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Preliminary
Comments Welcomed

I. INTRODUCTION AND GENERAL BACKGROUND

In recent years increasing attention has focussed on factors affecting demand for energy in the developing countries. For Mexico, such issues are of particular interest, since within the last decade Mexico has become one of the world's leading oil producers and exporters. The menu of energy policy alternatives in Mexico is therefore unusually rich for a developing country. Not only are there possibilities for constructing policies to affect demand for overall energy and for particular fuels, but national policies can also significantly determine the supply of individual fuels and electricity. This rich array of policy options underscores the need for a comprehensive energy analysis encompassing both supply and demand aspects. An important issue in this context is the price and income responsiveness of demand for energy fuels.

In this paper we report results of our analysis of one component within overall Mexican energy demand, namely, the transport sector. In 1975, the share of transport energy demand in the national total was about 34%, and by 1980 it is estimated that this share was slightly greater than 37%.[1] Hence the transport sector is an important one, and policies targeted to this sector could have important aggregate implications.

Within the Mexican transport sector, here we focus attention on energy demand in the railroad, air transport, and motor vehicle modes. Our approach is an econometric one with special emphasis placed on modelling more explicitly the structure for each mode. Our reasons for pursuing a more structural approach are simple but persuasive: An understanding of factors affecting energy demand in the transport sector is best obtained by considering explicitly both demand for the product (transport services) whose production or consumption involves energy usage, and the manner in which energy usage can be adjusted in producing the transport service. A related

advantage of this structural approach is that it facilitates explicit analyses of policies that affect demand for energy indirectly (through demand for the transport services, such as passenger-kilometers, prices and national GDP), as well as those that may affect energy demand more directly (e.g., a gasoline tax).

Our structural framework can be described briefly as follows. For two of the modes we employ a two-stage approach where in the first stage demands for services from the particular transport mode (e.g., railroad freight, airline passengers, etc.) are modelled, and then in the second stage energy demand is treated as a derived demand from this transport service. For the motor vehicle mode, gasoline demand is treated as the product of the utilization rate per vehicle times the total number of vehicles, and then both these components are related to economic and structural variables. Due to data limitations, demand for diesel fuel is modelled using a more reduced form approach. It should be noted that the data used in this study vary from national time series to cross-sectional data pooled over time.

The plan of this paper is as follows. In Section II we outline the models developed for the various transport modes. In Section III we discuss data construction procedures and sources, and then present results for each of the transport modes. Finally, in Section IV we present a brief summary and concluding remarks.

II. THE STRUCTURAL MODELS

Two types of models are used for estimating energy consumption patterns within the Mexican transportation system. The first type of model consists of a two-stage structurally recursive framework. In the first stage the equilibrium quantities of transportation services are modelled, while in the

second stage these transport service quantities are treated as exogenous and the relevant energy demand equation is then derived. This methodology is used for both the railroad and air transport modes.

For the motor vehicle mode, a different type of model is used, since data on transport services (e.g., passenger-miles) are not available. Here energy consumption is equated via an identity to energy consumption per vehicle times the number of vehicles. We now discuss these two types of models in greater detail.

II. A. The Two-Stage Models

A two-stage model is used for estimating energy use in the railroad and air transport industries. The first stage models demand for passenger-kilometers (hereafter, PK) and ton-kilometers (TK), while in the second stage the results of the first stage are employed to explain energy consumption in these modes. Since both the railroad and air transport services are to some extent inherently national, they are modelled at the aggregate national level. A more compelling reason, however, is that point-to-point and node-to-node transportation service quantity and price data simply are not available.

We first consider national demand for freight transportation. Under the assumption that firms in industries demanding freight transportation services maximize profits, the demand for TK -- a derived demand for a factor of production -- is a function of the output of the firms and the input price vector, including of course the cost per TK.

To explain the demand for PK one can employ basic consumer demand theory. Assume there exists a utility function whose arguments include the goods and services purchased, as well as the characteristics of the available

transportation modes. Under the assumption that, given income, individuals maximize their utility, the resulting optimal demand functions include as arguments the individual's income, commodity or service prices, and the attributes of the transport modes.

Turning now to TK, let $C(w_{TK}, w, x, y_1)$ be the cost function of the industry consuming freight transportation services, where w_{TK} is the price per ton-kilometer, w is a vector of other variable input prices, x is a vector of fixed factors, and y_1 is the level of output. The cost minimizing demand equation for TK can be derived by differentiating the function C with respect to w_{TK}. This yields demand equations of the form

$$(1)\quad TK = F(y_1, w_{TK}, w, x).$$

Similarly, based on the indirect utility function of the consumer, one can obtain the optimal demand equation for PK having the form

$$(2)\quad PK = G(y_2, w_{PK}, w, d),$$

where y_2 is measured real income, w_{PK} is the real price per unit of PK (nominal price divided by the cost of living index), and d is a vector of demographic variables. We note in passing here that y_1 and y_2 need not be one-element vectors; for example, in the air transport sector both domestic and foreign real income measures may be important, since both may affect demand for domestic and international PK.

