14. Transportation Energy Contingency Strategies: Part One--The Planning Process: Roles and Responsibilities. U.S. Department of Transportation, March 1980.
15. D.G. Stuart and R.J. Hocking. Contingency Transportation Plans for Urban Areas and Their Potential Impacts. Barton-Aschman Associates, Inc., Evanston, IL, April 1980.
16. Transportation Energy Contingency Strategies: Part Two--Synopsis of Actions. U.S. Department of Transportation, March 1980.
17. Energy Impacts of Transportation Systems Management Actions in New York State: 1978-1980. Planning Research Unit, New York State Department of Transportation, Albany, PPR 151, May 1979.
18. Analytic Procedures for Urban Transportation Energy Conservation. U.S. Department of Energy, Rept. DOE/PE/8628-1, Vols. I-IV, Oct. 1979.

Analysis of Long-Term Transportation Energy Use

THOMAS J. ADLER AND JOHN W. ISON

The structure of ENTRANS, a DYNAMO-based simulation model of the interactions between energy supply and transportation-related energy use, and some of its policy analysis applications are described. ENTRANS includes representation of the characteristics of transportation supply (public transit, highways, and automobiles) and households' travel-related decisions (car type, travel mode, trip length, and frequency). The model is capable of analyzing a wide range of policies designed to change automobile fuel use. The results of several detailed policy analyses are described. These results indicate that automobile fuel-efficiency standards can be both effective and cost efficient and that fixed additions to the gasoline tax can have substantial short-term, but little long-term, impact on fuel use. Overall, the model is a useful step in the development of a comprehensive tool for the analysis of transportation energy policy. Ongoing development will make ENTRANS more useful for specialized applications.

This paper describes the structure and applications of a model for forecasting transportation energy use at the national level. Development of the model started in September 1978 and over the course of the effort, U.S. gasoline prices doubled and use of gasoline for automobiles became a significant national concern. The original purpose of this research was to develop a better understanding of the long-term effects of transportation energy policy on gasoline use through an explicit representation of all of the important interactions among travel demand, transportation supply, and energy supply. The events of the past two years have both increased the importance of obtaining better understanding in this area and (to an even greater extent) increased the relevance of the research to the current debate on national energy policy. Attempts to reduce U.S. dependence on foreign energy sources have inevitably involved analysis of policies including gasoline pricing and taxation, automobile energy efficiency regulations, and increased support of public transit systems. The long-term effects of such policies are, however, not fully understood.

The model developed in this research effort--Energy Use in Transportation (ENTRANS)--represents a large subset of the factors that have an impact on the effectiveness of alternative policies. The model has been implemented in a way that allows easy access by policy analysts with diverse levels of computer experience. It has already been used in a range of policy analysis tasks and is continually being updated with recent data and improved structural elements. The model version whose results are described here, ENTRANS 4/15, was developed recently for the Solar Energy Research Institute.

WHY ANOTHER TRANSPORTATION ENERGY MODEL?

When this project was originally proposed, in November 1977, a number of completed transportation energy use models were already available. Although a few of these were actively being used for policy analysis, the difference in forecasts among the models was generally quite large. For example, Figure 1 shows the range in estimates of automobile fuel use from a sample of relatively current models (1). One could argue that this range in estimates represents a plausible (and even optimistically small) level of uncertainty about uncontrollable future events. However, our review of the existing models indicated that the differences in model forecasts were explainable not so much by uncertainty in the parameter estimates as by differences in model structure and, in particular, by differences in the factors and interactions that were included in the models. Generally, those models had been "first-generation" efforts. In addition, they had been built to address relatively limited ranges of policy issues. Our approach was to build on these efforts by piecing together a more structurally complete model set and, in addition, to draw more heavily on some of the recent work in transportation demand modeling.

A more structurally complete model is not necessarily a better model. In constructing our model, we wanted, in addition, one that would be easy to use and would be capable of representing, in a realistic way, the effects of a wide range of policies.

MODEL STRUCTURE AND COMPONENTS

The remainder of this paper summarizes the development and applications of ENTRANS. Substantially greater detail on both model structure and applications can be found elsewhere (2-5).

The basic components and relations included in this modeling effort are shown in Figure 2. Energy supply is described by the price and availability of crude oil. These quantities are determined in an externally linked energy supply model, NEP2000 (6). Energy consumption is divided into two end-use categories: transportation and all other uses. Transportation energy use is further split into passenger travel and freight transportation. ENTRANS represents, in detail, only those mechanisms that influence passenger travel. Other uses of crude oil are determined exogenously to the model.

Figure 1. Comparison of
fuel-use forecasts of various
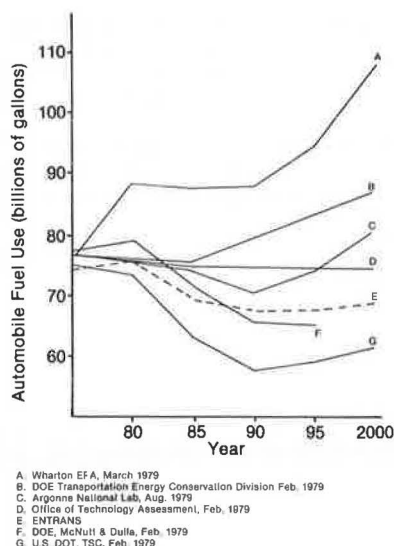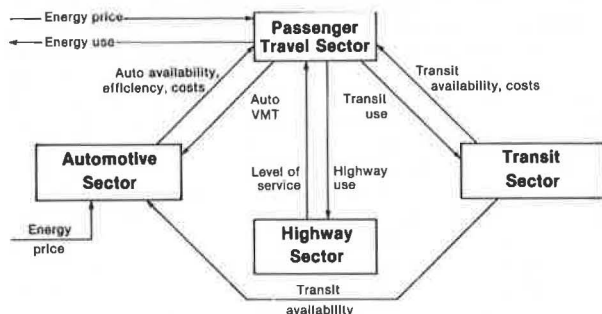models of national
transportation energy use.

A. Wharton EFA, March 1979
B. DOE Transportation Energy Conservation Division, Feb. 1979
C. Argonne National Lab, Aug. 1979
D. Office of Technology Assessment, Feb. 1979
E. ENTRANS
F. DOE, McNutt & Dulla, Feb. 1979
G. U.S. DOT, TSC, Feb. 1979

Figure 2. ENTRANS model structure.

The basic factors that influence passenger-travel
energy use include individuals' daily travel deci-
sions as represented in the travel sector, the
service characteristics of the public transit system
(transit sector) and of the highway network (highway
sector), and the fuel efficiency of the automobile
fleet (automobile sector).

In a general sense, this structure corresponds to
the classical economic supply-demand paradigm where,
in this case, transportation supply and demand are
nested within an energy supply-demand system. The
structure must also represent the mechanisms by
which supply-demand interactions are affected. Both
energy and transportation suppliers are regulated,
which means that it may be impossible to increase
prices in order to clear the market at given levels
of supply. In addition, many of the changes in
energy supply (e.g., construction of new production
facilities) and in transportation supply (e.g.,
improvement in fleet fuel efficiency) can be ac-
complished only over relatively long periods of
time. Together, price regulation and significant
physical delays to supply change mean that any
realistic model of these supply-demand interactions
should recognize the time dynamics of response to
system changes. Thus, interactions in the structure
in Figure 2 must be traced continuously through
time. This is accomplished in ENTRANS by implemen-
tation in the DYNAMO continuous systems simulation
language, which allows explicit representation of
physical and information delays.

