opportunity to make better regulatory decisions in 1985 and thereafter. However, the importance of this flexiblity and information may be less than might be hoped for or expected. In the comparison of the two cases with a $15,000 per car externality cost, a premature decision on particulate standard was shown to cost only $3 billion.

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*For a discussion of estimates of the value of life implied by observed choices, see Schwing, R.C. (1979). "Longevity Benefits and Costs of Reducing Various Risks," *Technology Forecasting and Social Change*, Volume 13. Elsevier, North-Holland.

This cost compares with the loss in public benefits of $50 billion caused by tightening of the CAFE standards in this case. Given the approximations and simplifications inherent in the formal analysis, the $3 billion cost-of-being-wrong must be within the "error noise" of the analysis.

At the margin, therefore, the choice of the best diesel emission standard may be quite difficult. The costs and benefits are highly uncertain, and the trade-offs will depend critically on the outcomes of future events. But on the average the problem does not appear to be the most significant issue facing the automobile industry or the nation. Many assumptions made in the analysis lead to a high value for the diesel option (e.g., presuming a high rate of sales for diesels, with a relatively small cost advantage). If the cost of tighter diesel standards--even if they are not optimum--is only $3 billion per year, further refinement of the data and analysis will probably not change this qualitative conclusion. The present analysis points toward the more relaxed standard of 0.6 g/mi, but at the margin the choice will be difficult. The most important step will be to collect better information over the next few years in order to sustain a later review of the decision and a possible tightening of the standards. However, if other factors, such as political constraints or simple errors in decision making, lead to stringent standards, the cost to society should not be great.

These conclusions are explored further in the full report of the Diesel Impacts Study Committee.

APPENDIX

The parameters of the automobile model and the decision tree model must be specified clearly in order to conduct the decision analysis. In some instances the parameters can be obtained by a suitable aggregation of empirical data; in other cases only subjective estimates of the parameters are available. This appendix reports the key assumptions and procedures used to obtain the parameters that comprise the nominal data base for the decision analysis.

BENCHMARKING DEMAND ELASTICITIES

The automobile model requires estimates of a number of elasticity parameters. A disaggregated model was used to obtain the parameters.

Size Classes

The first level of the demand model is the translog cost equation:

$$\ell n\ UA = \beta_{00} + \sum_{k}\beta_{k0}\ \ell n\ UB^{k} + 1/2\sum_{k}\sum_{j}\beta_{kj}\ \ell n\ UB^{k}\ \ell n\ UB^{j}$$

From Shephard's lemma we know the logarithmic derivatives of the cost of equation yield the value shares, i.e.,

$$s^{k} = \beta_{k0} + \sum_{j}\beta_{kj}\ell n\ UB^{j}$$

where

$$s^k = \frac{UB^k QB^k}{\sum_j UB^j QB^j}$$

Certain assumptions constrain the parameters. The differentiability of the cost function implies symmetry, or

$$\beta_{kj} = \beta_{jk}$$

Further, homogeneity of the cost function is assumed in component costs (i.e., a proportional change in all user costs does not change the value shares);

$$\sum_j \beta_{kj} = 0$$

and because the shares must add to unity,

$$\sum_k \beta_{k0} = 1.0$$

Given a reference forecast for user costs and shares, one can select the parameters of the cost equation to match the elasticities of any demand model that satisfies our restrictions.

For the purposes of the diesel analysis, Cardell (1980) exercised his auto demand model to provide estimates of the several elasticities.* Cardell's estimates were in terms of the value share elasticities for total sales as a function of sales price, i.e.,

$$v^k = \frac{P^k QB^k}{\sum_j P^j QB^j}$$

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*Cardell's model is an outgrowth of research reported in Electric Power Research Institute (1977). Methodology for Predicting the Demand for New Electricity-Using Goods. Palo Alto, Calif.: EA-593, Project 488-1.

Cardell's value share elasticities for small (S), medium (M), and large (L) cars were:

$$\frac{\partial \ln v^k}{\partial \ln P^j}$$

k \ j	S	M	L
S	-0.51	0.40	0.35
M	0.48	-0.82	0.32
L	0.21	0.20	-0.70

This automobile model requires converting these elasticities into the elasticities for value shares in terms of user costs.

