DOE/TIC--10753

MASTER

A DERIVED DEMAND MODEL OF ENERGY DEMAND IN THE TRANSPORTATION SECTOR*

MARK RODEKOHR
ECONOMIST
OFFICE OF OIL AND GAS ANALYSIS
FEDERAL ENERGY ADMINISTRATION

LEWIS RUBIN
ECONOMIST
OFFICE OF ENERGY SYSTEMS MODELING
FEDERAL ENERGY ADMINISTRATION

ABSTRACT

In this paper we present a derived demand econometric model of energy consumption in the transportation sector. Each fuel, gasoline, distillate residual, jet fuel, liquefied gases and coal are modeled seperately with various procedures depending on the availability of data. We show that interfuel substitution possibilities are limited in the transportation sector. We also show the importance of the capital stock in the various demand functions. The capital stock and the intensity of utilization of the stock play a central role in the determination of the demand for energy in the transportation sector.

INTRODUCTION

In this paper we present a transportation energy demand model, that estimates the demands for gasoline, diesel fuel, residual fuel, jet fuel, liquefied gases, and coal that are consumed in the transportation sector. The model developed is a recursive econometric model used to simulate future transportation energy demands as well as the effects of certain energy policies on these demands.

The transportation sector is critical to our nation's current energy situation for two reasons. One is the amount of energy this sector consumes which is 25 to 30 percent of all energy consumed in the United States[1]. The second is the number of possibilities for energy conservation.

Many individuals consider the transportation sector, in particular, to provide a relatively large number of possibilities for introducing inexpensive energy conservation measures. Therefore this sector provides a large potential for valuable research.

This paper is organized into four major sections. The first section presents an overview of the model in both a theoretical and structural sense. The second section discusses the data and estimated equations. The third section presents the price elasticities. The final section summarizes the major findings and discusses further research.

I. OVERVIEW

Where data permit the model is designed to estimate energy demand as a function of the capital stock of energy consuming capital, the intensity of utilization of this stock, and the efficiency of the stock. Or more simply, energy demand ($D_{k,t}$) by the K-th type of capital in year t is an identity equal to the intensity of utilization of the stock (γ) divided by the efficiency of the stock (δ)

$$(1) \quad D_{k,t} \equiv \frac{\gamma_{k,t}}{\delta_{k,t}} .$$

where
k = capital unit
t = time

In the case of transportation the intensity of utilization (γ) can best be thought of as vehicle miles. Vehicle miles are an input into either a household production function, in the case of passenger transit modes or a physical production function in the case of freight transit modes. Demand for vehicle miles ($VM_{i,t}$) can be expressed as a function of the fuel cost per mile (FCOST), other variable cost per mile (OTHCOST), and a measure of economic activity (ACT) of the i-th mode in year t or:

$$(2) \quad VM_{i,t} = f\,(FCOST_{i,t},\ OTHCOST_{i,t},\ ACT_{i,t})$$

The fuel cost is an identity equal to the price of fuel (PFUEL) divided by the efficiency of the stock (δ) of the ith mode

$$(3) \quad FCOST_t = PFUEL_t/\delta_{i,t} .$$

The efficiency of the stock (δ) is represented by the average miles per gallon (AMPG) of the stock that is determined

by vintaging the stock which consists of past purchases of vehicles (NCS) and the associated miles per gallon of the t-th vintage (MPGVINT). Therefore, assuming exponential scrappage (the survival rate equals β) and averaging over gallons per mile [2] equations (4) and (5) describe the determination of the average miles per gallon of the stock as a function of the above mentioned variables and the stock of vehicles (STK) of the ith mode in year t.