To fully represent the long-term effects of
policies, the model simulates system behavior to the
year 2020. Obviously, the quantitative values of

forecasts that far in the future involve great
uncertainty. The primary benefit of the long fore-
cast horizon of the model lies in tracing, through
time, the long-lasting effects of policy change,
given fixed assumptions about uncontrollable at-
tributes of the future.

ENTRANS contains seven sectors:

1. Travel--Computes mode-specific travel demand
and fuel use;
2. Automobile--Represents the effect, on automo-
bile fuel efficiency, of industry and consumer
response to gasoline prices and government policies;
3. Transit--Represents the transit sector re-
sponse to changes in ridership and to various poli-
cies;
4. Carpool--Represents carpool-specific levels of
service;
5. Highway--Determines the effect of highway
condition and congestion on average network speed;
6. Demographic--Projects economic and population
growth; and
7. Cost--Converts crude-oil prices to equivalent
gasoline prices.

The seven sectors, their interactions, and informa-
tion flows are shown in Figure 3.

Passenger Travel and Fuel Cost

The ENTRANS travel model computes travel demand and
modal splits. Household-level travel is determined
by assuming that households maximize the utility of
travel subject to time and money constraints.
Utility is measured by travel distance; it is as-
sumed that increased travel distance provides
greater utility by increasing the spatial range of
opportunities for satisfaction of household needs
and desires.

This theory implies that travel decisions for all
modes are based on two generic modal charac-
teristics--cost and speed--and two generic demo-
graphic characteristics--number of trip makers per
household and income. On a household level, trip-
making decisions are limited by the binding con-
straint of the mode with the maximum number of daily
miles possible. In general, travel modes are com-
pared on the basis of the maximum number of daily
miles possible by each mode. Since the maximum
number of daily miles associated with a mode is a
measure of the utility of that mode for a household,
it can also be used to determine modal splits in a
logit formulation.

The question of whether households' travel time
and money constraints are stable at the aggregate
level, as implied by this model, has recently been
the subject of active debate (7). In a sense, the
use of constant household travel time and money
constraints in ENTRANS could be viewed as a norma-
tive assumption. That is, given major increases in
the future cost of travel due to expected increases
in fuel prices, policymakers should not expect
households to spend an increasing fraction of their
budget on travel. ENTRANS is not intended to be
used to trace short-term responses (0-1 year), which
might well include variable expenditures on travel.
Rather, the model's focus is on the system's long-
term response, in which case the assumption of a
constant travel budget seems somewhat more reason-
able.

The travel model includes several other compo-
nents that predict other travel characteristics,
such as trip lengths, frequencies, automobile occu-
pancies, and travel speeds, all of which affect
automobile fuel efficiencies and, thus, fuel con-
sumption.

Automobile Industry and Consumer Responses

Two parallel structures are used to model the decisions of the automobile industry within ENTRANS. The first computes costs associated with automobile production and outputs price for each of five automobile size classes. The second finds the fuel efficiency within each class that minimizes consumers' life-cycle costs of automobile ownership.

Four cost factors influence the fuel-efficiency decisions of each automobile manufacturer: technology costs, gasoline costs, fines for not meeting government-mandated fuel standards, and government excise taxes. Each of these costs is a direct function of automobile fuel efficiency:

Figure 3. ENTRANS intersector information flows.
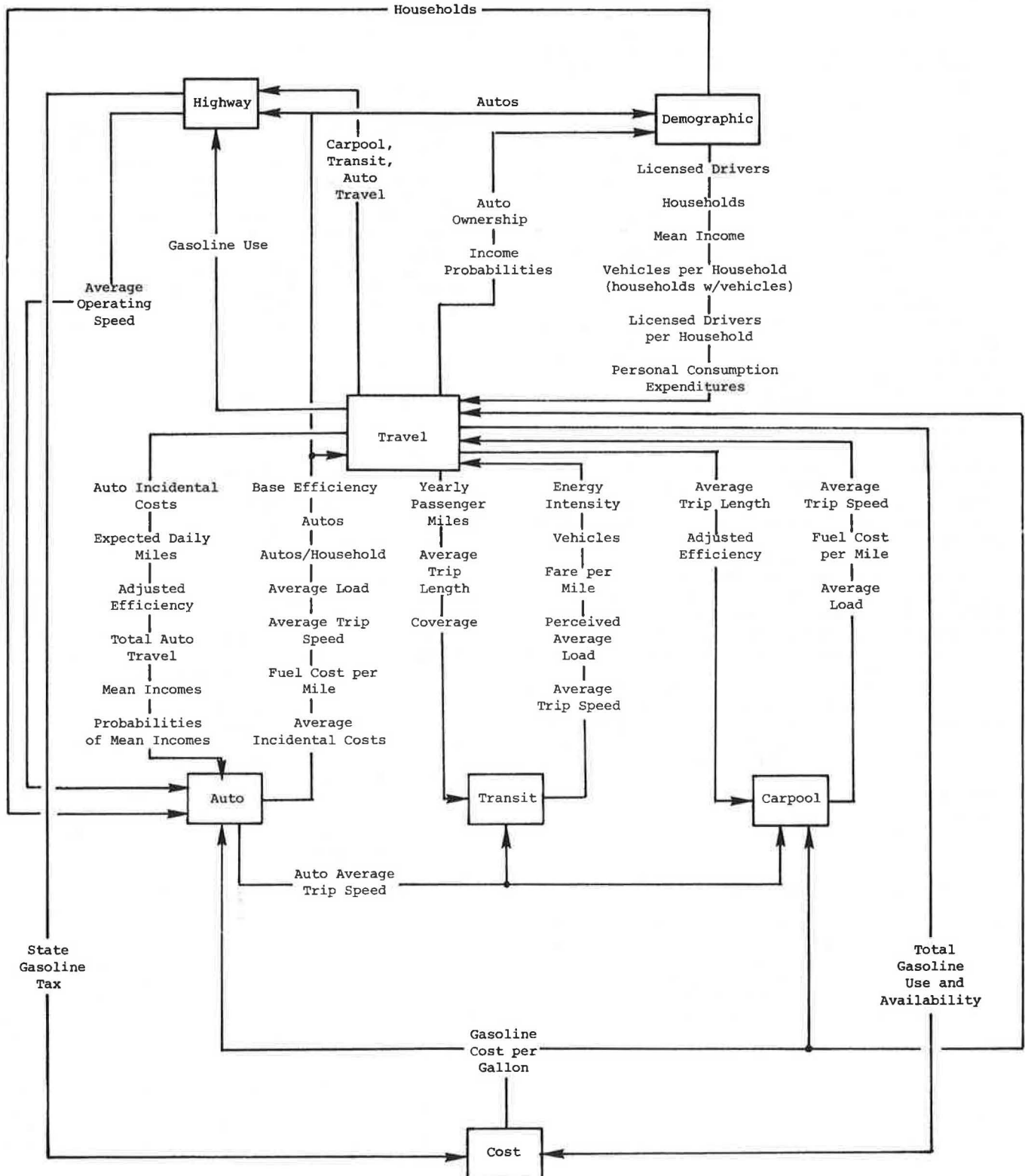
1. Technology costs increase as fuel efficiency is increased. These represent nonmonetary costs of small, down-sized automobiles as well as the additional costs of fuel-efficient technologies.

2. Gasoline expenditures expected over the lifetime of an automobile decline with improved efficiency and increase with higher gasoline prices.

3. Penalty fines are imposed for noncompliance with the government standards. Higher efficiency of any automobile will (other things being equal) increase the efficiency of a manufacturer's new-car fleet and reduce noncompliance penalty fines.

4. Excise taxes imposed by the government are directly related to the fuel efficiency of each automobile; as the efficiency of an automobile increases, excise taxes are reduced (in some cases, up to a specified fuel efficiency).

