A survey of energy demand elasticities in support of the development of the NEMS

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in Support
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by

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Table of Contents

List of Tables

Introduction

With NEMS, there has been increased interest in modeling energy markets and a resurgent interest in energy elasticities of demand. Since such elasticities are often a convenient way to summarize the responsiveness of demand to such things as own prices, cross prices, income, or other relevant variables, a substantial amount of resources have been devoted to estimating demand elasticities, at various levels of aggregation using a variety of models. The goal of this project is to survey these works for the U.S. on energy demand elasticities, do a critical analysis of them, attempt to come up with summary elasticities, discuss the scope and breadth of the work that has been done, and make suggestions for further research.

A variety of surveys have already been done on energy demand or related transportation demand. They include Taylor (1975) and (1977), Bohi (1981), Energy Modeling Forum (1981), Bohi and Zimmerman (1984), Kirby (1983), Kouris (1982), Dahl (1986), Dahl and Sterner (1991), Oum et al. (1992), Goodwin et al. (1992), and Dahl (1992). I begin by summarizing these earlier demand surveys and continue by analyzing the more recent work that has been done on energy demands by fuel in the US. The focus of the analysis is on price and income elasticities and the effects of the following issues on them: static versus dynamic models, reduced form versus structural models, single equation versus multiequation models, data type and periodicity, level of aggregation, and estimation technique.

I begin Section I with an overview of demand modeling approaches that have been taken. In Sections II through VI, I consider energy demand price and income elasticities for total energy, electricity, natural gas, coal, oil, and oil products, respectively. Each sections begins with the specific issues that are involved in modeling that market and the results of earlier surveys followed by a summary and analysis of more recent work in the area.

In Section VII and VIII, I consider the components of the demand for gasoline and the demand for transportation, and energy substitutability. I include overall conclusions and summary elasticities and make suggestions for continued research in Section IX.

I. Overview of Energy Demand Modeling Techniques

Energy and energy products may have been subjected to more demand studies than any other goods and factors. Since 1973, and even before, a large number of energy demand studies have been done at various levels of aggregation, on various time periods, and using various models for all sorts of energy products. These models have a variety of uses including forecasting, policy analysis, evaluating structural change, and understanding adjustment processes. Different models may be appropriate given the resources at hand, the available data, and the purpose of the model.

The simplest models used are one equation or reduced form models, which have the advantage of being simple and undemanding in terms of data requirements. The simplest of these models is a static model that regresses the quantity of the energy product (E) on the price of the fuel (P) and some measure of income (Y).

(1) $$E = ß_o + ß_1 P + ß_2 Y$$

These models can be made more complicated by adding other variables to represent demographics, weather, and may include the prices of competing fuels to measure substitution across fuels. All such models which do not include any lagged variables and do not include the stock of energy using appliances I will call static models (Stat).

To the simple static model we could add some measure of the stock of energy using appliances or equipment (Sk):

(2) $E = ß_o + ß_1 P + ß_2 Y + ß_3 Sk$

These models, which include a stock of energy using equipment, will tend to capture short run adjustments in energy demand and will be called static stock models. (StatSk) Neither of these models is likely to capture total long run adjustments. Although (1) might do so if adjustment time is very short or cross sectional data is used, whereas (2) might do so if adjustment time is short, the market is saturated, stock is measured as number of units owned, and all adjustment is in utilization or in changing the characteristics of the stock. Elasticities from model (1) will be included in Tables in the column under Pir and Yir to indicate their static nature, while elasticities from model (2) will be included in the Tables under Psr and Ysr. Their precise interpretation, however, may depend on the data and model type.

Linear or linear in the logs forms are often employed in these simple models with the choice of the functional form being made by the researcher. On occasion the functional form is subject to testing, a practice I would urge on more researchers. A simple test that can be employed uses the Box Cox (BxCx) function. For example, the Box Cox formulation for equation (1) would be

(3) $$\frac{(E^{\lambda}-1)}{\lambda} = ß_o + ß_1 \frac{(P^{\lambda}-1)}{\lambda} + ß_2 \frac{(Y^{\lambda}-1)}{\lambda}$$

When $\lambda = 1$ we have a linear function.
When $\lambda = 0$ we have a log function.
When $\lambda = -1$ we have a function in the inverses of the variables.
When λ = none of the above we get the Box Cox function.

Distinguishing between short run and long run is typically done in three ways in the reduced form framework. The first way is to associate strict cross sectional (C) with long run adjustments, particularly, if prices and incomes are very different across the cross sections. The cross sections that are included in this survey at the aggregate level include subregions of the US designated as: states (-s), other regional data such census regions (-r), urban areas (-ur) which may come from data on Standard Metropolitan Statistical Areas, nonurban or rural areas (-ru), and utilities (-ut). The advantage of greater price and income variation in cross sections has two disadvantages. First we may be capturing locational bias with energy intensive industries locating in cheap energy areas. Hence, for industrial demand or total energy demand we may find price elasticities biased towards being too elastic if prices in all areas were to increase simultaneously. A second bias may result from other non included variables in the model that influence energy demand. If these variables are correlated with price or income, their affects will be attributed to price and income by the estimating model with the direction of the bias uncertain and depending on the relationships between the included and excluded variables. Hartman (1979) feels that because of these locational and structural differences, cross sectional data overstates elasticities, particularly for price.

If the data is at a more disaggregate level, it is designated as (-h) for households or -plnt for plant data. Such data has the advantage of capturing more detailed adjustment within individual decision units for doing micro analysis. However, it only captures the behavior of existing units and there is so much variation across units, it is not clear whether it is useful at the macro level for aggregate forecasting and policy analysis.

