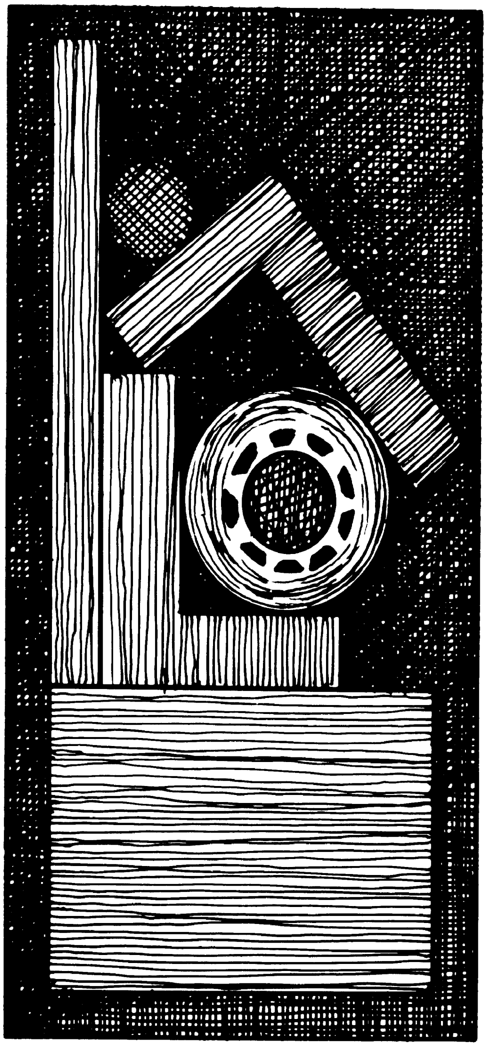
Limitations on the Use of Mathematical Models in Transportation Policy Analysis



ABSTRACT:
Government agencies are using many kinds of mathematical models to forecast the effects of proposed government policies. Some models are useful; others are not; all have limitations. While modeling can contribute to effective policymaking, it can contribute to poor decision-making if policymakers cannot assess the quality of a given application.

This paper describes models designed for use in policy analyses relating to the automotive transportation system, discusses limitations of these models, and poses questions policymakers should ask about a model to be sure its use is appropriate.

Introduction

Mathematical modeling of real-world systems has increased significantly in the past two decades. Computerized simulations of physical and socioeconomic systems have proliferated as federal agencies have funded the development and use of such models. A National Science Foundation study established that between 1966 and 1973 federal agencies other than the Department of Defense supported or used more than 650 models developed at a cost estimated at $100 million (Fromm, Hamilton, and Hamilton 1974). Many more models have been developed since 1973.

The appropriate use of models and their output can contribute to effective policymaking, but misuse of models or misinterpretation of their output can mislead decision-making.

The success of models that simulate physical systems has often been dramatic. A widely known example is the modeling that the National Aeronautics and Space Administration conducted in its lunar exploration program. Computer-simulated "landings" and "retrievals" were conducted hundreds of times before the first manned landing was attempted.

Successful simulation of physical systems has encouraged development of mathematical models of social/economic/political "systems." For example, mathematical models are used to forecast such economic indicators as the gross national product, capital investment rates, employment rates, federal tax revenues, and other measures of the national economy. These socioeconomic models are designed to project or forecast the future behavior of real-world systems under scrutiny. While physical principles are well understood and stable enough to be predictable, social, economic, and political behavior is not well understood, not stable, and not very predictable (with some exceptions) except within broad limits.

Some relatively new forms of mathematical models have been developed in recent years for use in analyzing the medium and long-range effects of federal policy decisions. A few of them have been applied in federal deliberations concerning policies relating to energy conservation, environmental pollution, automotive safety, and other complex issues. The use of mathematical models in policy analyses requires that policymakers obtain sufficient information on the models (e.g., their structure, limitations, relative reliability of output) to make informed judgments concerning the value of the forecasts the models produce. The appropriate use of models and their output can contribute to effective policymaking, but misuse of models or misinterpretation of their output can mislead decision-making.

What is a Model?