Lifetime fuel cost savings are offset by technology costs as fuel efficiencies increase. It is assumed that, within an automobile size class, the lowest life-cycle costs will always be the most attractive to consumers. It is further assumed that manufacturers provide the least-cost combination of technology costs, fuel-economy increases, penalty costs, and excise taxes to the consumer in an attempt to maximize automobile attractiveness, sales, and, hence, profits.

The second parallel structure used to represent the automobile industry is virtually identical to the first. The only major difference is that it computes incremental price and fuel-economy changes by using the derivatives of gasoline, technology, marginal penalty cost, and excise-tax functions. The minimum life-cycle cost is found when a selected fuel economy drives the sum of the four component derivative cost functions to zero. Since the life-cycle-cost function used in this model is analytically intractable (3), a numerical solution technique, first derivative search, is used to find the optimum value.

The factors that influence the utility of an automobile class, and therefore its market share, include operating costs, new-car prices, class-specific attributes, and household attributes. A multinomial logit model that represents the trade-offs among these factors is used to determine this market share (8).

A conceptually simple, though important, component of the model is a vintaging sector that traces the composition of the national automobile fleet. New automobiles enter the fleet each year with given fuel efficiencies, and old automobiles are scrapped or otherwise removed from the fleet, so that aggregate fleet efficiency changes over time. Actual fleet efficiencies are computed on a use-weighted basis; older cars have lower use weights than newer cars.

Other Transportation Supply Sectors

The transit, carpool, and highway sectors compute levels of service by mode given modal characteristics and travel volumes. These levels of service are used by the travel sector to determine travel patterns. The highway sector determines the impact of highway-specific policies on automobile operating speeds. Vehicle travel distance affects levels of congestion and rates of road deterioration.

Other Model Sectors

The demographic and cost sectors of the model consist of several exogenously determined factors. The demographic sector computes household characteristics such as number of households, mean house-

hold income, number of licensed drivers per household, and number of automobiles per household for households that own automobiles. Inputs include the total number of automobiles, from the automobile sector, and the distribution of automobiles across income classes, from the travel sector. The cost sector uses a wellhead crude-oil cost predicted by NEP2000 (6) and intermediate conversions and costs to compute the price of gasoline. One intermediate cost is the average state fuel tax, which is computed in the highway revenues subsector. Values for fuel use and fuel availability from the travel sector are used to compute a price multiplier resulting from fuel shortfall.

Use of the Model

ENTRANS is built with a user's interface that allows direct, interactive, English-language policy testing. Policies can be tested individually or in packages. A sample session is shown in Figure 4. Responses after question marks are given by the user. Results from this particular run are not included here but would follow immediately after the listing in Figure 4. Model runs cost approximately $3 on Dartmouth's Honeywell 6180 computer. Policies not included in the list of options can be specified interactively by changing equations, parameter values, or values of variables in "rerun" mode.

MODEL BEHAVIOR

Base Model Run: Historical Behavior

The validity of any model rests on both the reasonableness of its individual assumptions and the ability of these assumptions to produce reasonable aggregate behavior. The structure of ENTRANS is based on clearly defined economic theory that describes how the automobile industry responds to economic pressures (such as gasoline prices and government policy) and how consumers make travel decisions and select automobiles. Model parameters have not been chosen, nor has a structure been selected, solely in order to obtain a "good fit" with historical data. This is important, since a comparison of model output with history provides a good test of the reasonableness of its structure and assumptions.

In a system in which precise prediction is not desired or is not possible, it is important to compare the model variables with actual historical values. The model should be required to reproduce the historical behavior mode, though not necessarily the exact historical values. ENTRANS is not meant to predict exact numerical values but to illustrate the long-term dynamics of the system's structure and how various policies will change those dynamics. The model is valuable primarily as a tool for evaluating relative differences in system behavior due to different policies or alternative exogenous assumptions.

Since the concern of this study is the effect of energy price and availability on transportation-related energy demand, four variables are traced historically to check the consistency of the model with actual behavior: fuel use, automobile vehicle miles of travel (VMT), automobile price, and fuel efficiency.

Historically, automobile fuel use increased over the last 25 years. In the 1950-1975 period, actual use increased from 30.9 to 76.0 billion gal/year. As shown in Figure 5, the model closely replicates this behavior, starting out with 27 billion gal/year in 1950 and ending in 1975 with about 73 billion gal/year.

Figure 4. Sample ENTRANS run.

```
ENTRANS Interface here!
Foreground or Background?   foreground

End-Year? 2020

Plot/Print options (press return for available options) ?

Available options are:
     1)    PLOT Standard Plot
     2)    PLOT Extended Standard Package
     3)    PLOT Auto Prices
     4)    PLOT Passenger Miles by Mode
     5)    PLOT Daily mileage by income class
     6)    PLOT New car market shares
     7)    PLOT Trip Characteristics
     8)    PLOT Demographics
     9)    PLOT New car on-the-road economies
    10)    PLOT New car EPA economies
    11)    PLOT Generalized new car prices
    12)    PLOT Penalty costs
    13)    PLOT Technology costs
    14)    PLOT Transit Sector Response
    15)    PLOT Auto Vehicle Miles
    16)    PLOT Auto Fuel Use
    17)    PLOT Auto Maximum Daily Miles
    18)    PLOT Transit Maximum Daily Miles
    19)    PLOT Highway Sector Response
    20)    PRINT Standard Printout
    21)    PRINT Auto Prices
    22)    PRINT Passenger Miles by Mode
    23)    PRINT New car market shares
    24)    PRINT Trip Characteristics
    25)    PRINT Demographics
    26)    PRINT Transit Sector Response
    27)    PRINT Auto Vehicle Miles
    28)    PRINT Auto Fuel Use
    29)    PRINT Auto Maximum Daily Miles
    30)    PRINT Transit Maximum Daily Miles
    31)    PRINT Highway Sector Response
    32)    PRINT New car on-the-the-road economies
    33)    PRINT New car EPA economies
    34)    PRINT Technology costs
    35)    PRINT Penalty costs
    36)    PRINT Excise tax costs
    37)    PRINT Generalized new car prices
    38)    PRINT Lifetime gasoline costs
    39)    PRINT Auto stock
    40)    PRINT Fleet economies

Plot/Print options (press return for available options) ? 1,3

Enter policies.  Press an extra 'RETURN' when done.
Type LIST for options.
Policies?  list

Available policies are:

Code    Title
NMAN    No mandated fuel economies
HMAN    High mandated fuel economies after 1985
LPEN    Low Penalty rates ($ 25)
HPEN    High Penalty rates ($ 100)
LTAX    Low gasoline tax ($ .30) in 1985
MTAX    Medium gasoline tax ($ .60) in 1985
HTAX    High gasoline tax ($ 1.00) in 1985
TAX80   Gasoline tax in 1980
EXT     Excise tax on gas guzzlers (no rebate
RATD    Driver Based Rationing (1985)
RATV    Vehicle Based Rationing (1985)
CPPI    Carpool Parking Incentives (5 minute savings 1985)
CPSL    Carpool Special Lanes (1.3 times avg. auto speed in 1985)
UMTA    Increased UMTA Capital Expenditures (extra $ 500 mil. beyond 1985)
HCL     Increased Highway Construction Levels (30% increase in 1985)
HRL     Increased Highway Reconstruction Levels
HML     Increased Highway Maintenance Levels (30% increase in 1985)
TFAR    Decreased Transit Fares ($.05 decrease in 1995 and beyond)
NEP1    National Energy Plan 1
NEP2    National Energy Plan 1 & 2
N2000   NEP2000 World Price Scenario (default)
OPEC1   Low OPEC Price Scenario
OPEC2   Medium OPEC Price Scenario
OPEC3   High OPEC Price Scenario
HGNP    High GNP Growth Rates
MGNP    Medium GNP Growth Rates
ZMIG    Zero Mean Income Growth after 1980
HPOP    High Population Growth Rates
LPOP    Low Population Growth Rates

Policies?  hman
Policies?  hpen
Policies?  run high mandates and penalties
*RUN HIGH MANDATES AND PENALTIES
```