Time Series (T), particularly short ones, are more likely to capture short run effects. The disadvantage of short time series is often inadequate changes in the variables or not enough observations. Longer time series may provide more changes in the variables and more observations, but may also suffer from structural change.

Under these interpretations, under the best circumstances, cross section time series (CT) would give us the advantage of more variation across a much larger data set, which would measure some mix of long and short run effects. However, our CT also has the potential disadvantages of both types of data.

The data can be further divided in its periodicity. Annual data is by far the most commonly used. Quarterly (q) and monthly (m) data can dramatically increase the sample size. However, many series are not available this often and there are problems of seasonality that need to be taken into consideration. In the Tables when no periodicity is mentioned under type, the data is annual with monthly and quarterly data indicated. (e.g. Tq would be time series quarterly data.)

A second way of distinguishing long run from short run using CT data is described in Baltagi and Griffin (1983). Using their methodology the estimation equation is:

(4) $E_{it} = ß_o + ß_1 P_{it} + ß_2 Y_{it}$.

The across country variation will be associated with the long run and will be obtained by regressing the means of each countries quantity on the means of each countries prices and incomes and any other variables that are in the model or:

(5) $E_{i.} = ß_o + ß_1 P_{i.} + ß_2 Y_{i.}$

We will designate this model as being static on the means (StatMn). Within country variation will be associated with the short run and will be captured by a pooled regression where each countries quantities and explanatory variables are deviated from their respective means or

(6) $(E_{it} - E_{i.}) = ß_1 (P_{it} - P_{i.}) + ß_2 (Y_{it} - Y_{i.})$

This model, which will be designated as static on deviations from the mean (Statdv), is equivalent to running a pooled regression in which a dummy variable is allowed for each country.

The third, and probably most ubiquitous technique for separating out short and long run effects on reduced form single equation models, is to make the model dynamic by adding lagged values to the model. The simplest and most common way of doing this is use a lagged endogenous variable. Although I label these models as lagged endogenous models (LE), they have also been labelled stock adjustment, partial adjustment, adaptive expectations, Koyck, or geometric lag models after the economic process represented, the originator, or the shape of the lag. The simplest lagged endogenous model is:

(7) $E_t = ß_o + ß_1 P_t + ß_2 Y_t + ß_3 E_{t-1}$

The advantage of this model is that it is simple and flexible to use with an intuitively appealing lag shape. The disadvantages include a fairly restrictive shape for the lag constrained to be the same for all variables.

Further, collinearity between the lagged endogenous variable and the included current values of the other variables can render rather erratic estimates.

There are more flexible forms that nest the lagged endogenous model within a form that allows an inverted V lag as well. The two standard procedures for doing this are (LE^1):

$$(8)\quad E_t = ß_o + ß_1P_t + ß_2P_{t-1} + \delta_1Y_t + \delta_2Y_{t-1} + \sigma E_{t-1}$$

and (LE^2):

$$(9)\quad E_t = ß_o + ß_1P_t + \delta_1Y_t + \sigma_1E_{t-1} + \sigma_2E_{t-2}$$

Although these lags are less restrictive than the LE model they seem to suffer an even greater tendency towards multicollinearity.

A more general way to make a simple model dynamic is to put in lags on some or all of the independent variables. These models will be called distributed lag models (DL) and can be represented as:

$$(10)\quad Q_t = ß_o + \Sigma_i ß_i P_{t-i} + \Sigma_i \delta_i Y_{t-i}$$

This model has the advantage of being flexible and allowing different lags on different variables. In practice, however, there is often so much collinearity across time for the variables that the model does not perform very well and lags as long as adjustment might reasonably be expected to occur can rapidly chew up our degrees of freedom. If the lags are constrained to be on a polynomial to help deal with problems of collinearity and loss of degrees of freedom, the model will be PDL.

Each of the above dynamic approaches only indirectly accounts for the fact that energy is an indirect demand that is always consumed with energy using equipment. Often this equipment is very long lived and therefore complete adjustment can take a considerable amount of time. However, information on the stock may be unavailable and expensive to collect. Two early approaches to deal with a nonavailable stock of appliances are those by Houthakker and Taylor (1970) and by Balestra and Nerlove (1967).

The Houthakker and Taylor model (1970) (HT) is designed to deal with demand for a durable good where purchases of the good add to an existing stock or to a nondurable were the existing stock of the good is considered the habit of using the good with additional purchases adding to the stock of habits. It is not well designed to deal with a good where the purchased good is used with a stock of another good as in the case of energy. Nevertheless, the model is used occasionally in the energy context. where we must remember that the stock variable in the initial model is not the stock of energy using appliances but the habit formation variable. In their model, the demand for an energy source E is a function of price, income, and the stock of habitual energy use:

$$(11)\quad E = ß_o + ß_pP + ß_yY + ß_{sk}\,Sk \Rightarrow Sk = (E - ß_o - ß_pP - ß_yY)/ß_{sk}$$

Then the change in the habitual energy stock is equal to E minus the depreciation of the habit (rSk) or

$$(12)\quad \Delta Sk = E - rSk$$

Changes in energy consumption are:

$$(13)\quad \Delta E = ß_p\Delta P + ß_y\Delta Y + ß_{sk}\Delta Sk$$

Plugging in for ΔSk from (12) into (13) we get

$$(14)\quad \Delta E = ß_p\Delta P + ß_y\Delta Y + ß_{sk}\ (E - rSk).$$

Plugging Sk from (11) into (14) we get

$$(15)\quad \Delta E = ß_p\Delta P + ß_y\Delta Y + ß_{sk}\ (E - r(E - ß_o - ß_pP - ß_yY)/ß_{sk}).$$