$$(4)\quad AMPG_t = (1/(MPGVINT_{i,t} * NCS_{i,t}) + 1/AMPG_{i,t})/STK_{i,t}$$

$$(5)\quad STK_{i,t} = NCS_{i,t} + \beta * STK_{t-1}$$

Therefore, as new vehicles enter the stock and older vehicles are scrapped the miles per gallon of the stock or efficiency changes over time. However these changes in efficiency are relatively slow because of the large size of the stock of vehicles as compared to the new vehicles purchased in any time period and vehicles scrapped in any time period. Equations (1) through (5) represent a simulataneous system because the average miles per gallon of stock influences the fuel cost per mile which determines the demand for vehicle miles [3]. This suggests an adjustment process whereby higher fuel costs at first lowers the demand for vehicle miles but over time the efficiency of the stock can increase and reduce the fuel cost. The now lower fuel cost drives the demand for vehicle miles upward approaching the previous level before the price change [4].

Because of the lack of adequate data the structure outlined above can only be approximated for some modes. However the basic structure of the transportation energy demand model is the determination of the demand for vehicle miles and the average miles per gallon of the stock of vehicles.

Data on automobiles are the most plentiful and, thus the vintaging process is modeled in the most explicit manner. The efficiency of the stock of passenger cars in the long run is a function of the market shares of small, medium, and large size cars which explain the miles per gallon of the t-th vintage. The classes of cars are defined by a hedonic index which determines class on the basis of weight and horsepower of each make and model of car in any given year expressed in terms of 1971 equivalent cars [5]. The demand for a particular class of cars is determined by the generalized price (or the sum of the sticker price and present discounted value of gasoline costs) of the particular class of cars and the generalized price of any adjacent class of car and real income, all expressed in per capita terms. These market shares are normalized to sum to one and then multiplied by total new car sales to yield the normalized market shares for each case. Total new car sales are a function of the quantity weighted aggregate generalized price, income, and the lagged stock of cars

The normalization process determines the new car sales-weighted miles per gallon and, in turn, affects the total new car demand in the following period by changing the quantity weights in the aggregate price equation. Through the vintaging process the new car miles per gallon changes the miles per gallon of the stock. The stock efficiency affects gasoline demand directly and through changes in the cost per mile (or sum of fuel cost and time costs) which in turn affects vehicle miles. Changes in technology, holding all other variables constant, such as new car prices, changes passenger car gasoline demand through both changes in the average miles per gallon of the stock and the cost per mile.

In the short run the response to an increase in gasoline prices is primarily made by reducing vehicle miles. In the long run the adjustment to increases in gasoline prices is more complex. As gasoline prices increase both the sales-weighted miles per gallon of new cars and the stock increases, therefore the cost per mile decreases, and vehicle miles are again increased. The net effect of the price increase on vehicle miles tends, in the long run, to hold total vehicle miles at the same level as before the price increase as consumers adjust by purchasing more efficient automobiles. Therefore in total, the long-run effect of higer gasoline prices is to reduce gasoline demand.

The data did not explicity permit the vintage modeling of the efficiency of the capital stock of nonpassenger car fuels, however, the efficiency of the total stock is modeled for truck and bus fuel consumption. Fuel prices and macreoeconomic variables determine vehicle miles of trucks and buses. Macroeconomic variables influence the miles per gallon of the stock of trucks and buses, which in combination with vehicle miles, determine the fuel consumption of these modes. A multinomial logit function based on the relative prices of diesel fuel and gasoline then determines the demand for truck and bus gasoline and truck and bus diesel fuel. Distillate fuel demand by railroads is a function of the demand for ton miles. Commercial jet fuel is determined as a function of passenger miles and the load factor. Therefore truck and bus fuel and commercial jet fuel are all derived demand relationships based on the demand for travel. Residual fuel, liquefied petroleum gases, and coal demand are expressed as a function of certain macroeconomic variables, and only implicitly represent the derived demand for these fuels.