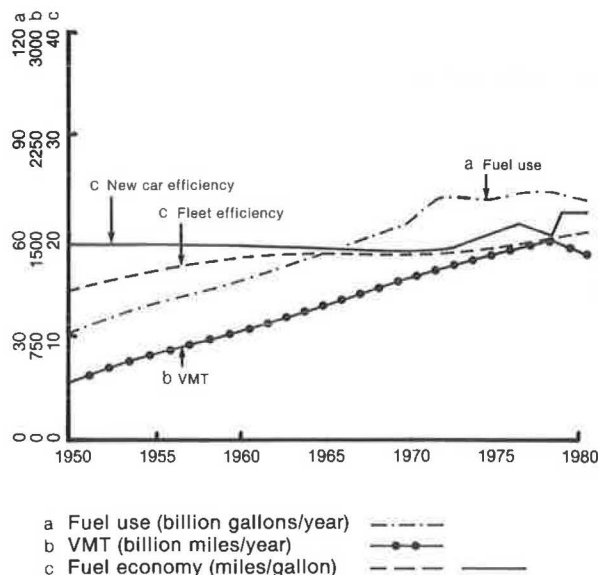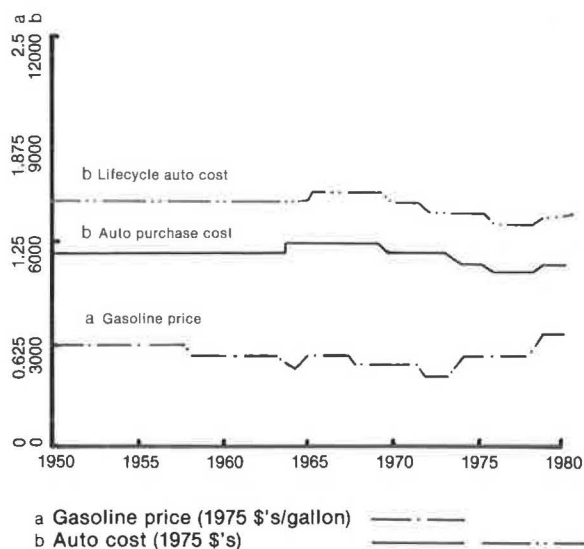Figure 5. ENTRANS simulation of historical values.

a Fuel use (billion gallons/year) —·—·—
b VMT (billion miles/year) —●—●—
c Fuel economy (miles/gallon) — — — ————

Figure 6. ENTRANS simulation of historical costs.

a Gasoline price (1975 $'s/gallon) —·—·—
b Auto cost (1975 $'s) ———— — —— —

During the 1953-1973 period, ENTRANS shows automobile fuel use to be consistently higher than the historical value (Figure 5). This is mainly due to consistent underestimation of automobile fuel efficiency. Unfortunately, Federal Highway Administration (FHWA) Highway Statistics (9), which provides data for past fuel consumption, VMT, and fuel efficiency, does not provide efficiency measures on a model-year or size-class basis. Thus, ENTRANS (which traces fuel efficiency for five automobile type classes) uses historical efficiencies developed for the Wharton econometric model (10), which are lower than those cited in Highway Statistics.

Historical and predicted automobile VMT both rise steadily between 1950 and 1973 and exhibit a slight decrease between 1973 and 1975. During the growth period, both household income and population, the prime determinants of gross travel demand, rise steadily. Increased income makes it possible for a larger portion of the population to own automobiles, thus increasing the availability of cars and, there-

by, VMT. Income growth also increases household transportation budgets. This budget increase, coupled with steadily declining operating costs resulting from gasoline prices falling more rapidly than car efficiency, allows each household to travel farther. Population growth during this period also makes an important contribution to total VMT.

As pointed out earlier, the historical automobile fuel-economy data were extracted from Highway Statistics (9) so as to be consistent with data plots for automobile VMT and fuel use. ENTRANS, however, has been designed around the lower on-the-road fuel efficiencies used in the Wharton model. During the entire period, fleetwide fuel efficiency steadily declines. This correlates well with the decline in gasoline prices seen over the same period (Figure 5). As gasoline price and operating costs fall, household incomes rise and operating costs assume secondary importance; consumers shift their emphasis from automobile cost to comfort, size, and performance considerations; the efficiency of cars decreases as consumers' tastes change; and the efficiency of the American automobile fleet declines.

As the model is specified, only changes in fuel efficiency affect the costs of automobile production and, thus, retail price. Prior to the implementation of government fuel-standards programs in 1978, only the price of gasoline affected the efficiency of cars manufactured in the United States. Fuel economy fell with gasoline price and automobile prices dropped, particularly between 1969 and 1975. ENTRANS produces prices that, on the average, accurately track the observed values (see Figure 6). Deviations can be seen during the 1950s, but they are primarily due to consumer shifts between automobile size classes and not to price differences within each size class.

Base-Case Assumptions

The values of a number of exogenous variables are specified in each model run. These values are included but are not computed within ENTRANS and therefore may be changed for purposes of investigating alternative future scenarios. Since the output of the model is directly tied to its exogenous assumptions, it is important to list these assumptions.

Specifically, four sets of exogenously determined variables are used in ENTRANS:

1. Population growth rates [base = 1.7 percent/ year (11)],
2. Gross-national-product growth rates [base = 3 percent/year, declining to 1.25 percent by the year 2020 (12)],
3. Fuel prices and production rates (6), and
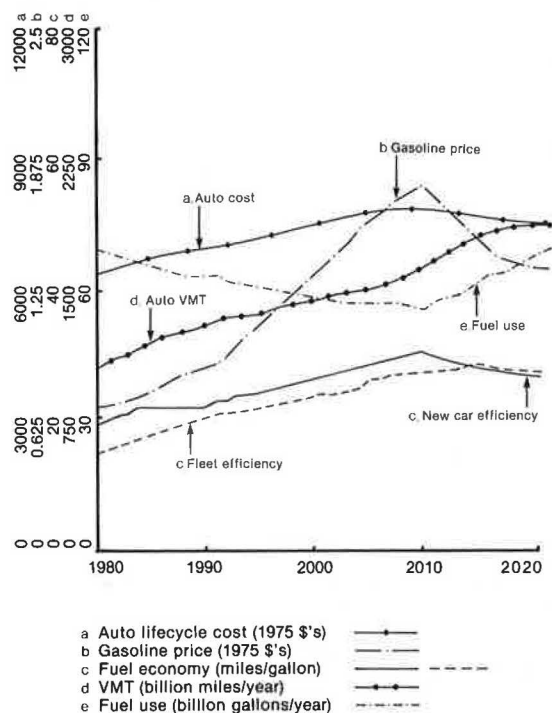4. Highway construction and reconstruction rates (9).

The model version whose results are described here, ENTRANS 4/15, differs from earlier versions primarily in its use of updated gasoline price projections and in the use of "optimistic" technology cost curves. These new cost curves, developed in consultation with the Transportation Task Force of the Solar Energy Research Institute (SERI), assume lower costs for implementing fuel-efficiency improvements than were assumed in the earlier model versions.