An explicit model incorporating all the possible ways different agents involved in the transportation sector interact with one another is beyond the scope of this paper. Therefore, to simplify we specify that demanders face

exogenous prices, that consumers maximize utility and producers minimize costs, that production of TK is unaffected by the level of production of PK and vice versa, and that this joint optimization yields demand equations at the national level of the form (1) and (2). This completes our discussion of the first stage.

Given the cost-minimizing demands for PK or TK, firms/individuals now generate derived demand equations for specific fuels. This is the second stage of our two-stage model. Under appropriate separability conditions, one can envisage this second stage as consisting of a cost or utility sub-function, whose arguments are the quantities TK or PK, w and x, where w now includes the price of fuels. Differentiating these subfunctions with respect to an element in w (say, the price of a particular fuel) yields the optimal derived demand for that fuel, having the form

$$(3)\quad \text{Fuel Demand} = H(PK, TK, w).$$

Equations (1), (2) and (3) comprise the two-stage econometric model. Outputs (PK and TK) are estimated using the first two equations, and energy inputs are estimated using the last equation.

Since TK and PK are dependent variables in (1) and (2) but appear as right-hand variables in (3), it would appear that for econometric estimation to be consistent and efficient, full simultaneous equations estimation procedures would be required. However, this turns out not to be the case, since the equation system is structurally recursive. Specifically, although fuel demand in (3) is a function of PK and TK, in (1) and (2) fuel demand does not appear as a regressor. This implies that the diagonal elements of the Jacobian matrix in the traditional log-likelihood function for full

information maximum likelihood estimation are unity, that the matrix is triangular, and thus that the natural logarithm of its determinant is zero. As a consequence, estimation using the iterated Zellner procedure is numerically equivalent to full information maximum likelihood estimation. This feature of our two-stage modelling approach is particularly attractive, for it permits efficient and consistent estimation of a potentially exceedingly complex model using simple and widely available computer algorithms.[2]

II. B. The Identity Models

The second set of models used in this analysis is typically based on the identity that gasoline consumption is equal to the utilization rate per vehicle times the total number of vehicles. Three models are postulated for motor vehicle energy use, the difference among them being various structural restrictions imposed on the basic identity. Specifically, in Model 1 it is assumed that fuel consumption is a function of some contemporaneous and lagged vectors of exogenous variables, in Model 2 total fuel consumption is decomposed into flexible and captive components, while in Model 3 a system of equations is specified in which the endogenous variables are the utilization rate, the stock of motor vehicles, gasoline demand and the investment in new motor vehicles.

At the outset, let us specify u_t to be the utilization rate (energy consumption per vehicle per time period), s_t to be the stock of motor vehicles at time t, and g_t to be the total energy consumption during time period t. The basic identity is therefore

$$(4) \quad g_t \equiv u_t * s_t \ .$$

Identity Model 1

This model postulates u_t and s_t as functions of contemporaneous and lagged exogenous variables. In particular, u_t is assumed to be a function of a set of variables denoted x_{1t} and s_t is a function of a set of variables denoted x_{2t}; the product g_t is then a function of these two sets of exogenous variables. Call this union of sets x_t.

The time or lag structure of these variables could be important. Equation (4) implies that both s_t and u_t are average values at time t. But since s_t includes both old and new motor vehicles, energy efficient and energy inefficient vehicles, and so forth, it is implicitly assumed that the total stock can be represented by an average measure and that one can attribute an average utilization rate to this average stock. The lagged exogenous variables can therefore be interpreted as explaining the actual stock due to past investment, as well as the actual utilization rate of older vehicles. Contemporaneous exogenous variables can be viewed as affecting the current rate of investment in new vehicles, as well as their rate of utilization. Let the resulting fuel demand equation be of the form

$$(5) \quad g_t = f(x_t, x_{t-1}, \ldots).$$

For estimation, an explicit functional form must be specified for f, including the number of time lags. Although a number of specifications are possible, here we limit ourselves to the well-known Koyck partial adjustment or geometric distributed lag specification in which fuel consumption lagged one period is introduced as a right hand variable. This retains scarce degrees of freedom, yet maintains dynamic aspects.

Identity Model 2

The second model builds on the distinction between flexible and captive

demand for energy, a distinction orinally implemented by Balestra and modified by Berndt and Watkins.[3] Let us denote the (gross) investment in new motor vehicles at time t as I_t, and the rate of replacement or depreciation as r_t. Assume r_t is constant over time. The actual stock of vehicles can be written as

$$(6) \quad s_t = I_t + (1 - r)*s_{t-1}$$

and thus equation (4) can be rewritten as

$$(7) \quad g_t = u_t*I_t + u_{t-1}*(1 - r)*s_{t-1}.$$

The first term on the right hand side of (7) is called flexible demand, and the second captive demand. Fuel consumption attributable to the new stock is modelled by the flexible component, while the captive component of fuel consumption is modelled as a function of the old stock surviving into the current time period. Denote flexible demand at time t as gf_t. Hence

$$(8) \quad gf_t = u_t*I_t = F(x_t)$$

where as before x_t is a vector of contemporaneous exogenous variables determining the utilization and investment decisions at time t. Finally, let the utilization rate be constant over time. This enables us to rewrite (7) as

$$(9) \quad g_t = gf_t + g_{t-1} = F(x_t) + g_{t-1},$$

i.e., total fuel demand is a simple sum of flexible and captive demand. Long-

run responses are a function of only the flexible component, but short-run responses are the product of the relevant long-run response and the ratio of flexible demand to total demand.