II. ECONOMETRIC ESTIMATION

Passenger Car Gasoline Demand

As we have previously noted the demand for passenger car gasoline demand is determined as a function of the average miles per gallon of the stock of cars and vehicle miles of these cars. The average miles per gallon of the stock is determined by the average miles per gallon of last period stock, the scrappage rate, and the shares of new small, medium, and large size cars (Q_S, Q_m, Q_L) and their respective miles per gallon. The quantities of small, medium, and large size cars are expressed as a function of generalized prices (GP_C) of these classes (c) of cars, real disposable income (YD), and the lagged stock (STK_{t-1}). The generalized price is a function of the sticker price (P_c), disbount rate (r), which is assumed to equal ten percent, average new car miles per gallon in each class (MPG_C), price of gasoline (PGAS), and vehicle miles per year (VM) which is assumed to be constant across each class and equal 10,000 miles per year. This is outlined in equation (6):

$$(6) \quad GP_C = P_C + \sum_{i=0}^{9} \frac{(PGAS/MPG_c)*VM_i}{(1+r)^i}$$

The total stock variable is constructed assuming exponential scrappage. Specifically the total stock which is a function of last year's stock and current new car sales (NCS).

$$(7) \quad STK = NCS_t + .92*STK_{t-1}$$

where:

$$NCS_t = Q_{s,t} + Q_{m,t} + Q_{L,t}$$

The annual scrappage rate is assumed to equal 8 percent[6].

Table I summarizes the econometric estimates of the new car class demands. All of the equations are expressed in log-linear and per capita terms, all prices in this analysis are expressed in real terms. The class demands are then normalized with a total new car sales equation. Total new car sales are expressed as a function of an aggregate price variable, income, and the lagged stock of cars. The aggregate price used is a quantity weighted index composed of the generalized prices of small, medium, and large cars and the corresponding lagged quantities. This aggregate price variable is summarized in equation (8), where GTP represents the aggregate price of all new cars.

TABLE I
ECONOMETRIC ESTIMATES OF PASSENGER CAR GASOLINE DEMAND BEHAVIORAL EQUATIONS
DEPENDENT VARIABLES

	Q_s	Q_m	Q_L	NCS	VM(7)
GP_s	-2.16	.25			
	(-4.98)	(.60)			
GP_m	6.72	.96	.51		
	(6.81)	(-1.30)	(.40)		
GP_L		1.13	-2.10		
		(2.24)	(-2.44)		
GTP				-1.84	
				(-8.02)	
YD	6.74	5.2	8.53	1.967	.98
	(3.34)	(8.9)	(8.50)	(4.91)	(11.15)
STK	-7.31	-3.72	-8.24	-2.33	
	(-2.67)	(-1.46)	(-2.11)	(-4.60)	
CP					-.359
					(-1.79)
RU					.0026
					(.94)
R	.88	.88	.90	.76	.996
D.W.	3.29	2.4	2.62	1.5	1.13

Note: t-values in parentheses.

$$(8) \quad GTP_t = \sum_i GP_i * Q_{i,t-1} / \sum_i Q_{i,t-1}$$

where i = small, medium, and large cars

The results of the estimation of total new car sales are also expressed in Table I.

Following the estimation of total new car sales a normalization process is used to produce estimates of the quantities of each class of automobiles. Letting TQ equal the sum of the nonnormalized class demand and NQ equal the normalized class demands equation (9) and (10) describe the normalization process where the nonnormalized class demands are converted to shares, which constrained to sum to one and then are multiplied by total new car sales to produce estimates of the class demands.

$$(9) \quad TQ_t = \sum_i Q_{t,i}$$

$$(10) \quad NQ_{i,t} = (Q_{i,t}/TQ_t)*NCS_t$$

The sales weighted miles per gallon of new cars is the quantity weighted average of the gallons per mile of each class of cars (GPM) or:

$$(11) \quad MPGVINT_t = (\sum_i NQ_{i,t}*GPM_{i,t})/NCS_t$$

The average miles per gallon of the stock of cars is determined in equation (5) after first adjusting the stock for differences in utilization rates of the various vintages [8].