Base Case: 1980-2020 ENTRANS Projections

Fuel Use

Figure 7 shows that between 1980 and 2010, automo-

Figure 7. ENTRANS base case.

a Auto lifecycle cost (1975 $'s)
b Gasoline price (1975 $'s)
c Fuel economy (miles/gallon)
d VMT (billion miles/year)
e Fuel use (billion gallons/year)

bile fuel use declines from 70 billion to 57 billion gal/year. Despite the fact that VMT increases over this period, increases in fleetwide fuel efficiency more than compensate, and the result is a net decrease in fuel use.

Between 2010 and 2020, VMT continues its upward growth but is not offset by increases in fleetwide fuel efficiency. This produces an increase in total automobile fuel use over this period, from 57 billion to 66 billion gal/year.

Automobile VMT

Over the entire period, 1980-2020, VMT increases, primarily because of population and income growth. Between 1980 and 1990, VMT increases relatively quickly but, beyond 1990, this rate declines because of high prices and, later, gasoline shortages. Despite rising gasoline costs between 1980 and 1990, automobile operating costs do not rise significantly because of increases in new-car and fleetwide fuel efficiencies brought about by federal fuel-economy programs. After 1990, fuel economy ceases its growth and operating cost begins to grow along with gasoline price, and thus the growth in VMT is less than what might be expected from population and income influences.

Automobile Fuel Economy

Between 1980 and 1985, increases in the price of gasoline force new-car fuel efficiency to increase at a rate greater than federally legislated fuel-economy improvement programs [Energy Policy and Conservation Act of 1975 (EPCA)]. This is shown as an increase in new-car fuel economy from 19.4 miles/gal in 1980 to 22.4 miles/gal in 1985 [these are on-the-road fuel efficiencies and are therefore below Environmental Protection Agency (EPA) ratings]. However, these improve automobile fleet efficiency only as inefficient models are replaced by the new, more fuel-efficient ones. Thus, fleet efficiency increases slowly during the simulation, lagging behind the improvements in the new-car fleet by about 10 years.

Automobile Prices

From 1980 until the end of the simulation in 2020, the average automobile retail price increases. This is a result of three factors:

1. As fuel efficiency is improved to meet federal regulations, cars become more expensive to manufacture and retail prices increase.
2. At the same time, the automobile industry offers incentives to purchase smaller, cheaper, more fuel-efficient cars and disincentives for the purchase of large ones.
3. Market shares shift toward the less expensive cars, and the average retail price does not increase as much as the technical costs would indicate.

The generalized new-car price (Figure 7) increases continually from 1980 to 2020. From 1980 to 1985, increases in generalized new-car price are caused primarily by increases in purchase price, but beyond 1985 they are caused by continuing increases in the lifetime gasoline cost.

General Model Price Elasticities

The elasticity of fuel use in relation to changes in gasoline price is not a direct input to ENTRANS but an output that results from the interaction of several model components. There are three primary determinants of gasoline price/fuel use elasticity: household travel patterns, production decisions by the automobile industry regarding new-car fuel efficiency, and consumers' automobile-type choices. Changes in automobile fleet composition are necessary before fleet efficiency equals a given year's new-car fuel efficiencies. The ENTRANS gasoline price elasticities are reduced in absolute value by traffic congestion effects. Increased prices cause automobile travel reductions that, in congested areas, increase highway operating speeds. This increase in speed is an incentive to travel that in part offsets the effect of the price increase.

To determine the price elasticity of fuel use in ENTRANS, it is necessary to construct a base run with fixed gasoline price beyond a certain year (chosen here as 1979) and compare outputs from a run with a small (1 percent) increment added to the fixed gasoline price in a particular year. In the runs described here, automobile fuel-efficiency regulations were removed so that a pure price response could be observed. The elasticities vary through time, ultimately reaching the long-term value, and they are also different at different base gasoline prices.

The elasticities computed at two base gasoline prices are shown in Figures 8 and 9. These figures indicate the model's general behavior. At a gasoline price of $1/gal (Figure 8), automobile fuel efficiencies have not yet improved to near their maximum potential. Thus, incremental price increases can easily be offset by improved automobile efficiency. In fact, the long-term elasticity value of -0.5 is composed of a -0.1 elasticity for VMT and a -0.4 elasticity for automobile fuel-efficiency improvements. New-car fuel efficiencies are not reflected in the fleet efficiency until approximately 10 years after the gasoline price change, when older cars have "vintaged out" of the stock.

At a gasoline price of $2/gal (Figure 9), the long-run elasticity is lower in absolute value than at $1/gal: -0.3 versus -0.5. In fact, the relative contributions of travel reductions and efficiency

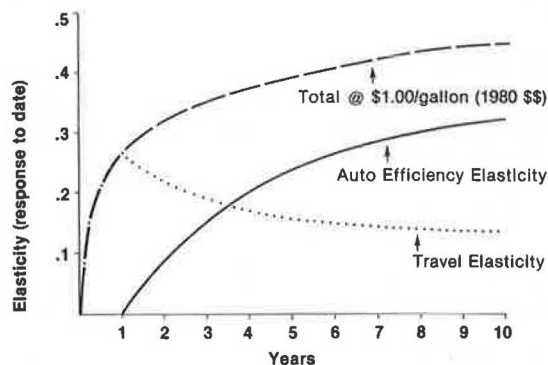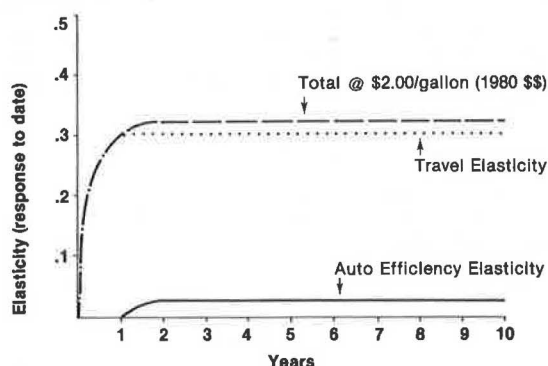Figure 8. Elasticities of gasoline price and fuel consumption at $1/gal.

Figure 9. Elasticities of gasoline price and fuel consumption at $2/gal.

Figure 10. Results of policy involving mandated 40-mile/gal fuel efficiency by 1995.

a Auto lifecycle cost (1975 $'s)
b Gasoline price (1975 $'s)
c Fuel economy (miles/gallon)
d VMT (billion miles/year)
e Fuel use (billion gallons/year)

improvements also change substantially. At $2/gal, automobile fuel efficiencies have already increased substantially and further improvements are progressively more difficult and, thus, more expensive. The result is that the fuel-efficiency elasticity is less than -0.05. By contrast, as gasoline prices increase, more households become constrained by travel costs, and thus the elasticity of travel with respect to price increases. At $2/gal, the elasticity of total travel is -0.25 as compared with -0.1 at $1/gal. Because the travel elasticity dominates at high gasoline price and because travel patterns can be shifted with little delay, the long-run equilibrium response is essentially achieved within two years. The behavior illustrated in these elasticity plots clearly indicates the inadequacy of conventional fixed-elasticity assumptions; fuel-use elasticities vary not only over time but also across different prices.