Rearranging and solving for E gives us the estimating equation:

$$(16)\quad E = ß_or/(r-ß_{sk}) + ß_p/(r-ß_{sk})\Delta P + ß_y/(r-ß_{sk})\Delta Y +$$

$$rß_p/(r-ß_{sk})P + rß_y/(r-ß_{sk})Y + 1/(r-ß_{sk})\Delta E.$$

This model can be estimated by OLS, but if you want to recover the coefficient $ß_{sk}$ it will have to be estimated by a nonlinear approach as the model is over identified. The interpretation of $ß_{sk}$ is as follows. In the long run E and Sk are both constant. Let them be E* and Sk*. Then

$$(17)\quad E^* = ß_o + ß_pP + ß_yY + ß_{sk}Sk^*$$

and the change in the stock is zero or

$$(18)\quad ??\Delta Sk = E^* - rSk^* = 0 \Rightarrow E^* = rSk^*$$

Deviation of current purchases of the good from the long term equilibrium equals

$$(19)\quad E - E^* = ß_o + ß_pP + ß_yY + ß_{sk}Sk - (ß_o + ß_pP + ß_yY + ß_{sk}Sk^*)$$

$$= ß_{sk}(Sk-Sk^*)$$

and is proportional to the difference of the current stock or habit of using the good from its long term level. If $ß_{sk}$ is negative, then current purchases are above the long-term level when the stock is below its long-term level which is the case of stock adjustment model. If $ß_{sk}$ is positive, then current purchases are above the long-term level when the stock is above its long-term level which is the case of habit formation. The variable r is the rate of depreciation if the good is a consumer durable. In the nondurable case as in the energy context it has a more nebulous interpretation.

Equations using this modeling approach will be designated as HT, but as mentioned above, this model is not well designed for nondurable goods used in conjunction with durable goods as is the case for energy although it has been used on occasion. Further, there is often a lot of correlation between the current variables and the change variables so the econometric results are poor as well.

Balestra and Nerlove (1967) design a model to indirectly take into account the stock of energy using equipment and apply their model to the demand for natural gas. They begin with the assumption that demand for natural gas may be different if you already have the energy using appliance than if it is a new demand. Suppose the new demand for natural gas is the following linear function of price and new energy demand:

$$(20)\quad Ng^*_t = ß_o + ß_1\ P_t + ß_2\ E^*_t$$

Let E_t be the total demand for energy and Sk_{t-1} be the stock of energy using appliances and λ_{t-1} be the rate of utilization. Then $E_{t-1} = \lambda_{t-1} Sk_{t-1}$. With constant depreciation r only $(1-r) Sk_{t-1}$ of the appliance will be present in period t and rate of fuel use associated with it will be

(21) $\lambda_{t-1} (1-r) Sk_{t-1}$

If the depreciation of the appliance stock is r, then committed fuel use in period t is

(22) $\lambda_t (1-r) Sk_t$

New fuel demand E^*_t is the difference between total demand for fuel and committed demand for fuel or:

(23) $E^*_t = \lambda_t Sk_t - \lambda_{t-1} (1-r) Sk_{t-1}$

If the fuel utilization rate λ is constant, we can write new demand as:

(24) $E^*_t = E_t - (1-r) E_{t-1} = (E_t - E_{t-1}) + r E_{t-1}$

which is the incremental change in consumption plus depreciation. Similarly the new demand for natural gas can be defined as

(25) $Ng^*_t = Ng_t - (1-r_g) Ng_{t-1}$

Where r_g is the depreciation on natural gas using appliances, which may be different from the overall depreciation on all energy using equipment (r). Solving for Ng_t from (25), plugging in for Ng^*_t from (20) and E^*_t from (24) we get

(26) $Ng_t = ß_o + ß_1 P_t + ß_2 (E_t - (1-r) E_{t-1}) + (1-r_g) Ng_{t-1}$

Total fuel consumption is found to be a function of population (N) and income (Y) in the original Balestra Nerlove formulation and I will follow their formulation. Alternatively, the price of energy might be included here as well and would be included in the same way as population and income.

(27) $E_t = \delta_o + \delta_1 N_t + \delta_2 Y_t$

Plugging E from (27) into Ng from (26) gives

(28) $Ng_t = ß_o + ß_1 P_t + ß_2 [(\delta_o + \delta_1 N_t + \delta_2 Y_t) - (1-r)(\delta_o + \delta_1 N_{t-1} + \delta_2 Y_{t-1})] + (1-r_g) Ng_{t-1}$

Collecting terms we get:

(29) $Ng_t = ß_o + ß_2 \delta_o - ß_2 (1-r) \delta_o + ß_1 P_t + ß_2 \delta_1 N_t - ß_2 (1-r)\delta_1 N_{t-1} + ß_2 \delta_2 Y_t + ß_2 (1-r)\delta_2 Y_{t-1} + (1-r_g) Ng_{t-1}$

and rearranging:

$$(30) \quad Ng_t = ß_o + ß_2\ \delta_o - ß_2(1-r)\ \delta_o + ß_1\ P_t + ß_2\ \delta_1\ \Delta N_t +$$

$$ß_2\ r\delta_1\ N_{t-1} + ß_2\delta_2\ \Delta Y_t + ß_2\ r\ \delta_2\ Y_{t-1} + (1-r_g)\ Ng_{t-1}$$