Identity Model 3

The basic innovation of the third model we consider here is that it explicitly specifies equations for the utilization rate, the purchase of new motor vehicles, and therefore the determination of the contemporaneous stock of motor vehicles.[4] Hence it is a four-equation system with four endogenous variables.

Although this model is based on the identities (4) and (6), it does not distinguish captive and flexible components. Rather, it postulates distinct investment and utilization rate functions. The investment function can be formed as the familiar stock adjustment model, wherein it is postulated that consumers have a desired level of stock of motor vehicles, and that each year they close a portion of the gap betwen actual and desired stocks, denoted by the function h. Let sd_t be the desired stock at period t, and then specify the investment equation as the sum of net plus replacement investment,

$$(10) \quad I_t = h(sd_t - sd_{t-1}) + r^*s_{t-1}$$

where the function h is non-negative, its first derivative is positive, and its second derivative is non-positive.

Next we make an assumption concerning factors affecting the desired level of vehicle stock. We assume that this stock is a function of contemporaneous exogenous variables, i.e.

$$(11) \quad sd_t = j(x_t).$$

To close the model, the utilization rate function must be specified. Since utilization is defined as gasoline consumption per vehicle per time period, utilization can be further decomposed into the product of gasoline consumption per kilometer times kilometers per vehicle per year. The first term, average fuel efficiency, depends on contemporaneous and lagged exogenous variables, while the second term, the average kilometers driven per vehicle per year, also depends on other contemporaneous exogenous variables and habits of the population. The lagged dependent variable can be envisaged as representing habits of the population and the lag structure of average fuel efficiency. Finally, it is reasonable to specify that utilization is a function of the stock of vehicles as well. Together these remarks imply a utilization equation of the form

$$(12) \quad u_t = u(x_t, s_{t-1}, u_{t-1}).$$

The complete model is formed by equations (4), (6), (10), (11) and (12).

Before closing this section, we comment briefly on long- and short-run elasticities. Note first that the multiplicative nature of (4) implies that the short (long)-run elasticities of fuel demand are equal to the short (long)-run elasticities of the utilization rate plus the short (long)-run elasticities of the stock of motor vehicles. Further, the short- and long-run elasticities of the utilization rate function (12) are analytically equivalent to the elasticities of Model 1. In turn, the short-run elasticities of the stock of vehicles are equal to the short-run elasticities of the investment function times the ratio of gross investment over total stock. Finally, given

that at the steady state net investment is zero (gross investment consists only of replacement investment), the long-run elasticities of the stock of vehicles equal the elasticities in equation (11), the function yielding the desired level of motor vehicle stock.

III. DATA AND EMPIRICAL RESULTS

In this section we consider data and empirical results for the railroad, air transport and motor vehicle modes. We consider each sector in turn.

Railroads

The vector of fixed factors x in this transport mode includes as elements the track length, number of freight and passenger cars, freight and seat capacity, hauling force, and number of locomotives. The locomotive fleet was changed from a steam-powered fleet to a diesel-powered one during the estimation period, and thus a variable is included to capture the effects of this technological change. Specifically, we assume that the time elasticity of fuel demand has two components, the first one independent of the fuel composition utilized by the locomotive fleet and the second one a function of it. This second function is defined as one minus the ratio of diesel use to total fuel use, where both quantities are measured in crude oil equivalent units (COEU). We expect the component representing the autonomous technological change to be negative, while the second fuel compositional component should be positive, implying that the change to diesel was energy-saving.

Among the variable input prices (w), the only element of this vector for which data is readily available is the fuel price index. In particular, data

on labor or capital costs in the railroad industry are not available. To create the fuel price index, we transformed quantities of the two fuels (diesel and combustoleo) into COEU, and then divided total fuel expenditures by total fuel use measured in COEU. A Divisia price index was also calculated, but econometric results were not sensitive to the price index used. The variables w_{PK} and w_{TK} were measured using the unit price paid based on national data. Ideally the per unit price of competing freight modes should be included in the vector w, but suitable data are not yet available for the full sample period of 1960-79.

As the measure of output of the freight-consuming sectors, we have summed the real gross domestic product of the agricultural products, mineral products, petroleum and petroleum subproducts, other inorganic products and industrial products into a single variable y_{1t}.

For both PK and TK a constant elasticity (log-log) functional form equation has been estimated. In the PK equation the right hand side variables are w_{PK}, the urbanization rate, national population (with an a priori value for its coefficient equal to unity implying that the dependent variable can be envisaged as PK per capita), track length, and seat capacity. In the TK equation, the explanatory variables are w_{TK}, y_1, and the number of freight cars.

The fuel demand equation is also specified in log-log form. The right hand side variables are TK from the first stage and the variable called DUM, discussed earlier, which captures technical change due to the shift from steam to diesel locomotives, defined as

$$(13) \quad DUM = (1.0 - (COEU_{diesel}/COEU_{total})).$$

We have excluded PK from the fuel demand equation because of its quantitative unimportance. Specifically, over the 1960-79 sample period, under the assumption that the typical passenger weighs 70 kilograms, PK as a percentage of TK is only one or two percent.