A model is a representation of reality. Necessarily it is a simplification or abstraction. A model may be a physical representation, for example, a globe. A mathematical model differs from the more tangible physical model, in that "reality" is represented by an equation or series of equations. There are many kinds of models. This paper is concerned with mathematical models, in particular, *econometric* models. Econometric models have their basis in economic theory, are derived using statistical techniques, and are used in studying relationships among economic variables.

Two important elements of equations are *variables* and *parameters. Variables* represent the elements of the system being modeled (e.g., the number of automobiles in the United States). In a mathematical model the values of some variables are specified outside the model. These variables are called *exogenous* variables. The values of other variables are calculated within a model. These variables are called *endogenous*. Knowing which variables are exogenous and which are endogenous can be important in understanding the results of a model. This is discussed later.

Parameters of an equation are factors that qualify the variables. For example, one might calculate the number of large-size cars sold in a year as a function of the annual income of car buyers and their tendency to buy large cars. People with higher incomes might purchase more large-size cars than people with lower incomes. Thus, a simple form of an equation to calculate large-size car sales might equate sales with some number "a" times the number of people with high incomes, plus some number "b" times the number of people with low incomes. In this example, the numbers chosen for "a" and "b" are the *parameters* of the equation. The interpretation of the parameters depends on the *specification of the equation structure,* that is, on the mathematical form of the equation. The specification of the equations and the derivation of the values of the parameters are important tasks in creating a model. Parameters remain constant for a particular analysis, while the values assigned to variables change.

The example above involves only one equation. Usually, a modeler needs to address more than one question at the same time. For example, the modeler may wish to predict both the demand for automobiles and fuel consumption. Since these variables are related to each other, a more complex model with more than one equation may be required. A modeler might create a model in which automobile demand is a function of several variables (e.g., income) and in which fuel consumption is a function of auto demand, plus several other variables (e.g., the fuel economy of the automobiles sold). The specification of the equations and the relationships among the various equations that describe how the variables are linked in the real world represent the overall *logic* of the model. An analyst needs to understand the logic of a model in order to use it intelligently.

When constructing models, model builders usually experiment with a wide range of alternative forms to find the closest fit of the equations to the sample data. Undue emphasis on close fit, however, sometimes leads to misspecification of the model structure, for example, by use of spurious variables in an equation to improve its fit. When used for forecasting or policy analysis, such a misspecified model is poorer than a proper specification that fits less closely to sample data.

A model is obviously based on observations of and *assumptions* about the real world. These observations and assumptions support the modeler's selection of variables, parameters, functions, and the basic logic of a model. Some models represent systems whose behavior is well understood. An example is an electrical circuit. Observations and assumptions concerning the behavior of such systems are explicit and objective.

An inherent limitation of models is that judgments are necessary in building them.

As information about real-world systems becomes less precise or harder to measure, more assumptions must be made. Modeling becomes a less precise endeavor as it moves away from physical systems and toward social systems. Modeling an electrical circuit is a straightforward task, compared to modeling human decision-making. Also, the nature of the information about physical and human systems is different. Good historical information about a physical system is quite valuable in modeling future performance, because the system usually does not change. Good information about a social system is equally desired but may be of less value in forming assumptions, because social systems often change and in ways that were not part of the past. Thus, to understand a model's limitations it is important to understand the *assumptions* that were used to create it.

Mathematical models have been used predominantly in two ways in studies of the automobile transportation system—forecasting and policy analysis.

When a model is used primarily for *forecasting,* the user exercises the model to produce a forecast based on the general assumption that past relationships among variables will continue. Often this is done to identify future problems that may occur if past relationships continue.

Policy analysis applications also produce forecasts, but the concern is with the different futures associated with different *policy* assumptions. Policy changes are imposed on the model and forecasts made to assess the effects of the changes.

For example, a *forecasting* use of an automobile demand model would involve specification of the exogenous variables and input using the best information available to the user. The primary interest is to estimate future automobile demand as it is likely to occur under future conditions. A *policy analysis* application might examine the expected effects on future automobile demand of increases in gasoline prices caused by an increased federal tax. In both cases, the model output—a forecast—is of interest.

Models that produce forecasts are usually designed to produce either short-term or long-term forecasts. The assumptions, structure, and associated factors required for the one purpose often make the model less suitable for the other. Models designed for long-term forecasting often do not produce good short-term forecasts and vice versa.