Let

$$C_1 = \sum_j UB^j QB^j$$

$$C_2 = \sum_j P^j \ QB^j$$

Then, if we assume the two models are equivalent at a reference point,

$$QB^k = \frac{s^k C_1}{UB^k} = \frac{v^k C_2}{P^k}$$

Hence,

$$\frac{\partial \ln QB^k}{\partial \ln UB^k} = \frac{\partial \ln s^k}{\partial \ln UB^k} + \frac{\partial \ln C_1}{\partial \ln UB^k} - 1$$

and

$$\frac{\partial \ln QB^k}{\partial \ln P^k} = \frac{\partial \ln v^k}{\ln P^k} + \frac{\partial \ln C_2}{\partial \ln P^k} - 1$$

Now, again from Shephard's lemma,

$$\frac{\partial \ln C_1}{\partial \ln UB^k} = s^k$$

And, as a reasonable approximation, assume that

$$\frac{\partial \ln C_2}{\partial \ln P^k} \approx v^k$$

i.e., a 1 percent increase in the price of the K^{th} car type produces an increase in total sales equal to the value share of the K^{th} car type x 1 percent.

Furthermore, by the local equivalence of the models,

$$\frac{\partial \ln QB^k}{\partial \ln UB^k} = \frac{\partial \ln QB^k}{\partial \ln P^k} \cdot \frac{\partial \ln P^k}{\partial \ln UB^k}$$

Therefore,

$$\frac{\partial \ln s^k}{\partial \ln UB^k} = \left(\frac{\partial \ln v^k}{\partial \ln P^k} + v^k - 1\right) \frac{\partial \ln P^k}{\partial \ln UB^k} - s^k + 1$$

From the cost function,

$$\beta_{kk} = \frac{\partial s^k}{\partial \ln UB^k} = \frac{\partial \ln s^k}{\partial \ln UB^k} s^k$$

Similarly,

$$\beta_{kj} = \frac{\partial s^k}{\partial \ln UB^j} = \left[\left(\frac{\partial \ln v^k}{\partial \ln P^j} + v^j\right) \frac{\partial \ln P^j}{\partial \ln UB^j} - s^j\right] s^k$$

As the reference point for making the conversion to obtain β_{kj}, use the data from Stucker _et al_.:*

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*Data are for 1976. Note that Stucker's data for user costs are annualized rather than the present value. Also, Stucker used a different formula for user costs--by assuming that miles driven are a function of user costs, not just the cost of driving. At the reference forecast, the two equations can be made identical, and there is no effect on the estimation of the elasticities.

	P^k	UB^k	QB^k	v^k	s^k
S	\$ 4100.	\$ 1468.	3.4×10^6	0.33	0.35
M	4740.	1638.	2.9×10^6	0.33	0.33
L	6190.	1979.	2.3×10^6	0.34	0.32

According to Stucker,

$$UB^k = 500 + 0.164P^k + (0.65/E^k)\,D$$

where E and D are efficiencies and miles driven, respectively.

Therefore,

$$\frac{\partial UB^k}{\partial P^k} = 0.164$$

and

		$\dfrac{\partial \ln P^k}{\partial \ln UB^k}$
	S	2.17
k =	M	2.09
	L	1.94

Combining these data and scaling with the appropriate value shares, we obtain:

$$\frac{\partial s^k}{\partial \ln UB^j} = \beta_{kj}$$

k \ j	S	M	L
S	0.67	0.43	0.40
M	0.45	0.81	0.34
L	0.24	0.24	0.63

Unfortunately, these data do not quite satisfy the symmetry or homogeneity conditions, Furthermore, Cardell expressed some concern about the high value (0.40) for the effect of large car user costs on small car shares.

The natural assumption is that large and small cars should interact more strongly with medium cars than with each other. To accommodate this judgment and meet the restrictions on the parameters, ad hoc adjustments were made to obtain the parameter estimates for use in the model:

β_{kj}

k \ j	S	M	L
S	0.67	0.44	0.23
M	0.44	0.84	0.40
L	0.23	0.40	0.63

Engine Types

Runs with the Cardell model also produced the data to estimate the elasticity of substitution in the constant elasticity production function used to aggregate the engine types within each size class. Within a size class, Cardell's price-value shares are

$$v_i^k = \frac{P_i^k \; Q_i^k}{\sum_j P_j^k \; Q_i^k}$$

For the trade-offs between engine types, gasoline and diesel, one may consider the estimates:

$$\frac{\partial \; \ell n \; v_G^k}{\partial \; \ell n \; P_G^k} = \begin{cases} S & -0.60 \\ M & -0.48 \\ L & -0.42 \end{cases}$$