POLICY ANALYSIS

Mandated 40-Mile/Gal Fuel Efficiency

Under a scenario that calls for 40-mile/gal mandated automobile fuel efficiency, government standards are extended beyond 1985. The standards increase from their 1985 value of 27.5 miles/gal (EPA-rated) to 40 miles/gal by 1995. Given the gasoline prices used in these ENTRANS runs, this target fuel efficiency would not be reached without regulation. After-tax penalty fines for noncompliance are doubled to $100 for each mile per gallon that a manufacturer's fleet is below the standard. This ensures that the standards are met by the manufacturers. The results are shown in Figure 10.
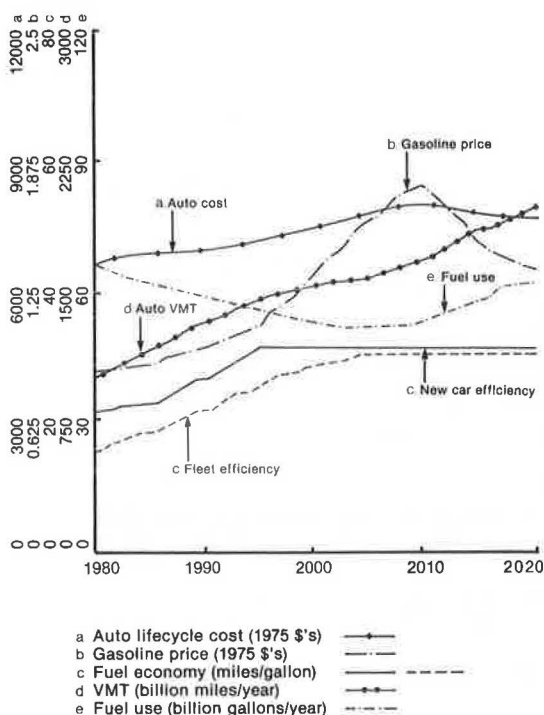
Fuel Use

Under these extended mandates, total fuel use declines over the 1980-2005 period, from 65 billion gal/year in 1980 to 51 billion gal/year in 2005 (as compared with 57 billion gal in 2005 in the base case). Increases in VMT are more than offset by increases in fleetwide fuel economy over this period. Later, fuel use increases to about 62 billion gal/year in 2020, compared with the base-case value of 68 billion gal, a 9 percent decrease.

Automobile VMT

Total VMT increases faster between 1990 and 2020 than in the base case. Increasing fleetwide fuel economy produces a lower operating cost, which allows a higher growth rate in VMT. In addition, the gasoline price declines during the years 2010-2020 with the assumed introduction of synthetic fuels. This further reduces operating costs and increases total mobility.

Automobile Fuel Economy

The higher noncompliance fines provide manufacturers with sufficient incentive to meet the higher fuel-economy standards. Beyond the year 2000, average new-car fuel efficiency is 31 miles/gal compared with the base-case value of 27 miles/gal in the year 2000.

Automobile Prices

Improved efficiencies increase the automobile's manufacturing costs, and hence the retail price increases. This, however, is more than offset by gasoline savings, and the life-cycle costs are slightly lower than in the base case: $7600 versus $7700 in 2020. Thus, the extended fuel mandate policy reduces both fuel consumption and automobile

Figure 11. Results of policy involving mandated 50-mile/gal fuel efficiency by 1995.
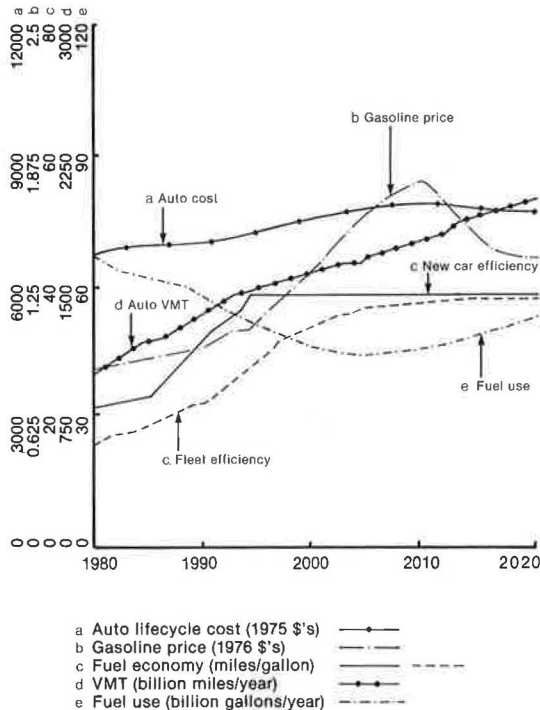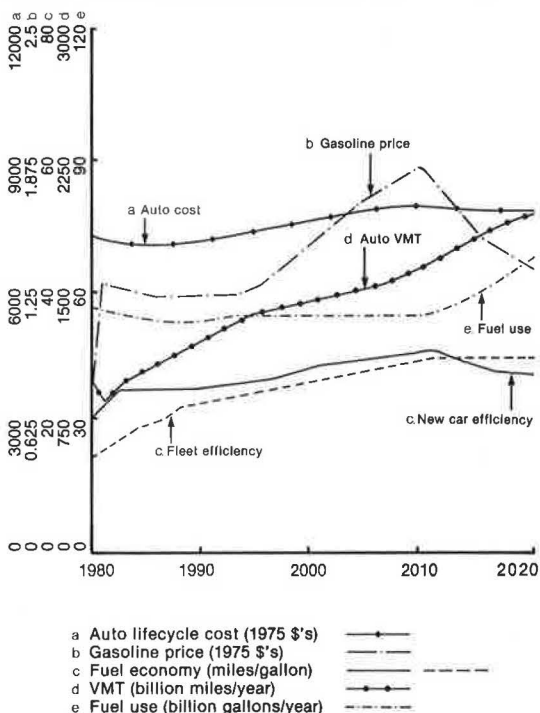

a Auto lifecycle cost (1975 $'s)
b Gasoline price (1976 $'s)
c Fuel economy (miles/gallon)
d VMT (billion miles/year)
e Fuel use (billion gallons/year)

Figure 12. Results of policy involving $0.50 current-dollar gasoline tax.

a Auto lifecycle cost (1975 $'s)
b Gasoline price (1975 $'s)
c Fuel economy (miles/gallon)
d VMT (billion miles/year)
e Fuel use (billion gallons/year)

ownership costs below those of the base case.

Mandated 50-Mile/Gal Fuel Efficiency

Figure 11 shows the results when government standards for fuel efficiency are increased to 50 miles/gal (EPA-rated) by 1995 from the 1985 target of 27.5 miles/gal.

Fuel Use

Under the 50-mile/gal mandates, total fuel use declines substantially to 44 billion gal/year by 2005 as compared with 51 billion gal in the 40-mile/gal mandate policy. This decrease comes despite continuing increases in automobile VMT. Automobile VMT continues to grow beyond the year 2005, but automobile fleet efficiencies catch up to new-car efficiencies by 2005. This causes fuel use to begin increasing to 50 billion gal/year by 2020.

Automobile VMT

Because of the lower operating costs of more fuel-efficient vehicles, automobile travel is increased over the base case by about 5 percent and over the 40-mile/gal mandate policy by about 3 percent.

Automobile Fuel Economy

New-car EPA-rated efficiencies increase, along the mandated schedule, to 50 miles/gal by 1995, which corresponds to 30 miles/gal on the road. Gasoline prices are not sufficiently high to increase vehicle efficiencies beyond that value through the year 2000.

Automobile Prices

Technical improvements in automobiles necessary to increase efficiencies do increase purchase prices, but these increases are more than offset by reduced life-cycle gasoline costs. Thus, total life-cycle automobile ownership costs are even slightly lower (2 percent) than under the 40-mile/gal mandate policy.

Current-Dollar Gasoline Tax

Figure 12 shows the effect of a $0.50 gasoline tax (in 1975 dollars) implemented in 1980. After its initial introduction, this tax is continually eroded by inflation (averaging only about 5 percent/year), which results in diminished effectiveness in later years.

Fuel Use

Fuel use declines sharply from 65 billion to 54 billion gal/year following the gasoline tax addition in 1980. This is due partly to the increasing fleetwide fuel efficiencies that result from the EPCA fuel-economy standards and partly from a decrease in VMT. Fuel use resumes growth beyond the year 2010, as in the base case.