Building a Model

Creating a model requires completing a series of steps. Obviously, these differ somewhat, depending on the type of model. There are, however, common elements that need to be understood in order to understand how the limitations inherent in a model come into being.

The steps start as the modeler specifies the general elements and relationships of the real-world system to be modeled. Data requirements and the availability of data are then assessed. Next, submodels of the subsystems of the real-world system are formulated. These submodels are combined to create the larger model. As these submodels are created and combined, data are gathered and the parameters of the model are estimated. Complex models using many equations are usually prepared in a form suitable for use on a computer. This is a complex process also. Once the model is built, it must be tested to establish its validity. This may be done by testing its effectiveness in reproducing values over some *historical period* where the output values are known. After this capability of the model is tested, it is placed into use.

An important inherent limitation of a model is created by what is left out.

The steps clearly are complicated but, as stated above, each step may seem relatively straightforward. In reality this is not the case. Each step requires judgment. It is difficult to represent real-world systems in terms of mathematical relationships. Data are often unavailable or inaccurate. Combining the subsystem models to create the model is seldom simple.

Assumptions and estimates must be made at almost every step of the process. In even the best models of social systems, the biases of the model builder are incorporated directly into the model as the necessary judgments are made. The fact that judgments are necessary is an inherent limitation. Thus, one who uses a model must understand the judgments and assumptions associated with the model and how they influence the model performance. This requires that those who build models make their judgments explicit and document them fully. Adequate model documentation is crucial because it is often the only link between the model and the model user.

Limitations of Models

Models have a definite role in policy analysis. They are important and powerful analytical tools that can add clarity and insight to many analyses. But they must be used carefully. Their appropriate use is most likely to flow from understanding their limitations and ensuring that such limitations are considered in any analysis.

We have previously spoken of "limitations" in a general sense. At this point, we present a series of examples of limitations that are associated with types of models commonly used in motor vehicle transportation system policy analyses. For the most part, we address problems related to use of econometric models, because they have been the most frequently used. Many of the limitations noted, however, apply also to other types of models.

For each limitation identified, the problem is stated, an illustration presented, and the significance discussed. As these selected limitations are only examples, our list is clearly not inclusive.

Limitation 1. Models are Incomplete

Models are abstractions of reality. Real-world systems are complex and composed of many interrelated components. A "good" model must attempt to capture all the critical elements of the real-world system. This is something that is virtually impossible to do in modeling social systems. Thus, an important inherent limitation of a model is created by what is left out.

The limitation may not be significant if the omitted elements are not of great importance. Difficulty will arise, however, if key aspects of the real-world system are left out or inadequately treated in a model.

Illustration

Automobile demand models typically predict total new car sales or registrations. These predictions are calculated as a function of variables associated with personal automobile purchases (e.g., family income, family size, etc.).

Recent data (Shonka, Loebl, and Patterson 1977) show that a significant percent of new car sales are not personal purchases but are fleet sales (e.g., to governments, companies, and leasing firms). Fleet purchases have been estimated to account for about twelve to twenty percent of new car sales. In recent years this percentage has increased.

Fleet purchases differ from individual purchases. For example, in 1976, fleet buyers bought fewer large-size cars (six percent of fleet purchases as compared to twenty-nine percent of all sales). Fleet buyers have also reacted more quickly to external influences, like the oil embargo, than have individual purchasers. In 1972 only about two percent of fleet purchases were small cars. In 1975, following the oil embargo, the percentage jumped to thirty-two percent.

Other differences also exist between fleet use and personal use. Fleet cars are driven more and sold more quickly.

Significance

Present automobile models in common use do not attempt to explain a significant part of the system they purport to model. Automobile demand predictions for all sales are based on factors traditionally associated with approximately eighty percent of the sales.

Automobile demand is not the only output affected. Attempts to compute fuel consumption may also be biased by the different use patterns of fleet-owned vehicles.

Because existing models ignore an important part of reality, the significance of their output can be understood only if the influence of fleet purchases and use are understood.

Limitation 2. Models Assume the Future will be Like the Past

Models are created to represent a system based on historical information. Yet, models are used to forecast what will happen in the future. If there are significant changes in the real-world system, the quality of the model suffers.