Following the same analysis as for car sizes produces

$$\frac{\partial \ \ln s_i^k}{\partial \ \ln U_i^k} = \left[\frac{\partial \ \ln v_i^k}{\partial \ \ln P_i^k} + v_i^k - 1\right] \frac{\partial \ \ln P_i^k}{\partial \ \ln U_i^k} + 1$$

where

$$s_i^k = \frac{U_i^k \ Q_i^k}{\sum_j U_j^k \ Q_j^k}$$

Therefore, the user cost-value share elasticities are:

$$\frac{\partial \ \ln s_i^k}{\partial \ \ln U_i^k} = \begin{cases} S & -2.11 \\ M & -1.73 \\ L & -1.72 \end{cases}$$

The constant elasticity production function has the share equation

$$s_i^k = \theta_i^k \left(\frac{UB^k}{U_i^k}\right)^{\sigma_k - 1}$$

Taking the derivative yields

$$\frac{\partial \ \ln s_i^k}{\partial \ \ln U_i^k} = (\sigma_k - 1) \ (s_i^k - 1)$$

From Cardell's data note that

$$v_1^S = 0.59$$
$$v_1^M = 0.58$$
$$v_1^L = 0.58$$

Following the close approximations in the Stucker data, assume $s_i^k = v_i^k$. Therefore,

$$\frac{\partial \ln s_G^k}{\partial \ln U_G^k}$$

S	M	L
-1.78	-1.46	-1.21

and the elasticities are

$$\sigma_k$$

S	M	L
5.34	4.48	3.88

Benchmarking Parameters

The benchmarking begins with a forecast of the user's costs and quantities for the six types of automobile, U_i^k and Q_i^k. With these data, calculate the value shares, s_i^k and s^k. Assume that the reference forecast satisfies*

$$QB^k = \sum_i Q_i^k$$

and

$$QA = \sum_k QB^k$$

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*Note that, in general, our aggregation according to the production functions dual to the cost functions will not satisfy this adding up equality for generic cars. We can think of this as a quality adjustment to account for changes in mix.

With these data, obtain the aggregate user costs as

$$UA = \sum_{ik} U_i^k Q_i^k / QA$$

and

$$UB^k = \sum_i U_i^k Q_i^k / QB^k$$

The Cardell data for β_{kj} are given. Therefore, calculate

$$\beta_{k0} = s^k - \sum_j \beta_{kj} \ln UB^j$$

and

$$\beta_{00} = \ln UA - \sum_j \beta_{kj} \ln UB^j - \tfrac{1}{2} \sum_k \sum_j \beta_{kj} \ln UB^k \ln UB^j$$

Given σ_k from the Cardell data and the shares from the reference forecast,

$$\theta_i^k = s_i^k \left(\frac{U_i^k}{UB^k} \right)^{\sigma_k - 1}$$

This completes the benchmarking of the model to duplicate the point estimate of the reference forecast and the elasticities from the Cardell data. We then solve this mode for the actual data as specified in the appropriate scenario.

CALCULATING USER COST

Most of the structure of the automobile model follows the work of Stucker et al., but we employed a different derivation of the user cost equation and adapted the equation to the data used in the Diesel Impacts Study. This user cost model has three components: a fixed component for each car that represents the operating, maintenance, and insurance costs over the lifetime of the car; and the fuel costs that are a function of the price of fuel, the miles driven, and the efficiency of the car. Hence,

$$U_i^k = \gamma_{0_i}^k + \gamma_1 P_i^k + \left(\frac{1-r^{n+1}}{1-r}\right)\frac{PF_i D}{E_i^k}$$

where

U_i^k = user cost;

$\gamma_{0_i}^k$ = operating and maintenance cost;

P_i^k = purchase price;

γ_i = one plus the variable insurance cost;

r = consumer discount factor;

n = life of the car(years);

PF_i = price of fuel(dollars);

E_i^k = efficiency of car(MPG); and

D = miles driven in a year.

The number of miles driven in a year is assumed to depend upon the variable cost per mile,

$$\frac{PF_i}{E_i^k}$$

(This is in contrast to Stucker who models miles driven as a function of total user cost, U_i^k.)