Automobile VMT

Automobile VMT decreases when the gasoline tax is implemented in 1980, due to the resulting sudden increase in automobile operating cost. This lasts only for two years; afterwards, VMT resumes its growth, sustained by increases in fleetwide efficiency (producing lower operating costs) and growth in population and income.
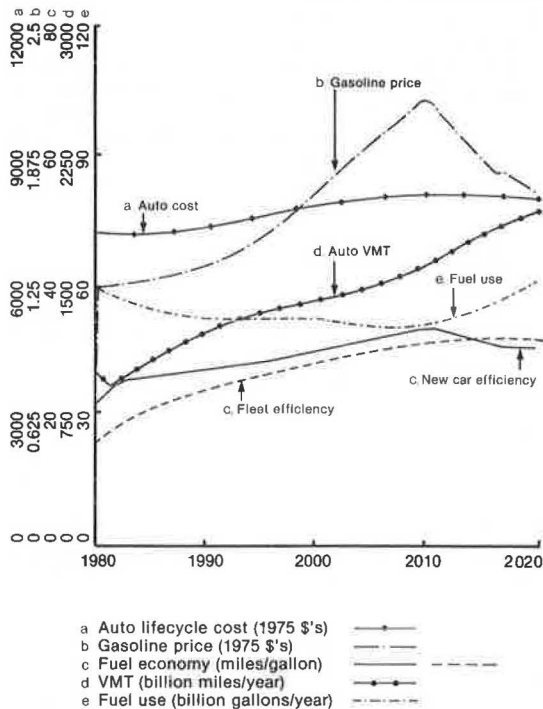
Automobile Fuel Economy

Fuel efficiency exhibits the same behavior as in the base case and for the same reasons.

Automobile Prices

New-car purchase prices do not change from the base case and generalized new-car price is slightly higher (e.g., $6700 versus $7000 in the 1985 base

Figure 13. Results of policy involving $0.50 real-dollar gasoline tax.

Figure 14. Policy comparisons: fuel use.

Figure 15. Policy comparisons: automobile VMT.

case) due to the increase in lifetime gasoline costs caused by the tax. Thus, this policy costs consumers more than the base case.

Real-Dollar Gasoline Tax

A $0.50 real-dollar gasoline tax has the effect of a sustained increase on gasoline price that keeps pace with inflation (see Figure 13). It is similar in principal to the proportional taxes common in Europe, although it is tagged only to general inflation rates, not specifically to energy price inflation.

Fuel Use

The real-dollar tax causes not only an immediate reduction in fuel use to 54 billion gal/year, as with the current-dollar tax, but also sustained reductions as long as the tax remains in effect. This longer-term effect is pronounced by the year 2020, when the current-dollar tax results in the use of 66 billion gal/year versus 60 billion gal under the real-dollar tax.

Automobile VMT

Since the real-dollar tax results in higher gasoline costs, automobile travel is depressed below the base-case level and slightly (1 percent) below levels under the current-dollar tax.

Automobile Fuel Economy

The higher gasoline costs cause on-the-road fuel-efficiency improvements to 31 miles/gal by 2020 versus 29 miles/gal under the current-dollar tax.

Automobile Price

Higher gasoline costs cause increased automobile life-cycle costs of about 2-3 percent over those
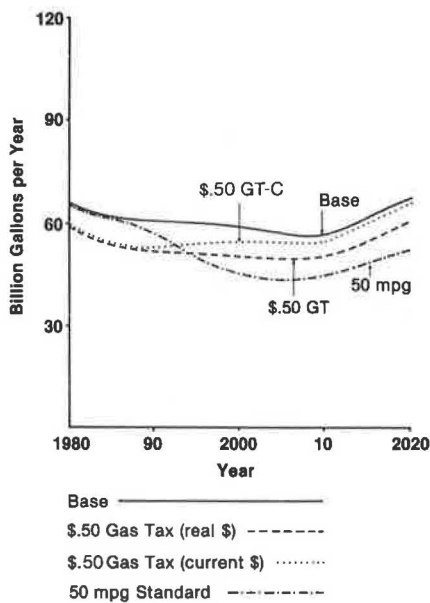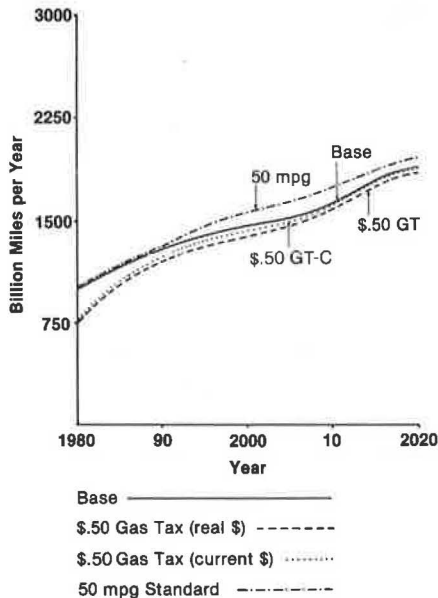
under the current-dollar tax.

POLICY COMPARISONS

Four of the ENTRANS policy runs described in the previous sections are summarized in Figures 14-17. In Figure 14, fuel use is compared for each policy. High fuel-economy standards have the greatest impact on long-term patterns of fuel use. A one-time current-value gasoline tax has a large immediate impact on fuel use, but this effect erodes over time in comparison with the effect of a real-dollar tax.

Fuel use is determined by both the amount of automobile travel and automobile fuel efficiencies. The policies are substantially different in their effects on these two factors. Figure 15 shows that the taxation policies achieve fuel savings partly by reducing automobile travel. By contrast, the extended mandates stimulate increased travel because

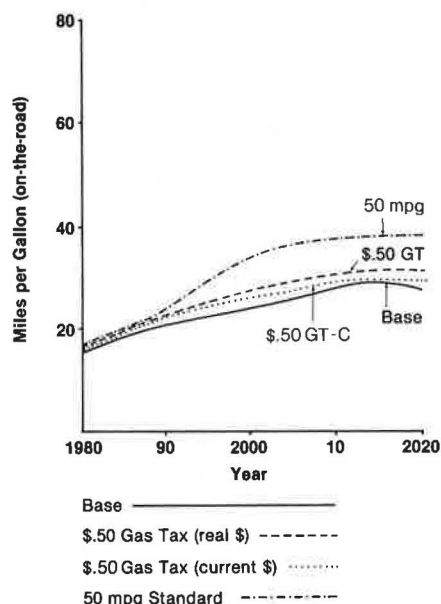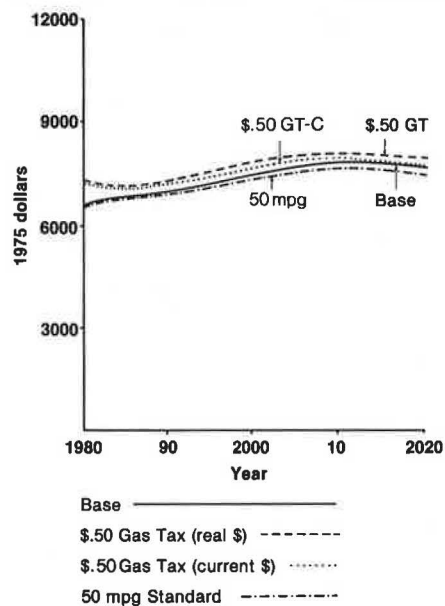Figure 16. Policy comparisons: automobile fleet efficiency.