Regarding estimation procedure, the econometric model is a simultaneous equation system consisting of output and fuel demand equations, with a first order serially correlated error allowed in each equation. As discussed earlier, since this system is structurally recursive, the Jacobian term within the likelihood function vanishes, and estimation by traditional iterated Zellner procedures is numerically equivalent to full information maximum likelihood.

The empirical results, using this annual data for 1960-79, are presented in Table 1. Briefly, they can be summarized as follows: For the TK equation, the GDP elasticity is 0.44 with a t-statistic of 2.47, while the price elasticity is small and statistically insignificant, -0.06 (0.60). In the fuel demand equation, although TK is positive and significant -- an elasticity of 0.98 with a t-value of 4.37, in earlier runs the coefficient on the price of fuel variable was very close to zero, positive, and insignificant. Hence we have constrained it to be zero. The coefficient on the structural change variable DUM is positive and marginally significant, 0.58 (1.34).

We conclude that in the railroad sector the primary factor affecting demand for fuel is the tonnage and distance with which freight is hauled, although the shift from steam to diesel locomotives has also been important.[5] Direct fuel price effects are not evident in this data for the railroad sector.

Table 1

Maximum Likelihood Parameter Estimates for the Railroad Sector of Mexico, 1960-1979

(asymptotic t-statistics in parentheses)

Ton-kilometers equations (R^2 = 0.983; DW = 1.69)

$$\ln(TK) = \underset{(0.30)}{0.199} + \underset{(1.86)}{0.604}\ln(\text{capacity}) + \underset{(2.47)}{0.440}\ln(\text{output}) - \underset{(0.60)}{0.056}\ln(\text{Price per TK}) + \varepsilon_t$$

$$\varepsilon_t = \underset{(1.89)}{0.758} \cdot \varepsilon_{t-1} + \mu_t$$

Fuel demand equation (R^2 = 0.875; DW = 1.88)

$$\ln(\text{fuel}) = \underset{(1.46)}{3.382} + \underset{(4.37)}{0.975}\ln(TK) + \underset{(1.35)}{.581}\ln(DUM) + \varepsilon_t$$

$$\varepsilon_t = \underset{(4.11)}{0.672} \cdot \varepsilon_{t-1} + \mu_t$$

AIR TRANSPORT

We now consider data and empirical results for the air transport sector in Mexico, in which the two transportation service outputs produced are domestic and international PK. The demand for PK is posited to depend on the real income level and the real price. However, some important differences should be noted between domestic and international PK. First, domestic PK are demanded primarily by Mexican residents. Hence the relevant income variable is real Mexican disposable income, and the relevant price variable is the real price per domestic PK. By contrast, for international PK one would expect that both domestic and foreign residents affect demand. Hence there are two groups of variables in the international PK equation, one capturing the demand by domestic residents and the other the foreigners' demand. In the first group we include Mexican disposable income measured in U.S. dollars (because expenditures abroad must be done in that currency), and the real price per international PK measured in pesos (because we assume that domestic residents pay for international tickets in Mexican pesos). In the second group we include a measure of the foreign (here, U.S.) GNP and the real price per international PK, both measured in U.S. dollars. Finally, we omit any demographic variables from the PK equations, since only a small fraction of the population in a developing country such as Mexico demands air transportation services. Data on such a small group are not available.

In summary, then, the first stage equations for domestic (PKDOM) and international (PKINT) PK are of the form

$$(14) \quad PKDOM = H(YD, DOMPR)$$

$$PKINT = K(YD/E, INTPR*E, USYD, INTPR)$$

where YD is real Mexican disposable income in pesos, DOMPR is the real domestic price for domestic PK in pesos, E is the exchange rate in pesos per dollar, USYD is real U.S. disposable income in dollars, and INTPR is the real international price for international PK in dollars.

With respect to the second stage, in Mexico two main fuels are used by the air transportation sector. It is reasonable to assume that piston airplane fuel (gasavion) is used only for domestic flights, and that both domestic and international flights use jet plane fuel (turbosina). Therefore the gasavion (GASAV) demand equation has only domestic PK appearing as an output, while both domestic and international PK appear in the turbosina (TUR) fuel equation. To allow for substitutability, we initially specified both turbosina and gasavion fuel price as regressors in each fuel demand equation. Since differences between the U.S. and Mexican jet fuel prices over the sample period may have provided incentives for foreign airlines to purchase turbosina in Mexico, it would have been desirable to introduce the jet fuel price in the U.S. relative to Mexico as an explanatory variable in the jet fuel demand equation. Unfortunately, we have not yet obtained U.S. jet fuel prices of sufficient quality to justify including them into the regression equation. Finally, as a proxy for measuring technical progress over time, we include a time variable in both the gasavion and turbosina fuel demand equations. This gives us the equations

$$(15) \quad GASAV = f(PKDOM, GASPR, TURPR, t)$$
$$TUR = g(PKDOM, PKINT, GASPR, TURPR, t)$$

where GASPR and TURPR are the real prices of gasavion and turbosina, respectively, in pesos.