This is a significant problem for modelers of social systems. Rapid technological, economic, social, and political change has been a characteristic of modern times. If the changes that occur are not reflected in the relationships that exist in the model, significant limitations result.

Illustration

The focus of automobile demand models now in use for federal policy analysis is on the domestic demand for vehicles. Excluding Canadian sales, past exports have accounted for less than two percent of annual sales. Thus, the lack of an export sector in auto demand models has not been considered a significant limitation.

The shift to small cars for the domestic market, the devaluation of the dollar, and the increased demand for vehicles in the world market has led to speculation that U.S. exports will increase in the future. U.S. small cars appear likely to become competitive in the "world car" market.

Significance

The existing models cannot predict the effects of significant increases in exports, because these relationships are not included in the models. Nor will it be easy to include such relationships because of the paucity of relevant data. Thus, auto demand predictions contain an unknown error associated with the future export market for U.S. automobiles.

Limitation 3. Data Problems

Mathematical models are dependent on data, both data used as input to the models, as discussed in Limitation 5, and also data used in building the models.

The data used in building a socioeconomic model may be incomplete and are usually estimates. For example, the U.S. Census data, even for Census years, are estimates, and the data for the intervening years are interpolations of the estimates.

Illustration

In 1978, the U.S. Department of Energy presented output from the Faucett Automobile Sector Forecasting Model (Difiglio and Kulash 1976) in a report to Congress (Energy Information Administration 1977). On the basis of the model output and other information, the DOE concluded that U.S. automobile companies would choose not to meet the 1985 fuel economy standard of 27.5 miles per gallon and, instead, would pay the penalties provided by law (Kelderman 1978). The forecasts were based heavily on estimates of how much it would cost the companies to redesign cars to achieve better gas mileage. The cost estimates, in turn, depend on projecting future fuel economy from historical data to determine how much improvement would be required over present fuel economy to meet the 1985 standard.

Uncertainty surrounding the values of the exogenous input variables compounds the difficulty of determining the accuracy of model output.

The data used to measure fuel economy were based on test information from the Environmental Protection Agency (EPA). The model authors knew that the EPA data were inaccurate and historically had overstated actual fuel economy. The authors adjusted the EPA figures on the basis of the best available information. The adjustment reduced the difference between the standard specified and the projected fuel economy. Using the adjusted data, the model forecasts supported the DOE conclusion.

Careful examination of later information indicated that the adjustments were too small. They still resulted in an overestimate of the difference between actual on-the-road fuel economy and the fuel economy standard. The overestimate of this difference resulted in an overestimate of the costs to the automakers required to achieve the 1985 standards.

The data were again revised to reduce this overestimate. When the revised model was run using these data, the results showed that a fuel economy level very close to the 27.5 miles per gallon standard could be achieved in 1985 at a cost no more than the penalties that would otherwise be imposed. These results produced a clarification of the original Department of Energy statements.

Significance

The consequence of data problems in this case is clear. An inaccurate report was submitted to Congress. Fortunately, Department of Energy analysts conducted more detailed examinations and revised the original position.

Despite this, the fuel economy data in the model are still "adjusted data" and the accuracy of the output is dependent on the accuracy of these data.

Limitation 4. The Operational Status of a Model may be Unclear

One of the major problems facing potential users is determining the model's status. Models take months and sometimes years to build, and many model builders frequently revise their models. At any one time, several versions of a model may exist. Frequently, full documentation does not exist because of the dynamic nature of model development. Thus, a user is faced with the need to determine the exact characteristics of the version of the model being used before the results can be understood. While this seems obvious, it is not always simple to do, and thus it is not always done.

Illustration

A part of the study conducted by the International Trade Commission (ITC) for the Senate Finance Committee to study the proposed "gas guzzler" tax is a classic example of this problem (U.S. International Trade Commission 1977). One important question addressed was the effect of the proposed energy policies on the potential increases in sales of foreign automobiles in the United States. In essence, forecasts of the relative market shares of domestic and foreign manufacturers were sought under different policy alternatives.