The estimtes of vehicle miles was developed by James Sweeney. Sweeney uses two equations which predict vehicle miles. The first one estimates the cost of travel. This cost per mile (CPM) is a function of the passengers per car (PC), a wage factor

(WF) which adjusts the total wage rate for the proportion of wages valued in transportation, the wage rate (WR), the average speed of cars (AVSP), the price of gasoline, (PGAS), and the average miles per gallon of stock of cars (AMPG from equation (4)). Equation (12) expresses this relationship which suggests that the cost per mile of travel is a function of opportunity cost and gasoline cost.

$$(12)\quad CPM_t = (PC_t * WF_t * WR_t/CPI_t)/ACVP_t + (PGAS_t/CPI_t)/AMPG_t.$$

Following the derivation of the cost component Sweeney expresses vehicle miles (VM) per capita as a function of the cost per mile, income per capita, and the unemployment rate (RU). The vehicle miles regression is summarized in Table I.

The final equation (13) expresses passenger car gasoline demand (PCARGAS) in period t as an identity equal to vehicle miles divided by the average miles per gallon of the stock. Therefore

$$(13)\quad PCARGAS_t \equiv VM_t/AMPG_t.$$

Other Transportation Modes

For truck and bus fuel consumption vehicle miles of trucks (VMTRK) and vehicle miles of buses (VMBUS) and their respective miles per gallon of the stock (AMPGTRK and AMPGBUS) are modeled explicitly. However, there was not enough data to permit vintaging these modes. Table II presents the results of the econometric estimation. Unless otherwise noted all equations are estimates with ordinary least squares. Truck vehicle miles are estimated as a function of last period's weighted average highway fuel price, GNP, and the Federal Reserve Board index of industrial production (JFRB). The weighted average highway fuel price is a function of both gasoline prices and diesel fuel prices weighted by the corresponding quantities. The unemployment rate was included as an attempt to capture some expectational effects. Average truck miles per gallon are a function of the unemployment rates (RU), the interest rates (RA), the industrial production index, and last period's percentage of diesel in total truck and bus fuels (PCTDF). The inverse relationship between diesel percentage and miles per gallon is explained by the relatively larger size (and thus inefficiency) of diesel trucks.

Bus vehicle miles are estimated as a function of the weighted average highway fuel price of last period and per capita disposable income. Average bus miles per gallon are estimated as a function of the average speed of buses and the unemployment rate. The negative sign of the average speed variable is consistent with experience, as higher speeds tend to lower efficiency.

TABLE II

ECONOMETRIC ESTIMATES OF TRUCK AND BUS FUEL DEMAND EQUATIONS

Dependent Variables

Independent Variables	VMTRK	AMPGTRK	VMBUS
CONSTANT	.2 (.07)	2.078 (50.35)	7.71 (47.9)
PRFL	-.545 (-1.93)		-.475 (-2.68)
GNP58	1.74 (3.89)		
JFRB	-.51 (-1.49)	.393 (3.89)	
RU		.00755 (.236)	
RA	-.968 (-3.05)		
PCTDF		-.13 (-2.26)	
YD			.285 (4.81)
R^2	.9914	.7278	.9353
D.W.	1.7617	1.9348	1.1489

Dependent Variables

Independent Variables	AMPGBUS*	RATIOB*
CONSTANT	.229 (47.9)	-.27 (-1.43)
JFRB		-.399 (-1.85)
RU	.0018 (.418)	
AVSPBS	-.183 (3.54)	
RATIOA		-.414 (-.88)
VMTTL		.421 (1.66)
SUTCOM		-.148 (-.848)
RHO	.829 (6.35)	.94 (12.64)
R^2	.6869	.9954
D.W.	1.3976	1.3267

* First order autoregressive.