In terms of functional forms, after some experimentation we settled on the semi-logarithmic and non-constant elasticity form of log PK on the right hand variables in linear form, whereas for the fuel demand equations the constant elasticity (log-log) function was utilized. The four-equation model (14) and (15) was estimated using the method of maximum likelihood. The sample period was 1969-1979.[6] We summarize the econometric results in Table 2.

Table 2

MAXIMUM LIKELIHOOD ESTIMATES OF PARAMETERS IN THE AIR TRANSPORT SECTOR OF MEXICO, 1969-1979

(Asymptotic t-statistics in parentheses)

Gasavion Equation:

$$\ln(GASAV) = \underset{}{3.056} + \underset{(6.79)}{0.198}*\ln(PKNAT) - \underset{(3.35)}{0.103}*t \qquad \underset{(3.86)}{} \qquad DW = 1.77$$

Turbosina Equation:

$$\ln(TUR) = \underset{}{-2.006} + \underset{(3.51)}{0.285}*\ln(PKNAT) + \underset{(3.80)}{0.702}*\ln(PKINT) \qquad \underset{(6.70)}{} \qquad DW = 1.88$$

International PK Equation:

$$\ln(PKINT) = \underset{}{11.166} + \underset{(27.02)}{0.0002}*YD - \underset{(8.83)}{0.447}*INTPR - \underset{(7.55)}{0.096}*E \qquad \underset{(10.01)}{} \qquad DW = 1.72$$

Domestic PK Equation:

$$\ln(PKDOM) = \underset{}{7.148} + \underset{(70.11)}{0.0004}*YD - \underset{(12.97)}{3.329}*DOMPR \qquad \underset{(5.16)}{} \qquad DW = 1.59$$

These results merit discussion. For the first stage models represented in the bottom two equations, it is clear that disposable income and price per PK both affect air transport demand in a significant and expected manner. In the domestic PK demand equation, over the sample the implied Mexican income elasticity varies from 1.46 to 2.60, a plausible range, while the price elasticity ranged from -1.03 to -1.41. For the last year in the sample, 1979, the elasticity estimates are 2.60 and -1.07, respectively.

In the international PK demand equation, the respective Mexican income and price elasticities range over the sample period from 0.73 to 1.33, and -0.16 to -0.20. Again, for 1979 the elasticity estimates are 1.33 and -0.16, respectively. These results are satisfying, for it is usually assumed that international air transport services are only moderately price elastic, but more responsive to income. The real exchange rate coefficient is negative and significant, suggesting that the positive exchange rate effects on international travelers flying into Mexico is dominated by the negative effect on Mexican residents flying abroad. Finally, since earlier runs suggested small and insignificant coefficients on the U.S. GNP variable in the PKINT equation, its value was constrained to zero.

Turning to the second-stage fuel demand equations, we found in preliminary runs that the price of the fuels was not statistically significant and occasionally of the wrong sign; hence we deleted the price variables from these equations. In the turbosina equation, the relative sizes of the PKNAT (0.28) and PKINT (0.70) output elasticities suggest that international PK have about two and a half times larger an impact on jet fuel than do the domestic PK. Finally, in the gasavion equation, the PKNAT elasticity is 0.20 -- positive and significant, but relatively small in magnitude. The negative coefficient on the time variable may reflect both improvements in fuel

efficiency over time and economies of scale with gradually larger aircraft.

In conclusion, therefore, as in the railroad sector we find that the direct effect of fuel price changes on air transport fuel demand are very small--indeed, in this sample they are not evident at all. This result may reflect the relative unimportance of fuel costs in total airline generating and capital costs, which in turn is partly due to the fact that these fuel prices have been subsidized by the government.[7] However, demand for air transport services, both domestic and international, is price responsive, and both PKINT and PKDOM are affected substantially by changes in real income. An implication of this is that future air transport fuel demand will be dependent primarily on Mexican income growth, to some extent on Mexican and international air fares, and least of all on fuel price changes.

Motor Vehicles

We now analyze Mexican motor vehicle energy demand using Models 1, 2 and 3 described earlier in Section II. A constant elasticity form equation is used for Model 1, for the flexible component of Model 2, and for the investment-utilization functions of Model 3. The various grades of gasoline have been aggregated into a single measure. We also report in this section results of a reduced-form equation for diesel fuel demand. Since over the sample period hardly any automobiles used diesel as a fuel, the diesel price variable was not incorporated into the gasoline demand equation; hence no long-term substitution elasticity estimates between diesel and gasoline have been estimated for the automobile mode.

Regarding data, for gasoline we have a national time series data set 1960-79, and a pooled cross-section and time series data set covering the time period 1973-1978. For the pooled data, the thirty-two states have been

aggregated into 14 regions to accommodate the fact that a number of PEMEX distribution centers are located on the borders between adjacent states, implying that gasoline sales should be considered to be consumed also by residents of the bordering states.[8] Since the number of results obtained for motor vehicle demand is rather large, here we briefly summarize principal findings. We begin with a discussion of results for the three models based on national data, and then turn to consideration of findings using the pooled cross-section and time series data. In general, the results obtained for the motor vehicle transport mode are gratifying.