The ITC analysts used the Wharton EFA Automobile Demand Model (Schink and Loxley 1977) in their study, but were unaware that, in the version they were using, the splits between foreign and domestic shares by type of car were set as *exogenous* variables. The splits had been preset by the model authors. This point was mentioned most obscurely in the model documentation. A later version of the model includes these foreign/domestic splits as endogenous variables.

Significance

The model output provided estimates of the foreign and domestic market shares. These estimates were not calculated by the model. They were specified a priori—a fact that was unknown to the analysts who treated the results as forecasts. Thus, the Senate Committee received information labeled as an output when in fact it was an input. The information is not available to assess the significance of this particular event. Common sense suggests that policymakers would be likely to place different weight on information known to be a simple estimate than on information believed to have been derived from a more formal forecasting process.

Limitation 5. Input Data may be Uncertain

Problems with data used in building models were discussed above. Another type of data problem stems from exogenous input to the model. Uncertainty surrounding the values of the exogenous input variables compounds the difficulty of determining the accuracy of model output. Future-year values of these variables are forecasts, often from other models, and the accuracy of these values is uncertain.

The types of exogenous inputs that are typical in auto demand/gasoline consumption models are trends in population, unemployment, and gross national product. In the case of current automobile models, exogenous forecasts of economic trends are usually taken from the results of running an econometric model of the national economy. For population, trend estimates are available from the U.S. Bureau of the Census. Sometimes there is little information available on which to base an important trend, an expert opinion may be the only guide.

The most sophisticated method of setting exogenous trends cannot remove the uncertainty of these forecasts. This uncertainty is greater the further into the future a forecast is carried. The values the model builder or the user imposes on the model can greatly affect the output of the model. Knowing what exogenous data and assumptions have been used, determining whether they are reasonable, and finding out how much the forecasts from the model would change if different data or assumptions were used is crucial in using any model.

Exogenous input may take the form of assumptions specified by the user. These may represent quantifications of key aspects of proposed alternative policies. An example of this type of exogenous data in an auto demand/gasoline consumption model is gasoline price. Future-year values of this type of variable may either be assumed by the model user or may be obtained from some existing source (of unknown accuracy).

If the model is sensitive to the exogenous variables, it will produce significantly different results for different values of the input data.

Correct use of a model requires knowing and understanding the purposes of the model.

Illustration

This problem is illustrated by an example presented in a Jack Faucett report to the Federal Energy Administration. The report compared output of the Faucett Automobile Sector Forecasting Model in which two different assumptions concerning the price of gasoline were used. In one case gasoline price was assumed to remain constant until the year 2000, and in the other an annual growth rate of three percent was assumed. The model predicted that in the case of the three percent per annum increase in gasoline price, new car sales would be about twenty-five percent less in the year 2000 than if the gasoline price remained constant (Jack Faucett Associates 1976). This demonstrates how sensitive output may be to a change in an exogenous input that may be regarded as small given today's rapidly increasing gasoline prices.

Significance

This illustration demonstrates the influence that exogenous variables can have on model output. It is important to realize that the validity of the model output is directly dependent upon the validity of the exogenous input. This requires a careful examination of input data as part of establishing the utility of the model output in policy analysis.

Limitation 6. The Usefulness of a Model may be Limited by Its Original Purpose

Most models are developed for specific purposes and reflect the performance or behavior of particular systems. Correct use of a model requires knowing and understanding the purposes of the model. Failure to do this can lead to unsuccessful or improper application of a model or misinterpretation of its results.

Models are adaptable to uses other than the ones they were originally designed for. This adaptability is one of the great attractions of models. The adaptation of a model usually involves adding to it or restructuring parts of it. This is a task that requires considerable care and technical expertise. The extra cost of adapting a model is usually not large compared to the original cost of building it. However, when an adapted model is used, the user needs to know what the model was originally intended to do, what its new purpose is, what changes have been made, and whether these have been done correctly.

Illustration

Several examples drawn from uses of automobile demand models can serve to illustrate what can occur. Both of the major econometric models of automobile demand (Faucett and Wharton EFA models) in use for federal policy analysis were created primarily to evaluate impacts of energy policies such as mandatory fuel economy standards and various tax, rebate, and penalty policies related to fuel economy and fuel consumption. Attempts have been made to use one or the other of these models to investigate policy in other areas. In general, these attempts either have been unsuccessful or have worked only after additions or revisions were made to the models.