This equation can be estimated by OLS but since it is over identified, retrieving all the separate coefficients requires a nonlinear estimation procedure. Models that are estimated using model (30) will be called Balestra Nerlove models (BN). Once estimated we can compute elasticities for new and old gas demand in the following way:

The elasticity for new demand is:

$$(31)\ \varepsilon_p = (\partial Ng^*/\partial P)(P/Ng^*) = ß_1\ (P/Ng^*)$$

Where: $Ng^*_t = Ng_t - (1-r)\ Ng_{t-1}$ and is often evaluated at the mean of the data and the elasticity for old demand which is smaller is:

$$(32)\ \varepsilon_p = (\partial Ng/\partial P)(P/Ng) = ß_1\ (P/Ng)$$

Other ways of making models dynamic are typically used in the context of more complicated multiequation models and will be discussed below. Before going on to multiequation models, one last issue that has been studied in a single equation reduced form context is reversibility or whether changes in quantity demanded from an independent variable increasing are equal but opposite in direction from the same variable decreasing.

Dargay (1990) measures reversibility using three different price definitions. P+ is the sum of all price increases from time = 0. It increases in periods when prices rise but stays constant when prices fall and is defined as:

$$(34) \quad P+_t = \Sigma^t_{i=0}\ [P_i - P_{i-1}] \text{ for all } P_i > P_{i-1}.$$

It P+ and P are included in the model, then the coefficient on price decreases is the coefficient on P and the coefficient on price increases is the coefficient on P+ plus the coefficient on P.

A second way of representing this same system would be to have a P+ and a P- in the equation where P- represents the cumulative price decreases or:

$$(35) \quad P-_t = \Sigma^t_{i=0}\ [P_i - P_{i-1}] \text{ for all } P_i < P_{i-1}.$$

Alternatively elasticities might only be different if price rises higher than the previous maximum. To test this alternative a new variable Pmax, which is the maximum price to date, can be used where:

$$(36) \quad Pmax_t = \max\ \{P_o, \ . \ . \ . \ P_t\}$$

Gately (1992a) uses two further cumulative price measures. In Pcut, only the portion of a price cut below a cut the previous period is accumulated, or:

$$(37) \quad Pcut_t = \min\ \{0,\ \Sigma^t_{i=0}\ ((P_{i-1} - Pmax_{i-1}) - (P_i - Pmax_i))\}$$

For price recovery (Prec), only the portion above a price increase the period before is accumulated or:

(38) $Prec_t = \max \{0, \Sigma^t_{i=0} ((P_{i-1} - Pmax_{i-1}) - (P_i - Pmax_i))\}$

Multi Equation Models Static reduced form models gave way to dynamic reduced form models. These in turn gave way to models gradually becoming more sophisticated in their behavioral specifications requiring multiequation models. I will consider four types of multiequation models.

1. A popular set of models are those that investigate interfuel substitution using some kind of energy share equations (Sh) or other systems of equations such as a Generalized Leontief. Flexible functional forms have been most popular in this context and have been used to investigate questions of substitution between total energy demand and other factors such as labor as well as the choice between energy products. This approach has the advantage of putting in cross equation restrictions implied by producer or consumer theory. However, since these models are typically estimated on aggregate data, it is not clear whether such restrictions have any meaning.

2. Another type of simultaneous system includes structural models with equations describing the use of the stock of energy using equipment as well as the purchase decisions for the stock of energy using equipment. These types of models have become increasingly popular as household surveys have provided data on appliances and fuel choices.

3. Expenditure system models (Ex) consider consumer expenditures on goods simultaneously and also allow restrictions to be placed on the estimated equations implied by consumer theory. However, since they require data on all expenditures with energy specifically broken out from other data expenditures, they have not been nearly as popular as the above translog models where separability of a subset of energy products is assumed. Also since they are typically estimated on aggregate data, as for the substitution models, there is the obvious question of whether these restrictions have any meaning in an aggregate context.

4. Last are true simultaneous systems models representing a particular market. In these models, supply and demand are estimated simultaneously or at least one equation in the model is estimated using exogenous variables from the other equation or equations. Although most demand models are estimated with a fleeting wave at supply in passing, a few models do consider the supply side more explicitly. The demand equations typically fit into the other categories of models but are estimated simultaneously.

I begin with the interfuel substitution share models. In these models, a total energy demand equation model is typically used along with shares for each of the different energy products and the whole system is estimated using seemingly unrelated regressions. Let the share (Sh_i) for fuel i equal (E_i/E), which is typically modeled as a function of the fuel prices of the i different energy products (P_i). While the demand for total energy is a function of the price of energy (P), which is some weighted average of the fuel prices (e.g. $P = ß_1P_1 + ß_2P_2 + \ldots ß_n P_n$) and other factors of production and output. The elasticity from the share equations shows the change in fuel consumption holding output constant and is sometimes referred to as the partial elasticity.