In Table 3 we present maximum likelihood estimates of the parameters and elasticities for the three models using national data, 1960-79. Parameter estimates of Model 1, based on equation (5) with first-order autocorrelation, indicate that gasoline demand is price-responsive, even in the short run. Specifically, the estimated short-run price elasticity is -0.17, with a t-statistic of 2.67; the corresponding long-run price elasticity estimate is -0.33, but a 95% confidence interval for this elasticity includes values as large as -1. The corresponding income elasticities are larger in absolute value, 0.70 in the short-run and 1.35 in the long-run.

While the above estimates appear plausible, their interpretation is somewhat ambiguous due to the very simple structure of (5). Hence we now consider estimates based on Model 2, in which the Balestra-Nerlove structural distinction between captive and flexible demand is employed. Since tests for first-order autocorrelation were negative, in Table 3 we present estimates assuming no autocorrelation is present. Note that parameter estimates on the GNP and PGAS terms can be interpreted directly as long-run income and price elasticities; thus we find that the elasticities are each about .5, but differ of course in sign. The corresponding short-run elasticity estimates for income

TABLE 3

Maximum Likelihood Parameter Estimates of Motor Vehicle Gasoline Demand Equations Based on National Data for Mexico, 1960-79

(Asymptotic t-statistics in parentheses)

Model 1

$$\ln (GAS_t) = \underset{(2.07)}{-4.181} - \underset{(2.67)}{0.171} \ln (PGAS_t) + \underset{(2.56)}{0.73} \ln (GNP_t)$$

$$+ \underset{(2.41)}{0.481} \ln (GAS_{t-1}) + \varepsilon_t$$

$$\varepsilon_t = \underset{(4.06)}{0.781}\ \varepsilon_{t-1} + \mu_t \qquad R^2 = 0.998$$

Elasticities	Short-Run	Long-Run
Income	0.70	1.35
Price	-0.17	-0.33

Model 2

$$GAS_t = \underset{(4.72)}{-1752.1} + PGAS_t^{\underset{(4.50)}{-0.492}} * GPN_t^{\underset{(8.22)}{0.478}} + \underset{(8.00)}{0.721} * GAS_{t-1} + \varepsilon_t$$

$R^2 = 0.998$ DW = 1.56

Elasticities	Short-Run	Long-Run
Income	0.15 to 0.17	0.478
Price	-0.15 to -0.17	-0.492

Model 3 (in per capita form)

Stock Equation:

$$S_t = \underset{(67.27)}{0.989} * S_{t-1} + I_t + \varepsilon_{S,t} \qquad r = \underset{(0.77)}{.011}$$

Investment Equation:

$$\ln (I_t) = \underset{(0.73)}{-15.033} + \underset{(0.70)}{1.976} * \ln (GNP_t) + \underset{(0.19)}{(d - 0.216)} * S_{t-1} + \varepsilon_{I,t}$$

$$\varepsilon_{It} = \underset{(0.56)}{0.399} * \varepsilon_{I,t-1} + \eta_{It}$$

Table 3 (continued)

Utilization Equation:

$$\ln (GAS_t/S_t) = \underset{(1.89)}{-4.348} - \underset{(3.22)}{0.236} * \ln (PGAS_t) + \underset{(0.63)}{0.152} * \ln (GNP_t)$$

$$- \underset{(2.23)}{0.338} * \ln (S_t) + \underset{(3.15)}{0.812} \ln (GAS_{t-1}/S_{t-1}) + \varepsilon_{u,t}$$

$$\varepsilon_{ut} = \underset{(0.40)}{0.202}\ \varepsilon_{u,t-1} + \eta_{u,t}$$

Elasticities	Short-Run	Long-Run
Income	0.31 to 0.39	2.76
Price	-0.24	-1.21

range from 0.15 to 0.17, while those for price range from -0.15 to -0.17. Note that, in comparison to Model 1 estimates, the short-run price elasticity estimates are virtually identical, but Model 2 income elasticity estimates are generally smaller.

As noted earlier, the model with greatest economic structure is Model 3, with separate equations determining the average rate of depreciation, the rate of investment, and the rate of utilization (GAS_t/S_t). When combined with the identity (4), this yields an aggregate demand for gasoline equation that separately identifies stock accumulation and utilization components.

A number of alternative stochastic specifications were estimated for the three-equation system, with the preferred specification being that with first-order autocorrelation in (10) and (12).[9] The estimated average rate of depreciation r in the stock equation was somewhat low at 0.011, with a 95% confidence interval including values of r up to about 4%. Parameter estimates in the investment equation are of the right sign, but in general are estimated with substantial imprecision. Note that the estimate of the partial

adjustment coefficient h [see (10)] is 0.216, but its t-statistic is only 0.19.

Statistical estimates from the utilization equation, however, are both of the correct sign and statistically significant, especially for the price coefficient. When the three equations are combined into the identity (4), the short-run price elasticity estimate for gasoline demand is about -0.24, while the corresponding long-run estimate is -1.21. For income, the estimates are again larger in absolute magnitude -- 0.31 to 0.39 in the short-run, and a rather substantial 2.76 in the long-run.

In summary, estimation of various models using national data suggest a short-run price elasticity of about -0.2, while the long-run elasticity is estimated less precisely; an "average" estimate is about -0.7. For income, such "average" elasticity estimates are about 0.3 and 1.5 in the short- and long-run, respectively.