An attempt was made in the Department of Transportation to use the Wharton EFA auto model to evaluate the impact on fuel consumption of the fifty-five-mile-per-hour speed limit. This failed because there was no way in the model to separate the changes in fuel consumption achieved by lowering the speed limit from those resulting from use of more fuel-efficient vehicles or from changes in the number of miles people drove.

The Wharton EFA auto model has been adapted to analyze nonenergy policies, such as vehicle emission control standards and passive safety restraints. In these cases other models to estimate costs of controls or restraints had to be built or run to provide the Wharton EFA model with necessary cost input data. The model has also been adapted to forecast the impact of battery-powered automobiles. In this case a special submodel had to be built to generate the cost factors related to electric vehicles, and the main model had to be restructured to account for the new battery-powered cars.

Frequently a user may not know how accurate model results are.

Significance

Because models are designed for limited purposes, attempts to use them for what may seem to be logical extensions can lead to failure. Models are adaptable, but adaptations frequently mean that additions have to be made to the model and structural changes have to be made inside the model. When changes are made inside the model, total model performance may be affected because the parts are so interconnected. The results of previous sensitivity tests may no longer be a guide to how the model performs, and new tests will be required.

Add-on submodels are a common way to modify models and increase their utility. However, when an add-on model is created to provide new input, the accuracy of the main model output becomes dependent on the accuracy of the output from the add-on.

The obvious significance with regard to policy analysis hinges on whether the model "blows up" or produces output. If it does not work, the user has a clear indication that something is wrong. However, if output is produced, the user may be unaware that it is useless, and policy recommendations may be made based on the output.

Limitation 7. The Apparent Precision of Model Forecasts may be Misleading

Model output appears very precise. It is given as a specific number with several significant digits. That does not mean it is accurate or reliable. If a model is built using statistical techniques, as econometric models are, a confidence band can be constructed that gives a range around the numerical result within which the true value can be expected to lie with a certain probability, if the appropriate assumptions hold. It is similar to saying that a falling satellite will, with a 90% probability, hit a certain latitude plus or minus a few degrees.

Confidence bands can easily be calculated for small models. For very complex models, like the ones of interest in the transportation policy area, simple analytical techniques do not yet exist to calculate precise confidence limits. Relatively sophisticated techniques are available to calculate confidence bands for forecasts of larger models, but are expensive and not widely used. Frequently therefore, a user may not know how accurate model results are.

In policy studies, models are used to study the differences between impacts of alternate proposed policies. Because the accuracy of model output is uncertain, it is difficult to know when a difference between two forecasts is large enough to be meaningful. Failure to recognize this can lead to unsound conclusions about which alternative is likely to produce the desired results.

Illustration A

Two illustrations of this problem are presented here. The first deals with the confidence band on the forecast values of the vehicle-miles-of-travel-per-household (VMT) equation of the Faucett Automobile Sector Forecasting Model. Values of this variable were calculated for 1977, 1978, 1979, and 1980. The values of these were approximately 15544, 15956, 16298, and 16637, respectively. These values seem to be of reasonable magnitude and to exhibit a reasonable growth pattern. However, the confidence band for each of the values was calculated to be approximately ±1000, at the ninety-five percent level of confidence.

Significance

The consequences of relying on output data with such confidence limits are obvious. The confidence bands in this case are so large that there may not be true differences among the year to year values of the VMT estimates. A policy based on this type of information may be unsound. Yet, unless such a lack of precision were made explicit, policymakers could easily be misled.

Illustration B

A second illustration deals with two applications of the Wharton EFA Automobile Demand Model by two different sets of analysts.

The National Highway Traffic Safety Administration (NHTSA) made prominent use of the Wharton EFA Auto Demand Model in the documentation supporting the fuel economy standards for automobiles for 1980-1984. NHTSA reported that the proposed 27 miles per gallon standard for 1984 would lead to only 210,000 fewer new car sales than the 1980 standard of 20 miles per gallon. The difference was 1.8 percent of the forecast 1984 sales. NHTSA labeled this difference as "insignificant, given the difficulties of projecting the sales initially" (National Highway Traffic Safety Administration 1977).