The total demand elasticity would be computed by this share or partial elasticity plus the change in the total energy demand. The share elasticity is:

(39) $\partial \ln(E_i/E)/\partial \ln P_i = \partial \ln(E_i)/\partial \ln P_i - \partial \ln(E)/\partial \ln P_i$

Where $\partial \ln(E)/\partial \ln P_i = \partial \ln(E_i)/\partial \ln P \ \partial \ln P/\partial \ln P_i$. Therefore the total fuel price elasticity can be computed from the share and total energy elasticities as the total fuel elasticity

$$(40)\quad \partial \ln(E_i)/\partial \ln P_i = \partial \ln(E_i/E)/\partial \ln P_i + \partial \ln(E)/\partial \ln P \ \partial \ln P/\partial \ln P_i$$

In the simplest share model (Sh) either a linear or a log linear form is chosen for each of the equations. But soon the most popular approach to estimating these types of systems was to use a flexible functional form such as the translog (Tl). Where the share is the share of expenditures (Ex) on the ith energy form. To model consumers in this approach, we begin as in Pindyck (1980) with the indirect utility function

$$(41)\quad \text{Ln } V = \alpha_o + \Sigma_k\ \alpha_k \ln(P_k/Ex) + \frac{1}{2}\ \Sigma_k\ \Sigma_j\ \beta_{kj} \ln(P_k/Ex)\ln(P_j/Ex).$$

This function is considered to be a second order Taylor approximation of any indirect utility function. The estimating equations become the budget shares of goods, which for the jth good is equal to: (summations always run to m, the number of goods).

$$(42)\quad Sh_j = (P_j\ X_j)/Ex = \frac{(\alpha_j + \Sigma_i\ \beta_{ij} \ln(P_i/Ex))}{(\Sigma_i\ \alpha_i + \Sigma_i\ \Sigma_k\ \beta_{ik} \ln P_i/Ex)}$$

Typically shares are most often included on energy subchoices such as oil, coal, gas, and electricity. From this formulation partial own, cross price, and income elasticities can be computed.

Income elasticity of demand for good j is

$$(43)\quad \varepsilon_{jy} = 1 + \frac{\Sigma_i\ \Sigma_k\ \beta_{ki} - \Sigma_i\ (\beta_{ji}/Sh_j)}{(\Sigma_i\ \alpha_i + \Sigma_i\ \Sigma_k\ \beta_{ik} \ln P_i/Ex)}$$

The own price elasticity for good j is

$$(44)\quad \varepsilon_{jj} = -1 + \frac{(\Sigma_i\ \Sigma_k\ \beta_{ki} - \Sigma_i\ (\beta_{ji}/Sh_j)}{(\Sigma_i\ \alpha_i + \Sigma_i\ \Sigma_k\ \beta_{ik} \ln P_i/Ex)}$$

The cross price elasticity of demand is

$$(45)\quad \varepsilon_{ji} = (\beta_{ji}/Sh_j - \Sigma_k\ \beta_{ki})\ /\ (\Sigma_i\ \alpha_i + \Sigma_i\ \Sigma_k\ \beta_{ik} \ln P_i/Ex)$$

These elasticities are made assuming that expenditure Ex stays constant or if applied to a fuel subaggregate, like energy which is composed of various fuels, it assumes that the expenditure on energy (ExE) is constant. To get total elasticities $\varepsilon_{jj}*$ for a subaggregate j, we use the following formula:

$$(46)\quad \varepsilon_{jj}* = \varepsilon_{jj} + \varepsilon_{jExE}(1+\varepsilon_{EE})$$

Where ε_{jExE} is the energy expenditure elasticity for j, or percentage change in consumption of j for a percentage change in expenditure on energy. To get the total cross elasticity for fuel j we use:

(47) $\varepsilon_{ji}{*} = \varepsilon_{ji} + Sh_i\varepsilon_{jExE}(1+\varepsilon_{EE})$

Under the assumption of homotheticity $E_{jEx}{*}=E_{ExE}$.

For the firm, the translog model becomes somewhat simpler. Following Griffin (1979), the indirect cost function C is the following function of input prices (P_i):

(48) $LnC = ß_o + \Sigma_i\ ß_i{*}\ln(P_i) + 1/2\ \Sigma_i\ \Sigma_j\ ß_{ij}{*}\ln(P_i)\ln(P_j)$

From the cost function, the share equation to be estimated can be derived as:

(49) $Sh_i = \partial \ln C/\partial \ln(P_i) = ß_i + \Sigma_j\ ß_{ij}\ \ln P_j$

We compute elasticities from these estimated equations from the following:

(50) $\sigma_{ij} = (ß_{ij} + Sh_iSh_j)/Sh_iSh_j$ for all $i \neq j$

(51) $\sigma_{ii} = (ß_{ii} + Sh_i^2 - Sh_i)/Sh_i^2$

The own and cross price elasticities are

(52) $\varepsilon_{ij} = \sigma_{ij}\ Sh_j$ for all i,j.

This function has been used for the aggregate economy where the factors of production are typically Capital (K), Labor (L), Energy (E), and Materials (M). (TlKLEM). If the cost function is for some subaggregate such as energy which consists of shares for coal, oil, natural gas, and electricity (TlCONgEl) these elasticities are interpreted as partial elasticities or the changes in the share of each subfuel holding total energy consumption constant. If both a TlKLEM model and a TlCONgEl have been estimated then the total elasticity say for coal $\varepsilon_{cc}{*}$(holding total output constant) would be estimated as

(53) $\varepsilon_{cc}{*} = \varepsilon_{cc} + (\partial \ln Coal/\partial \ln E)(\partial \ln E/\partial \ln P)(\partial \ln P/\partial \ln Pc)$

With linear homogeneity this reduces to

(54) $\varepsilon_{cc}{*} = \varepsilon_{cc} + Sh_e\ \varepsilon_{ee}$.