To first order relative to base demand D_0 at cost $\frac{PF_0}{E_0}$,

$$D = D_0 \left(1 + \frac{PF}{E} \cdot \frac{E_0}{PF_0} \varepsilon - \varepsilon\right)$$

where ε is the elasticity of demand for miles driven. Therefore, the user cost equation satisfies

$$U_i^k = \gamma_{0_i}^k + \gamma_1 P_i^k + \gamma_2 \frac{PF_i}{E_i^k} + \gamma_{3_i}^k \left(\frac{PF_i}{E^k}\right)^2$$

where

$\gamma_{0_i}^k$ = operating, maintenance and insurance costs;

γ_1 = one plus variable insurance cost;

$\gamma_2 = D_0(1-\varepsilon)\left(\frac{1-r^{n+1}}{1-r}\right)$

and

$$\gamma_{3_i}^k = \frac{D_0 \varepsilon E_0}{PF_0}\left(\frac{1-r^{n+1}}{1-r}\right)$$

The assumed elasticity, $\varepsilon = -0.20$, is in accord with Stucker *et al*. and Sweeney (1978). The Diesel Impacts Study Committee's Analytic Panel constructed user cost estimates consistent with a 25 percent market in the sale of diesel car demands (National Research Council, 1981). Lacking data on insurance, the analyst assumes the user cost estimates as $\gamma_1 = 1$. Using a discount rate of 5 percent and a fuel cost of $2.00 per gallon, with base driving demand at 9,500 miles per year (hence, $\gamma_2 = 98{,}268$), the base case Diesel Impacts Study Committee assumptions imply the parameters in Table 5 for the user cost equation.

BENCHMARKING THE DEMAND CURVE

The elasticity data taken from Cardell define the shape of the demand curves for each period. Given one point on the curve, therefore, the demand mode can be fixed to simulate different scenarios. For the base case analysis, the assumed demand for new car sales is the same as in 1976, plus an additional 25 percent for diesel

TABLE A-1

USER COST PARAMETERS[a]

	Gasoline			Diesel		
	S	M	L	S	M	L
E_0 (mpg)	35.2	25.3	21.4	43.4	34.2	27.4
γ_0 (\$)	3.423	4.038	4.619	3.652	4.267	4.848
γ_3 ($x10^2$)	-2636858	-2071817	-1752446	-3554026	-2800638	-2243786
P (\$)	5,500	6,500	7,500	5,950	7,050	8,100
U (\$)	14,010	17,012	19,773	13,520	16,300	18,840

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[a] All dollar figures are 1980 present values using a real discount rate of 5 percent.

engines when the user costs give approximately the 5 percent advantage to diesel engines (see Table A-1).

HEALTH AND ENVIRONMENTAL EFFECTS ASSUMPTIONS

Lacking data on the health impacts of diesel emissions, the sensitivity tests relied upon judgments about the relative effects of different types of cars. Using large gasoline cars as the standard, Table A-2 presents four different estimates of the health and environmental effects of automobiles from accidents, particulate emissions, and all other causes. The four cases vary by particulate standard and high and low diesel effects.

These relative risks are the most troublesome elements of the analysis to make explicit. Health and environmental effects are always difficult to measure and clouded in great uncertainty. Furthermore, such estimates are often a focal point of emotional attention that gives rise to a natural caution in a reputable scientist confronted with conflicting information of poor quality. True to the disciplines of empirical observation and replication, the scientist defers judgment on such important issues. Even so, many decisions must be made now, before all the evidence is in, and some judgment must guide the choices, explicitly or implicity. According to the arguments of decision analysis, it is better to include a subjective estimate of important parameters, with a characterization of the uncertainty, than to assume the point estimate implied by ignoring the parameter.

TABLE A-2 RELATIVE EXTERNALITY RISK

		Safety	Systemic	NO_x	CO	Visibility	Cancer[b]	Weighted Total[a]	
								Low	High
Gasoline	S	2.0	1.0	1.0	1.0	1.0	0	1.75	1.75
	M	1.5	1.0	1.0	1.0	1.0	0	1.39	1.39
	L	1.0	1.0	1.0	1.0	1.0	0	1.00	1.00
Diesel 0.6 Gram Per Mile	S	2.0	1.2	2.5	0.14	1.50	0.02	1.75	1.86
	M	1.5	1.7	2.5	0.14	1.75	0.08	1.39	1.61
	L	1.0	1.7	2.5	0.14	2.00	0.08	1.00	1.26
Diesel 0.2 Gram Per Mile	S	2.0	1.2	2.5	0.14	1.25	0.02	1.75	1.82
	M	1.5	1.2	2.5	0.14	1.375	0.02	1.39	1.47
	L	1.0	1.2	2.5	0.14	1.50	0.02	1.00	1.11
Weight		20×10^9	3×10^9	0.5×10^9	0.5×10^9	2.8×10^9	20×10^9	--	--