In contrast, analysts of the International Trade Commission (ITC) used the same model in conducting a study for the Senate Finance Committee of the proposed "gas guzzler" tax. This study projected a shift of 300,000 in sales from domestic to foreign producers in 1985 if the tax and rebate plan were enacted (U.S. International Trade Commission 1977). This represented a shift of slightly more than two percent of total sales. Senate Finance Committee staff members report this was viewed as significant and it contributed to the delay in action on the gas guzzler tax proposal.

Significance

Both of the projected differences are of about the same size. One group determined the figure to be significant while the other labeled the amount insignificant. In both cases, the judgments of significance and insignificance were subjective. Both the magnitude of the estimate (number of cars), and the degree of precision of the estimate judged to be significant depend on the different perspectives of NHTSA and the ITC in the context of specific problems. In this case, however, it is not clear that these judgments were derived from an adequate understanding of the uncertainty of the forecasts since confidence intervals were not associated with the predictions. While practical and theoretical difficulties may preclude the computation of statistical confidence intervals for the predictions of large models such as Wharton EFA's, less rigorous estimates of prediction precision would be a great aid to decision makers.

One can only speculate what the outcomes would have been if each "number" had been properly qualified. The differences in interpretation of similar numbers highlight the need to properly qualify results and to inform policymakers of the uncertainty of forecasted values.

Questions a Policymaker Should Ask Before Using a Model

Given the complexity of models used in the policymaking arena and the limitations inherent in their use, a policymaker should obtain answers to several questions before making any decisions based on the output of a model. Several such questions are discussed here.

How well does the model perform?

Assuming that an analyst has chosen a particular model for use in a particular policy-related application, the policymaker should check on the quality of its performance. There are three ways of doing this if the model is based on historical data: first, by examining the model's output over the sample period and comparing it with observed data for that period; second, by examining the model's output for the time period starting just after the fit period of the model through the present and comparing it with actual data for that period, if they are available; and third, by examining the model's output for future years and checking for its "reasonableness."

Of these three, the second alternative is probably the best way of checking the model's "track record." It affords the opportunity to test the model in a forecasting mode, yet it offers the advantage of having historical data available to compare with the output. Note, however, that this method will be less useful if only short-term data are available when a long-term model is being tested.

Testing over the historical period is sometimes neither feasible nor appropriate because of the nature of the model, its method of construction, or other factors. Testing the model over the future may not yield adequate information to make the decision about its accuracy, since sometimes it is impossible to judge whether the output is reasonable. There simply may be no basis for comparisons.

Has the model been analyzed by someone other than the model authors?

Often in the course of building a model, the author will perform various tests in an attempt to validate the model. These test results, if they include model output and are objective, can probably be viewed with some confidence. However, modelers often do not take the time to rigorously analyze or assess their models themselves, primarily because the time and resources allocated to model building are limited. Contracts requiring model construction usually do not include a separate task for model analysis.

Model validation tests performed after a model has been constructed give little insight into the theory and dynamics of the model. For a user to have an understanding of the model, he should have access not only to the model documentation but to any assessments performed by people other than the model builders. Such assessments can provide insight into the strengths and weaknesses of a model and provide a more objective view of the model than may be provided by a model author. The results of such an assessment should be carefully reviewed and taken into account before a model is chosen for use in policy-related studies. It should be noted, however, that model assessments are not often performed.

Is adequate documentation of the model available for all who wish to study it?

Adequate documentation is crucial if persons other than the model builders are to understand it. The documentation should describe the method of model construction, the theory behind it, the data and assumptions used, the equations, the method of operation, the input required for running the model, and sample output. The user should have enough information available to evaluate the reasonableness of the assumptions used in constructing the model. The documentation should make clear what parts of the model have been based on historical fact and what assumptions have been made.

What assumptions and data were used in producing model output for specific applications?

The assumptions and data used in running a model for specific applications are generally different from those used in constructing the model. In running econometric models to produce projections, a set of exogenous data consisting of forecasts of several variables is generally required as input. These input data are themselves forecasts of the unknown future and should be used only with care and an understanding of their limitations.