A second function that has been used for share equations is the logit equation. This model has been used for shares of energy, but its most popular application has been in structural models of appliance choice. The relevant equations in the logit model are developed and discussed in Considine (1989). He begins with share equations as:

(55) $Sh_i = \exp(ß_i + \Sigma_j\ ß_{ij}\ln P_j)/\Sigma_i\ (\exp(ß_i+\Sigma_j\ ß_{ij}\ln P_j))$

Where the own elasticity is

(56) $\varepsilon_{ii} = \partial \ln Sh_i/\partial \ln P_i + Sh_i - 1$

and the cross price elasticity is

(57) $\varepsilon_{ik} = \partial \ln Sh_i / \partial \ln P_k + Sh_j$

606
The logit cost share model collapses to a constant elasticity of substitution (CES) model for two inputs or when the elasticities of substitution are all equal. Producer theory constraints can not hold globally but are constrained to hold around specific shares, Sh_i*, which are typically chosen to be the shares at the mean of the data. Under these constraints the estimation equation for the ith input used in the logit model are as follows for n inputs

$$(58)\quad \mathrm{Ln}(Sh_i/Sh_n) = (ß_i - ß_n) + [\Sigma_{k \neq i, k \neq n} (ß_{ik} Sh_k^*) + Sh_{i*} + Sh_{n*}] \ln(P_i/P_n) + [\Sigma_{k \neq i, k \neq n} (ß_{ik} - ß_{kn}) Sh_k^*] \ln(P_k/P_n)$$

With own and cross price elasticities equal to

$$(59)\quad \varepsilon_{ik} = ß_{ik} - \Sigma_j Sh_j^* ß_{jk} + Sh_k$$

$$(60)\quad \varepsilon_{ii} = ß_{ii} - \Sigma_j Sh_j^* ß_{ji} + Sh_i - 1$$

The above three approaches looked at interfuel substitution from share equations. An alternative formulation that has been used is the Generalized Leontief (Gl). In this model, following Dowd et al. (1986) for the linear homogeneous case, the cost function conditional upon output Q is:

$$(61)\quad C = Q(\Sigma_i \Sigma_j ß_{ij}(P_i^{.5} P_j^{.5}))$$

From Shepherds lemma $X_i = \partial C/\partial P_i = Q\ (\Sigma_j ß_{ij}(P_j^{.5}/P_i^{.5}))$, which can be estimated using

$$(62)\quad X_i/Q = (\Sigma_j ß_{ij}(P_j^{.5}/P_i^{.5}))$$

Factor demand elasticities are:

$$(63)\quad \varepsilon_{ii} = (\partial X_i/\partial P_i)(P_i/X_i) = \frac{ß_{ij} \Sigma_i \Sigma_j P_i^{.5} P_j^{.5} \Sigma_j ß_{ij} P_j^{1.5} P_i^{-0.5}}{2 X_i X_j P_i^{.5} P_j^{.5} Q \Sigma_i \Sigma_j ß_{ij} P_i^{.5} P_j^{.5}}$$

$$(64)\quad \varepsilon_{ij} = (\partial X_i/\partial P_j)(Pj/Xi) = \frac{-\Sigma_j ß_{ij} P_j^{0.5}}{2X_i^2\ P_i^{1.5}} \frac{\Sigma_i \Sigma_j P_i^{.5} P_j^{.5} \Sigma_j ß_{ij} P_i^{-0.5} P_j^{1.5}}{Q \Sigma_i \Sigma_j ß_{ij} P_i^{.5} P_j^{.5}} \quad \text{for } i \neq j$$

There are a few functional forms that have simpler functional forms nested within them. Mountain et al. (1989) discuss the quadratic quasi Cobb Douglas QQCD which has the CES, Cobb Douglas, Leontief, and some quadratic forms as subcases. Following their discussion, the demand system for the ith input with l as numeraire is written as:

$$(65)\quad \ln(X_{it}/X_{lt}) = ß_i + \Sigma_j ß_{ij} \ln(P_{jt}/P_{lt}) + 1/2\ \Sigma_j \Sigma_m ß_{ijm} \ln(P_{jt}/P_{lt})$$

For the CES case: $ß_{ijm}=0$, $ß_{ii}=ß_{jj}$, $ß_{ij}=ß_{ji}$, for all i,j, and m.

For the Leontief case: $ß_{ijm}=0$, $ß_{ij}=0$, for all i,j, and m.

For the Cobb Douglas case: $ß_{ii} = -1$ for all i, $ß_{ij}=0$ for all $i \neq j$, and $ß_{ijm} = 0$ for all i,j,m. See the original paper for additional linear and quadratic cases.

ßerndt and Khaled (1979) develop the generalized Box Cox (GBxCx). For their linear homogenous cost function:

$$(66) \quad C = [1 + \lambda\{ß_o + \Sigma_i\ ß_i P_i(\lambda) + 1/2\ \Sigma_i\ \Sigma_j\ ß_{ij}\ P_i(\lambda) P_j(\lambda)]^{1/\lambda}\ Q$$

where $P_i(\lambda) = (P_i^{\lambda/2}-1)/(\lambda/2)$.

In this function, we have the generalized square root quadratic (GSRQ) when $\lambda = 2$; the generalized Leontief (Gl) when $\lambda = 1$, and the translog (Tl) is obtained in the limit when $\lambda \Rightarrow 0$ and $\Sigma_i\ ß_j = 1$.

For more complex formulations including technical change and nonconstant returns to scale and nonhomotheticity see the original article. The estimating formula for the simplest of GBxCx is

$$(67) \quad X_i/Q = (2/\lambda)\ ß_{ij}(P_i/P_j)^{(\lambda/2)}$$

with symmetry requiring $ß_{ij}=ß_{ji}$.