We now move on to a discussion of results based on the pooled cross-section and time-series data. A variety of stochastic assumptions and alternative econometric procedures were utilized, with the results for Models 1 and 2 seeming to suggest that more general and more sophisticated estimation procedures yielded less precise parameter estimates. Hence for Models 1 and 2 we report results based only on the simpler stochastic specifications.

For Model 1, we estimated a regional model over time by stacking the 1973-78 observations for each region into a long vector, and constraining the coefficients to be equal across the various years and regions. Note that since the equation contains a lagged dependent variable, regional effects, which would normally be manifested through different intercept terms, in this case are "picked up" by the coefficient on the lagged dependent variable. As seen in the top rows of Table 4, the estimates of short- and long-run elasticities based on the pooled data tend to agree rather nicely with the

Table 4

Maximum Likelihood Estimates of Various Gasoline Demand Elasticities
Mexico, Regional Data, 1973-1978

Model 1 (per-capita data)

Elasticities	Short-run	Long-run
Income	0.146 (3.16)	0.900
Price	-0.168 (-2.35)	-1.035

Model 2 (Aggregate Data)

Elasticities	Short-run	Long-run
Income	0.05*	0.413 (7.25)
Price	-0.07*	-0.646 (-4.40)

*Evaluated at the midpoint of the sample.

national results; in particular, the short-run price and income elasticity estimates are -0.168 and 0.146, respectively (each is statistically significant), while the corresponding long-run estimates are -1.035 and 0.900.

Elasticity estimates based on the pooled data and Model 2 are presented in the bottom row of Table 4. Compared with regional estimates of Model 1, here we find elasticities that generally are smaller in absolute value. Specifically, the Model 2 price and income elasticity estimates are -0.07 and 0.05 in the short-run, and -0.65 and 0.41 in the long-run, respectively.

Unlike Models 1 and 2, for Model 3 our results improved with use of more general and sophisticated stochastic assumptions. Results for the investment and utilization equations are particularly interesting. Treating each year as a separate equation, specifying equal parameters across equations, different variances across years and non-zero covariances, we estimated the investment equation using the method of maximum likelihood. Initially we related I_t per capita to GNP per capita, S_{t-1} per capita, $PGAS_t$, and the price index for new cars divided by the regionally-specific consumer price index using a log-log functional form. Preliminary estimation revealed a positive but statistically insignificant coefficient on the PGAS variable; hence we deleted this variable from subsequent regressions. Preferred results are presented in Table 5.

Table 5

Maximum Likelihood Estimates of Model 3 Parameters
Mexico, Pooled Regional Data, 1973-1978

(Asymptotic t-statistics in parentheses)

Investment Equation:

$$\ln (I_{it}) = \underset{(8.09)}{3.028} + \underset{(5.96)}{0.992} \ln (GNP_{it}) - \underset{(10.16)}{0.976} \ln (S_{i,t-1}) - \underset{(32.40)}{1.340} \ln (PAUTO_t)$$

Utilization Equation:

$$\ln (GAS_{it}/S_{it}) = \underset{(3.02)}{-1.557} - \underset{(2.31)}{0.234} \ln (PGAS_{it}) + \underset{(3.76)}{0.230} \ln (GNP_{it})$$

$$- \underset{(3.82)}{0.236} \ln S_{i,t} + \underset{(12.00)}{0.756} \ln (GAS_{i,t-1}/S_{i,t-1})$$

Elasticities	Short-Run	Long-Run	Total Short-Run	Total Long-Run
Income	0.23	0.94	0.31	1.25
Price	-0.23	-0.96	-0.24	-0.96

As seen there, each of the estimated coefficients is statistically significant, and has the expected sign. Of particular interest is the estimated elasticity of new automobile sales (I_t) with respect to the real price of new cars; this estimated elasticity is -1.34, while the corresponding elasticity with respect to income per capita is virtually unity (0.992). Since in 1978 the ratio of new car sales (I_t) to the stock of cars (S_t) is about .076, it follows that stock elasticities of automobiles with respect to new car price and income per capita are about -0.10 and 0.08, respectively. These results are plausible and reassuring, and suggest that automobile demand in Mexico is affected by economic growth and automobile pricing policies.

The final gasoline demand equation we consider is the regional utilization equation of Model 3. It has been estimated using assumptions similar to that of the investment equation above, except here we constrain the variances across equations (years) to be the same, and covariances to be zero. Parameter estimates are presented in Table 5. As seen there, short-run price and income elasticities, given the stock of motor vehicles, are -0.234 and 0.230, respectively, while the long-run values, holding S_t fixed, are -0.96 and 0.94, respectively. Note, however that since increases in income per capital affect new automobile purchases, these long-run income elasticities holding S_t fixed are smaller than the income elasticities that allow the automobile stock to change; these latter "total short-run" and "total long-run" elasticities are estimated at 0.31 and 1.25, respectively.

In summary, econometric estimates of price and income elasticities for motor vehicle gasoline demand are plausible and gratifying, and suggest that Mexican motor vehicle demand for gasoline is affected in a significant manner by changes in price and income. As expected, the price and income responses are larger in the long-run than in the short-run.