If a model has already been run for a specific purpose, the set of assumptions and data used to produce the output should be known, so that their reasonableness and applicability can be determined.

Why is the selected model appropriate to use in a given application?

There may be many models that are suitable, at least based on initial inspection, for use in a particular situation. It is up to the policymakers to satisfy themselves that the most appropriate model has been selected. Questions that should be asked include: What is the stated purpose of the model selected? What does it measure? What does it not measure? Is its intended use compatible with the present need? Is this the easiest model to run that is applicable to the study area of interest? Are there other models equally suited to the job?

Finding the answers to these questions may be a very time-consuming effort. However, it is advisable to have the answers in hand so that resources may be most effectively used. Many models may forecast the same variables, but some may do more. If two models are of equal quality (which is difficult to determine) and a user is interested only in the output of the less complex model, clearly it would be wasteful to run the more complex model.

It should also be determined that the model chosen for use actually forecasts the variables of interest and that they are not buried somewhere internally in the model, or worse, set exogenously. Often this distinction is not clear.

Was the model run directly and specifically for the present purpose?

A given model may be run by a number of users for a variety of purposes. It may be that for one of those past uses, the model input and output seem similar to those desired for a present policy analysis. Extreme caution should be exercised if output from other applications is used. Caution must also be exercised when individuals in other agencies perform model runs on request for a specific application. One can never be sure of the exact circumstances under which a model was run. Input may not coincide directly with current needs. Alternative options in programs may sometimes be exercised. Biases in interpretation of the meaning of output may exist. If a model is not run by a user for a particular policy application, the chances of errors appearing in the analysis are greatly increased.

What is the accuracy of the model output?

Many models have output that is accurate only within some error band. The larger the error band at some level of confidence, the less accurate the output. It is relatively straightforward to determine confidence bands for small, single-equation models, but more difficult for large-scale models. Nevertheless, it is imperative that the model user have some idea of the accuracy of the model output before it is used in specific applications. In comparing output of a model run that uses two different sets of input data, the error bands on the output may be so large that results that look different may not be, in a statistical sense. Knowing the accuracy of the output helps to put the usefulness of the model into perspective.

Does the structure of the model resemble the system being modeled?

A model is an abstraction of reality. In translating from reality to mathematical equations, some components of the real-world system are omitted. It is important to identify which, if any, pivotal elements of the real system have not been included in the model. Key items and relationships included and the key ones omitted should be identified. In addition, while an attempt may be made to include in the model some aspect of the real-world system, its representation in the form of an equation may be inappropriate or inadequate. The bases of the mathematical representation should be clear to the model user.

Is the model appropriately sensitive to the inputs being varied?

A model is constructed to represent a real-world system and predict the response of that system to changes made to it. The latter is referred to as the sensitivity of the model. Even though a model was constructed so that its output would vary appropriately with changes in its input, this does not always occur.

It is the responsibility of the model user to ascertain, either through review of the model documentation or assessments of the model, whether the model is appropriately sensitive to changes in the input variables of interest. If it is not, the output of the model may indeed be useless for the intended purposes.

Summary and Conclusions

Mathematical models are in widespread use in policy analyses related to the transportation system. There are many kinds of mathematical models, with econometric models being the primary kind used in the motor vehicle transportation policy sector.

While mathematical models may provide policy analysts with strong tools to use in their studies, they may also provide very misleading results if not applied correctly. There are many limitations in the correct use of models. Some limitations are inherent in a model (e.g., models are incomplete, and model output is uncertain although it may appear precise). Other limitations arise when models are used (e.g., the accuracy of input data may be unknown, and the operational status of a model is often unclear).

To help ensure proper use of models in policy analyses, a policymaker should ask several questions relating to model use. These include queries concerning the model's performance record, results of model assessment, the purpose of the model, its appropriateness in specified applications, assumptions contained in the model, and availability of model documentation. Analysts who use models to formulate or analyze policies have an obligation to answer such questions. These answers should be public so that peers can review their reasonableness.

The proper use of models can add considerable insight to the policymaking process, but model output should be regarded only as approximations. Only if policymakers are aware of the limitations inherent in models can mathematical modeling enhance the policymaking process.

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