Note: t values in parenthesis

Note: All equations are log linear

Using multinomial logit analysis the ratio of truck and bus gasoline to truck and bus diesel fuel (RATIOB) is estimated using a nonlinear first order autoregressive scheme. It is a function of the ratio of gasoline to diesel price (RATIOA), total truck and bus vehicle miles (VMTTL), the ratio of single unit to combination truck vehicle miles (SUTCOM), and an industrial production index. The negative sign of the single unit: combination vehicle-mile variable is explained by the growth in the number of small, gasoline burning pick-up trucks for personal use. Clearly their increased efficiency offsets their increased usage, and thus the gasoline fraction can be expected to drop even as the vehicle miles of small trucks rise.

Estimates for the remaining modes are summarized in Table III.

Rail ton miles (TMRL) are estimatd as a function of rail diesel price (PDFW) (retail not including highway taxes) and railroad plant and equipment expenditures (CXPRL). Rail diesel fuel (RLDF) is estimated, as a function of rail ton miles and average compensation per man hour in the nonfarm sector (JRWSSEA) as a proxy for nonfuel costs.

Air passenger miles (PMAIR) are estimated to be a function of average revenue per passenger mile (ARPM) and per capita disposable income. Here average revenue is considered to be a proxy for operation cost (including fuel cost) when it is viewed from the passenger mile demand side. Commerical jet fuel (FPJTC) is estimated to be a function of the ratio of air passenger-mile to load factor or the percent of capacity utilized. Non highway gasoline (NHWYGS) is estimated as a function of GNP and a time trend. Residual fuel (FPRFT) is estimated to be a function of railroad diesel fuel, gross activity originating in marine transport (X58D), and the ratio of diesel fuel to residual fuel prices (PDFL/PRF). The estimates for the nontruck and bus modes are summarized in Table III. Coal (FBTB) (in BTU's) is estimated bY ordinary leastsquares to be a function of last period's coal consumption. Liquefied gases (FPLGT) are estimated as function of an industrial production index and a farm production index (JQAF). Thus both of the major LPG transportation uses (warehouse vehicles and farm vehicles) are considered.

TABLE III

ESTIMATED FUEL DEMANDS FOR RAIL, COMMERCIAL JET, NONHIGHWAY GASOLINE, COAL, AND LPG

Dependent Variables

Independent Variables	TMRL	RLDF*	PMAJB*	FPJTC*
CONSTANT	5.47 (17.6)	2.251 (10.71)	.246 (1.9)	1.827 (19.04)
PDFW	-.62 (-3.08)			
CXPRL	.243 (6.62)			
TMRL		.423 (5.37)		
JRWSSEA		.02 (.363)		
ARPM/CPI			-1.23 (-3.35)	
YD				1.457 (1.79)
PMAIR/ LOADFAC				.575 (1.03)
R^2	.88	.939	.994	.963
D.W.	1.33	1.869	2.13	1.95
RHO		.59	.99	.79

Dependent Variables

Independent Variables	NHWYGD**	FPRFT*	FBTB	FPLGT
	5.002 (4.16)	.93 (2.773)	.137 (.98)	5.04 (291.3)
GNP	.627 (2.96)			
TIME	-.0399 (-4.76)			
RLDF		.2206 (-.502)		
X58D		.3092 (1.168)		
PDFL/ PRF		.1183 (1.11)		
FBTB			.975 (1.11)	
JFRB				.785 (5.78)
JQAF				.064 (.156)
R^2	.91	.897	.98	.94
D.W.	1.63	1.74	2.04	2.05

* First order autoregressive.

** Developed by James Sweeney, Director, Office of Energy Systems, Federal Energy Administration.

Note: t values in parenthesis.

Elasticities

Table IV summarizes the price elasticities. Both the short and long run elasticities are presented. The short run refers to the one year elasticity and the long run refers to the 16 year elasticity. In both the short and long run the own price elasticities are negative. In general all of the cross price elasticities are positive and relatively small therefore we conclude that there exist few possibilities for interfuel substitution.