[a] Weighted total normalized to large gasoline cars, with low assuming no difference caused by the engine type and high assuming the weighted total of relative risks apply to diesel engines.

[b] Not included in gasoline column, which has no cancer deaths attributed. Added to the diesel impact as a premium above the total weight of 26.8×10^9.

Here we applied the decision analysis approach in preparing estimates of the health and environmental risks of various types of cars, relative to large gasoline cars. While the estimates are based on discussions with the members of the Diesel Impacts Study Committee and other experts, the final estimates are the responsibility of the author. The "weights" for aggregating the relative risks are based on subjective estimates of the total externality costs in 1980.

The high or low estimates conform to the high or low branch at node 13 of the decision tree. The particulate standard is determined at nodes 1 and 8.

Using these relative assumptions, different health and environmental costs are postulated for the large gasoline car. If the relative risk measures are correct, one can calculate the value of reducing the exposure to diesels by calculating the change in total externality costs produced by changing the size and composition of the fleet. By varying the assumed cost for the large gasoline car, the externality cost value that produces indifference in the choice of standard can also be calculated.

SETTING AUTOMOBILE EFFICIENCIES AND COSTS

Automobile efficiencies, which are exogenous to this automobile market model, are expected to change during the next two decades. The efficiency assumptions for the nominal data base are summarized in Table A-3.

TABLE A-3

AUTOMOBILE EFFICIENCIES
(miles per gallon)

		1980	1983[a]	1985	1987[a]	1990	1995
Gasoline	S	30.0	31.1	32.2	33.5	34.5	36.9
	M	23.6	23.4	23.3	25.2	27.1	29.0
	L	20.0	20.7	21.4	22.2	23.0	24.6
Diesel	S	40.5	42.0	43.4	45.0	46.6	48.0
	M	32.0	33.1	34.2	35.4	36.6	37.7
	L	26.0	26.7	27.4	29.2	31.0	32.0

[a] Obtained by averaging data in adjacent columns.

The simplified production cost equation assumes an exogenous estimate of the variable cost of producing each type of car. Insufficient data were available to apply the Stucker model of endogenous determination of production costs as a function of the efficiency, and the model was not used for that purpose. The base line of the nominal data uses the purchase price, from the benchmark user cost calculations, as the estimate of production cost--i.e., $5,500, $6,500, and $7,500 for small, medium, and large gasoline cars, respectively; $5,950, $7,050, and $8,100 for small, medium, and large diesels.

During the execution of the decision analysis, production costs for diesel cars are changed according to the status of the control technology, using the figures in Table 1.

UNRECOUPED CAPITAL COSTS

Dewees (1980) provided the estimate that the capital component of an efficient diesel engine plant costs $500 million and produces 384,000 units per year. Half of those costs can be recovered by switching the plant in the first year. However, this requires the complete shutdown and conversion of the plant. Alternatively, assume one can restrict the plant to diesel use and attempt to recover the costs over the life of production. If the life of the plant is 20 years, then the recovery, c, on each car each year must satisfy

$$\frac{0.500}{0.384} = \sum_{j=0}^{20} c\left(\frac{1}{1+r}\right)^j$$

or

$$c = \left(\frac{.500}{.384}\right) \sum_{j=0}^{20} \left(\frac{1}{1+r}\right)^j$$

where r is the discount rate.

The cost estimates in the auto model include a component for the amortized capital cost c. However, if the actual demand for diesel engines does not exceed the capacity put in place in decision nodes 3 and 10, then these capital costs will not be recouped. Hence, for each target year of the simulation, unrecouped capital cost is added equal to

$$PEN = c \sum_{k} (\bar{Q}_2^{\,k} - Q_2^k)$$

This cost is subtracted from the estimate of consumer and producer surplus after the solution of the model, which implicitly assume that excess does not induce the automobile industry to price at below long-run costs.

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