Figure 17. Policy comparisons: automobile life-cycle cost.

of the model system. Clearly, an informed evaluation of the relative desirability of alternative fuel-conservation policies must be based on information about the wide range of impacts that will result. Although each of the policies is evaluated here by using only four measures, the model traces and can display many other impact measures, including the incidence of impacts across income groups. A more complete description of these results can be found elsewhere (2).

CONCLUSIONS

The ENTRANS model is one of several existing models of transportation energy use, each of which has unique advantages and a different range of appropriate uses. The advantages of ENTRANS are its relatively complete structural representation of energy use in passenger transportation, its ease of use in analyzing a wide range of different policies, and its flexibility in incorporating alternative structural assumptions, input data, or empirical parameters. Current users of the model include groups within the U.S. Department of Energy and SERI, and the model is continually being updated and expanded. The model, as currently structured, is not useful for short-term prediction, nor does it include the full range of transportation energy uses (e.g., freight movement). It is hoped that efforts elsewhere will complement this research and provide policymakers with a full spectrum of models for analyzing the important issues concerning U.S. gasoline use.

ACKNOWLEDGMENT

REFERENCES

1. R. Knorr and M. Millar. Projections of Direct Energy Consumption by Mode. Argonne National Laboratory, Argonne, IL, ANL/CNSV-4, Aug. 1979.
2. T.J. Adler, J.W. Ison, and J.C. Geinzer. Interactions Between Energy Supply and Transportation-Related Energy Use. Research and Special Programs Administration, U.S. Department of Transportation, Rept. DOT-RSPA-DPB-50/80/7, Vols. 1 and 2, 1980.
3. J.W. Ison. The Effect of Government Policy on Future Automobile Fuel Efficiency. Resource Policy Center, Thayer School of Engineering, Dartmouth College, Hanover, NH, Rept. RP-203, Jan. 1980.
4. J.C. Geinzer. Travel in an Energy-Constrained Future. Resource Policy Center, Thayer School of Engineering, Dartmouth College, Hanover, NH, Rept. RP-200, Nov. 1979.
5. T.J. Adler, J.W. Ison, and J.C. Geinzer. ENTRANS: A Model of the Interactions Between Energy Supply and Transportation Energy Use. Proc., 1979 Summer Computer Simulation Conference, Toronto, Ontario, Canada, AFIPS Press, Montvale, NJ, 1979.
6. G. Backus. Integrated Energy Analysis. Resource Policy Center, Thayer School of Engineering, Dartmouth College, Hanover, NH, Rept. RP-194, Dec. 1979.
7. H. Kirby. A Conference on Personal Travel Budgets. Institute for Transport Studies, Univ.

of lowered vehicle operating costs. In all cases, changes in automobile travel are diluted somewhat by the congestion effects described earlier. As shown in Figure 16, the mandate policy has a significant effect on automobile fleet fuel efficiency, whereas the taxation policies have noticeable though somewhat smaller effects.

In Figure 17, automobile ownership costs are compared for the alternative policies. Shifts to smaller, more fuel-efficient, less expensive cars cause net reductions in consumers' life-cycle automobile costs under the more stringent mandate programs. Taxation policies cause increased life-cycle costs because of the higher cost of gasoline.

The policies described here represent only a small subset of the ones that have been evaluated by using ENTRANS. Describing the forecast results of the policies does, however, illustrate the structure

of Leeds, Leeds, England, May 1979.
8. C. Lave and K. Train. A Disaggregate Model of Auto-Type Choice. Transportation Research, 1979.
9. Federal Highway Administration. Highway Statistics Summary to 1975. U.S. Government Printing Office, 1979.
10. G.R. Schink and C.J. Loxley. An Analysis of the Automobile Market: Modeling the Long-Run Determinants of the Demand for Automobiles. Wharton EFA Inc., Philadelphia, Vols. 1-3, 1977.
11. U.S. Bureau of the Census. Current Population Reports. U.S. Government Printing Office, Series P-60, No. 118, 1979.
12. Energy Modeling for Our Uncertain Future. Committee on Nuclear and Alternative Energy Systems, National Academy of Sciences, Washington, DC, Supporting Paper 2, 1978.

State-Level Stock System Model of Gasoline Demand

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A summary overview of the specification and econometric estimation of a state-level model of highway gasoline demand is presented. The model, which was developed by Oak Ridge National Laboratory for the Energy Information Administration, was designed for policy- and technology-sensitive forecasting of gasoline use by light-duty highway vehicles over the 1980-2000 period.

This paper provides an overview of a model developed for use by the U.S. Department of Energy (DOE) in conducting policy- and technology-sensitive forecasting over a 5- to 15-year horizon of regional demand for motor fuel for light-duty vehicles. A policy- and technology-sensitive long-range gasoline demand model must integrate three major elements: (a) the demand for travel, (b) the demand for vehicles used to accomplish that travel, and (c) the technology by which those vehicles transform motor fuel into travel. Models by Difiglio and Kulash ($\underline{1}$) and Sweeney ($\underline{2}$) were the first to incorporate these elements into unified models for long-range forecasting of gasoline demand in the United States. Unlike these models, the model developed here takes as its theoretical basis the household production theory of consumer demand. In this framework, households are viewed as purchasing goods in the marketplace, which they transform, in conjunction with available technology, into commodities whose consumption directly yields utility [as shown, for example, by Pollak and Wachter ($\underline{3}$)]. Thus, gasoline, or even travel, is not necessarily desired for its own sake but is rather an input to the production of something else that is.

In household production theory, demand functions exist for goods (e.g., gasoline) and have equal standing with demand functions for produced commodities (e.g., travel). As a result, it is perfectly valid to estimate direct demand equations for gasoline. Furthermore, in the short run, the demand function for gasoline will be conditional on the technology available for producing travel. These concepts form the basis for the model structure shown in Figure 1.

Given exogenous variables that include new-vehicle prices and characteristics, the demand for new vehicles by vehicle class and state is determined. Next, given existing state fleet compositions, new-car prices, and other variables, state used-vehicle holdings are determined by class and vintage. New purchases and used holdings combine to

make up the fleet composition. Based on fleet composition, historical and exogenously specified data on vehicle fuel efficiencies, and state characteristics, fleet fuel efficiency is determined. Finally, fleet composition, fuel efficiencies, and other variables such as gasoline price determine the state gasoline demand.

It is not possible in this brief overview to provide full details of the specification or estimation of the model, nor is it possible to characterize the sources and construction of the data base used in its estimation and calibration. The interested reader is referred to the five-volume model documentation prepared for DOE ($\underline{4}$), in which these issues are fully addressed.

This paper is divided into two parts: The first describes the theoretical specification of the model, and the second discusses the results of its econometric estimation.

MODEL SPECIFICATION

Demand for New Vehicles

The preferred approach to modeling automobile demand has, until recently, been the stock-adjustment model introduced by Chow ($\underline{5}$) and Nerlove ($\underline{6}$). This model specifies current sales as a function of current prices and income and lagged stock (other variables may be included):

$$q_{jt} = q_j (P_t, y_t, q_{jt-1}) \tag{1}$$

New vehicles are viewed as additions to current stock; i.e., new and used cars are assumed to be aggregatable commodities. Recent work has challenged that view. Wykoff ($\underline{7}$) proposed the hypothesis that the services of new cars are considered by consumers to be qualitatively superior to those of used cars. In this perspective, new-car purchases are not merely additions to the existing stock but rather reflect the demand for a unique commodity, new-car services, measured independently of the existing stock of used cars. Both Wykoff and Johnson ($\underline{8}$) found the superior-goods hypothesis performed well empirically, and Wykoff found it to be superior to the stock-adjustment approach. The superior-goods hypothesis was adopted in the model, and new and