The long run income elasticity for gasoline is .775, 1.021 for passenger car gasoline, and 1.457 for airline passenger miles.

IV. SUMMARY AND CONCLUSIONS

We have presented an econometric model of energy demand in the transportation sector. This model is a derived demand model based on the demand for vehicle miles and the efficiency of the stock of capital which produces the vehicle miles. In the case of automobiles the capital stock is vintaged over time to allow for changes in its compostion. For other transportation modes data were not available to vintage the stock so the stock is modeled in an aggregate fashion. This analysis has shown that, in general, interfuel substitution possibilities are limited. The limited nature of interfuel substitution is due to the relatively high capital investment required to switch from one fuel to another and the fact that the physical capital structure such as highways, road bed etc., tend to support the consumption of one type of fuel as opposed to several fuel types.

Our anaysis has not explicitly dealt with modal choice issues because of the limited national data, and problems of using modal choice data on a national scale. Further work could include a vintage analysis of all modes other than automobiles and an analysis of the public sector's role in

TABLE IV
PRICE ELASTICITIES

SHORT RUN PRICE				
QUANTITY	PGAS	PDF	PRF	PJT*
GASOLINE	-.323	.026		
DISTILLATE (DIESEL)	-.090	-.267	.069	
RESIDUAL			-.01	
JET FUEL				-.15
LONG RUN PRICE				
QUANTITY	PGAS	PDF	PRF	PJT*
GASOLINE	-.420	.010		
DISTILLATE (DIESEL)	-.024	-.323	.153	
RESIDUAL			-.10	
JET FUEL				-.15

Note: All elasticities are numerically computed.

*Calculated by assuming that jet fuel cost represents 20 percent of average revenue per passenger mile in each year.

financing and maintaining the physical structure such as roads which play a large part in the determination of the predominate mode of travel.

Our analysis has assumed that vehicle miles are homogenous units; further analysis would assume that vehicle miles are composed of nonhomogenous units satisfying different demand functions. For example automobile trips could be disaggreated by work trips shopping trips and personnel travel. In the case of truck and rail travel the vehicle miles could be represented by length of trip as well as numbers of trips of a certain length. Definitional changes such as this could more explicitly model modal choice decisions and provide more detailed data on travel demand and resultant energy demand in the transportation sector.

FOOTNOTES

[1] See Mineral's Yearbook, Bureau of Mines, (Washington, D. C.: U.S. Department of the Interior.)

[2] Averaging over gallons per mile is equivalent to taking the harmonic mean of miles per gallon which is necessary to preserve the proper units.

[3] In our analysis we do not model a simultaneous system but a recursive system because of institutional considerations and the traditional lagged response of consumers to changes in prices in the automobile market.

[4] For a complete description of this theoritical structure see James Sweeney "A Vintage Capital Stock Model of Gasoline Demand," draft working paper, Office of Energy Systems Modeling, Federal Energy Administration 1975.

[5] A full description of the automobile gasoline demand model presented in this paper appears in A. Bradley Askin and John Kraft (eds.), Econometric Dimensions of Energy Demand and Supply, (Lexington, Mass.: D. C. Heath Co., forthcoming) as Chapter 3, "The Capital Stock Adjustment Process and The Demand for Gasoline: A Market Share Approach," by Derriel Cato, Mark Rodekohr, and James Sweeney.

[6] From James Sweeney, "Passenger Car Use of Gasoline: An Analysis of Policy Options," draft working paper, February 1975, Office of Energy System, Federal Energy Administration.

[7] Ibid.

[8] See Sweeney, "A Vintage Capital Stock Model of Gasoline Demand," for an explanation of differing utilization rates by vintage.

[9] See Sweeney, "Passenger Car Use of Gasoline: An Analysis of Policy Options."

*The views expressed in this paper are those of the authors and do not necessary reflect those of the Federal Energy Administration. The authors wish to thank Renee Barnow for her helpful editing. All errors are those of the authors.