Guilkey et al. (1983) report results of tests comparing some of the above functional forms and come to the following conclusions. Tl performs better at elasticities of substitution close to 1, Gl performs better at elasticities of substitution close to 0. Both forms perform better when there is less dispersion across the dependent variables in the estimating equations. The Tl performs better than the Gl when the partial elasticities of substitution have similar large values, but the Gl performs better when the elasticities of substitution have similar small values. The Tl performs fairly well as technologies increase in complexity as long as the partial elasticities of substitution do not depart substantially from 1. The Tl outperforms the other two forms tested (the Gl and Extended Generalized Cobb Douglas (EGCD)) except when partial elasticities of substitution are small and positive.

Moving on, various approaches have been used to make these more flexible multi equation approaches dynamic. Berndt et al. (1981) consider three generations of dynamic models. In the simplest first generation cases, lagged endogenous or other variables have been included as in the above reduced form models. In later generation models outputs are separated into fixed and variable.

They discuss two second generation models. In the first by Nadiri and Rosen (1973), the Koyck model is generalized to multiequations in which disequilibrium in one factor market is related to disequilibrium in another factor market. In this approach if x_t is a vector of inputs and $\mathbf{x}^*_t$ is a vector of desired inputs then

$$(67) \quad \mathbf{x}_t - \mathbf{x}_{t-1} = ß\ (\mathbf{x}_t^* - \mathbf{x}_{t-1})$$

Where ß is an n x n partial adjustment matrix. $\mathbf{x}_t^*$ is chosen to be some function of the prices of factors and can be one of the functional forms above such as Tl or Gl. In a slight modification of this model, Lucas (1967) assumes an adjustment matrix only for the quasi-fixed factors such as capital and makes the ß matrix a function of variables such as the discount rate and a technology parameter.

Another second generation approach discussed by Berndt et al. (1981) is to estimate a restricted cost function with variable factors represented by price (P_v), quasifixed factors represented by quantities (X_f) and with output (Y) included. Or

(68) $C = C(P_v, X_f, Y)$

Estimating this cost or the related demand or share equations gives us the short run elasticities. From the restricted cost function one can also derive the long run elasticities from the long run relationship that the negative of the price of the fixed factor ($-P_{xf}$) equals the partial derivative of the restricted cost function or

(69) $-P_{xf} = \partial(C(P_v, X_f, Y))/\partial X_f$

By solving this equation for desired fixed factor (X_f*), long run elasticities can be obtained. I will refer to this type of second generation model by the number 2. For example, in the translog formulation this model would be designated as Tl2. This model allows us to capture short run, long run and capacity utilization, but does not allow us to capture an adjustment path.

In a third generation model, the change in the fixed variable ($\dot{X}_f$) is added to the restricted cost function to represent the cost of adjustment or:

(70) $C = C(P_v, X_f, \dot{X}_f, Y)$

This function can be estimated directly or factor demand or factor share equations can be estimated depending on the functional form.

From dynamic cost minimization, the time path of capital accumulation must satisfy

(71) $-C_{X_f} - r\ _{\dot{X}_f} - C P_{X_f} + C_{\dot{X}_f \dot{X}_f} \ddot{X}_f + C_{X_f \dot{X}_f} \dot{X}_f = 0$

Where C is the estimated restricted cost function and r is the interest rate, $_f$ and are the first and second derivative of the fixed factor with respect to time, which in long run equilibrium will be zero. I will designate these third generation models by 3. For example, in the generalized Leontief case the model would be Gl3. Examples of this last approach can be seen in Berndt and Watkins (1977), Pindyck and Rotemberg (1983), Walfridson (1987), Morrison (1988), and Kolstad and Lee (1992). I refer the interested reader to these papers for a more complete discussion of this technique.

2. Structural models. Structural models are theoretically pleasing because they provide more detailed information on adjustment and hold promise for micro analysis. Since they tend to find rather different results than reduced form models on aggregate data, their usefulness for aggregate forecasting and policy analysis at the macro level needs to be investigated. In structural models - the short run decision is on the use of the ith appliance stock U_i while the long run decision is to decide on what the appliance stock is to be Sk_i. Total demand for energy at any point in time is

(72) $E = \Sigma_i U_i Sk_i$

Where use of the ith stock of equipment might be represented as

(73) $U_i = E_i/Sk_i = F(P_i, Y, Sk_i, X)$

Where X represents other relevant variables. The purchase decision of the ith piece of equipment might be

(74) $Sk_i = F(P_i, Ps, Pk_i, Pk_s, Y, X)$

Where Ps represents the price or prices of substitute energy products, Pk_i is the price of the stock of ith energy using equipment, and Pk_s is the price of substitute energy using equipment. In the case of consumer appliances a popular approach has been to model the appliance choice using a logit or other discrete choice model.

In the context of automobile decisions, U_i is typically vehicle miles travelled (VMT), while the stock equation might be replaced by an efficiency measure such as miles per gallon (VMT/G)=(MPG). Then gasoline consumption G = VMT/(VMT/G) with miles and miles per gallons estimated separately.