Turning now to the results for the analysis of diesel demand, we first note that data were available to us only at the national level. The data sample is for the years 1960 to 1979, but data on diesel consumption by motor vehicles for the years 1974-1976 is still missing from the sample. Econometric estimation was done for functional forms similar to those of Models 1 and 2 in the gasoline demand context, with diesel fuel price in constant pesos, GNP and lagged consumption as explanatory variables. Regressions were run both in level and in per capita terms.

Using the Model 1 framework, the short-run price elasticities for diesel fuel demand were estimated to be -0.246 (t-statistic of 1.41) and -0.261 (t-statistic of 1.51) in the level and per capita forms, while the corresponding long-run price elasticity estimates are -1.106 and -1.205. The estimated income elasticities in the short-run were 0.254 (t-statistic of 1.64) and 0.253 (t-statistic of 1.27) for the level and per capita representations, while the corresponding long-run income elasticity estimates were 1.138 and 1.169. Using Model 2, as with the gasoline demand specification the price-elasticity estimates are very similar but income elasticity estimates are smaller. Specifically, the long-run price elasticity estimates are -1.065 (t-statistic of 2.89) and -0.875 (t-statistic of 2.54) for the level and per capita forms, while the corresponding long-run income elasticity estimates are 0.571 (t-statistic of 3.05) and 0.532 (t-statistic of 2.07). Note that in general, short-run price responses of diesel demand are slightly larger than those for gasoline; this may be due partly to the fact that diesel fuel is used extensively in the more cost-conscious commercial and industrial sector.

In summary, then, in this section we have reported estimates of price and income elasticities for gasoline and diesel fuel demand in the motor vehicle

portion of Mexican transportation demand for energy. As was the case with demand for fuels in the railroad and air transport sectors, income plays a very important role in affecting demand for fuels. However, in contrast to the railroad and air transport sectors, for gasoline and diesel fuel demand there appears to be a modest yet statistically significant own-price response, a response that becomes quite substantial in the long-run.

IV. CONCLUDING REMARKS

Our purpose in this paper has been to report results of a substantial empirical research effort in modelling and estimating the responsiveness of demands for energy in the transport sector of Mexico to changes in income, prices, and other variables. Throughout this research project, unless data constraints dictated otherwise, our approach has been structural in nature, rather than stochastic or reduced-form. We have done this because we believe this approach offers the greatest opportunity for better understanding and therefore planning for future energy demand growth.

Our principal finding is quite clear: In terms of affecting demand for energy quantitatively, output or income appear to be considerably more important than price, especially in the railroad and air transport sectors. For the gasoline and diesel fuels in the motor vehicle mode, however, price is of substantial importance.

For a developing country such as Mexico, such a set of findings is eminently plausible. Moreover, it suggests that one of the principal factors responsible for the less-than-anticipated growth in energy demand from the developing countries over the last several years has been the substantial decline in the rate of economic growth, a growth rate which at times has become even negative. Since energy demand growth in energy-rich Mexico is so

dependent on income growth, and since income growth in turn is impacted considerably by developments in the Mexican energy supply system, we believe that analysis of energy-economy interactions in the Mexican economy is a particularly fascinating, important, and challenging topic for future research.

FOOTNOTES

1. SEPAFIN, Programa de Energia, Metas a 1990 y Proyecciones al Ano 2000, (Balances de Energia y Estadisticas Complementarias), Mexico, 1981, pp. 15-20, 30-31, and 44-45.

2. For the results reported here, we used the Time Series Processor program, Version 3.5, on the Digital VAX computer.

3. Pietro Balestra, The Demand for Natural Gas in the United States: A Dynamic Approach for the Residential and Commercial Market, North-Holland Publishing Co., Amsterdam, 1967. Also E.R. Berndt and G.C. Watkins, "Demand for Natural Gas: Residential and Commercial Markets in Ontario and British Columbia," Canadian Journal of Economics, February 1977.

4. For a similar model, see Robert S. Pindyck, The Structure of World Energy Demand, Cambridge: MIT Press, 1978.

5. The shift from steam to diesel was virtually completed by 1968. In 1960, diesel accounted for 28% of total consumption, while by 1968 the same share was 99.6%. Source: Memorandum from Oficina de Asesores del C. Presidente de la Republica.

6. Even though most of the variables are available since 1960, the time series for PKDOM begins only in 1969.

7. Indeed, at times a portion of the direct fuel payments to PEMEX have been reimbursed to the airlines.

8. Region 1: Baja California Sur and Norte; Region 5: Yucatan, Quintana Roo and Campeche; Region 6: Tabasco and Chiapas; Region 8: Calima, Jalisco, Aguascalientes, Guanajuato and Queretaro; Region 10: Chihuahua, Durango and Coahuila; Region 11: Nuevo Leon and Tamaulipas; Region 14: Veracruz, Puebla, Hidalgo, Tlaxcala, Mexico, Morelos, Guerrero and The Distrito Federal; Regions 2, 3, 4, 7, 9, 12, and 13: Sonora, Sinaloa, Nayarit, Oaxaca, Michoacan, Zacatecas and San Luis Potosi, respectively.

9. Even though t-statistics on the autocorrelation parameters indicate lack of statistical significance, joint tests based on the likelihood ratio criterion suggested the presence of statistically significant autocorrelation. The difference in inference is likely due to nonlinearities in the specification.