<u>Expenditure System Models</u>

Expenditure system models look at all consumer expenditures as a system. The simplest of these models is the linear expenditure system (Ex-l) where the estimating equations for the jth product take the form

(75) $p_j q_j = p_j \gamma_j + ß_j \ (Ex - \Sigma_k \ p_k \gamma_k)$

p_j is the price of good j, q_j is the quantity consumed of good j, and Ex is total expenditure. The first expression on the right of the equals sign is considered the base expenditure, perhaps representing the basic necessity, and the second amount is the portion of income above subsistence that the person consumes on this good. $\Sigma ß_i = 1$. Dividing through by p_j gives the representative estimating equation for the system as:

(76) $q_j = \gamma_j + ß_j/p_j \ (Ex - \Sigma_k \ p_k \gamma_k)$

Where the $ß_j$ and γ_j are the estimated parameters. Desirable properties of this technique are that it satisfies all the theoretical restrictions on systems of demand equations and it can be derived from a specific utility function. A disadvantage is that the restrictions are imposed and hence can not be tested. A model developed to test some of the restrictions is the Rotterdam model Ex-Rot discussed in Deaton and Muellbauer (1980). In this model the estimating equation becomes the following difference equation in the natural logs:

(77) $w_i \ d \ln q_i = ß_j \Sigma_k \ w_k \ d \ln q_k - \Sigma_j \ ß_{ij} \ d \ln p_j$

Where w_i represents the budget share of good q_i and d represents the total differential, which is represented by the first difference, for estimation purposes.

With the development of the translog and other flexible functional forms, Deaton and Muellbauer (1980) wanted a model with the flexibility of the translog and the Rotterdam model. The expenditure system model they developed (Almost Ideal Demand System Ex-AIDS)), with its rather unfortunate acronym, is estimated using the following equation:

(78) $w_i = ß_o + \Sigma_j ß_{ij} \ln P_j + ß_{yi} \ln (Ex/P)$

Where P is the translog price index for all goods defined as:

(79) $\ln P = \alpha_o + \Sigma_k \alpha_k \ln P_k + \Sigma_k \Sigma_m ß_{km} \ln P_k \ln P_m$

See the original article for restrictions testing in the context of this model.

As with modeling approaches, both functional forms and estimation techniques have taken on more sophistication over time. The most popular functional forms, early on, were log linear (ln) and linear (l), but increasingly translog (Tl), logit (Lg) and other more complicated models have been used. With estimation techniques, ordinary least squares (OLS) gave way to techniques that paid more specific attention to econometric problems and included generalized least squares (GLS) with corrections for serial correlation (-s) or heteroskedasticity (-h) or an error components model (EC). Other techniques reported include maximum likelihood, (ML), two stage least squares (2S), seemingly unrelated (SUR), three stage least squares (3S), nonlinear least regressions (NL) and full information maximum likelihood (FIML). Estimation techniques, where reported, are noted in the table under ET.

In the coming sections I consider energy demands for various energy aggregations. Tables from earlier surveys are summarized and I limit my new survey work to studies I have found that have been either done since 1980 or since the last survey on the particular product in question. The studies are stratified by fuel type (total energy demand (E), demand for coal (C), oil (O), natural gas (Ng) and electricity (El). These demands can be further stratified by sector. The major sectors considered traditionally are residential (-r), commercial (-c), industrial (-i), electricity generation (-e), and transport (-t). In some cases studies are done by industry (e.g. E-mt is energy in the primary metal industry, the whole category for energy demands by specific industries will be designated -ii.) Oil demand can be further broken down into separate fuels: aviation gasoline (G-av), jet fuel (J), LPG, gasoline (G), kerosene (K), diesel (D), highway fuel, which includes gasoline and distillate (F-hw), distillate or light fuel oil (FO-lt), and residual or heavy fuel oil (FO-hv). All variable definitions are given in the Appendix.

II. Total Energy Demand

II.1 Previous Surveys. In the 1970's the notion of limits to growth led to a fair amount of work considering total energy demand and whether substitutability and productivity increases would solve problems of energy shortages. I consider three surveys of this early work. Two special issues that have been considered when modeling total energy in these studies regard how to aggregate fuels and where to measure energy. The choices of indexes for aggregating energy have been BTU's, Laspeyre, Paasch, Ideal, and Tornquist, while energy can be measured as gross energy, sometimes referred to as primary energy, or net energy, sometimes referred to as secondary, end use, or useful energy.

Estimates from the three surveys, Taylor (1977), Energy Modeling Forum (1981)(EMF81), and Kouris (1983) are summarized in Table 1 for total energy demand, energy demand in the industrial sector (-i), energy demand in the residential sector (-r,) and energy demand in the commercial sector (-c).

The average long run price elasticities[2] for total energy and energy demand by sectors are surprisingly close to each, near −0.45, despite a fair amount of variation within each category. The income elasticities based on fewer estimates suggest that energy demands are less than 1 with residential demand perhaps more income elastic than total and industrial demand.

Although the 16 models included in (EMF81) are not all econometric models, the care with which issues have been defined and the models have been compared leads me to summarize their survey. The issues considered were the distinction between aggregate and single fuel elasticities, aggregation of heterogenous fuels, choice of index, composition of price change, standardization of aggregate economic activity, selection of measurement point, examination of dynamics, and characterization of uncertainty.

In their experimental model runs or long run elasticities, (25 year) these diverse models showed a surprising degree of consistency and appear to have similar results to the other studies surveyed. They found that for secondary elasticities only the BTU weighted index led to different calculated elasticities than for Paasche, Laspeyres, Ideal, or Tornquist index. More comprehensive models with more sectors and more fuel substitution tended to have higher elasticities. Statistically estimated models tended to have higher elasticities, whereas judgmental and engineering models tended to have lower elasticities. In general, the models tended to not give much information on the dynamics of the adjustment process and uncertainty was incorporated into almost none of the models.

They recommend that EIA should develop a consistent accounting framework and that modelers should improve their documentation with funding agencies requiring and supporting such documentation. Modelers should provide more information on all specification tried and should publish their data. If possible they should compute and report aggregate elasticities from disaggregate estimates for short run, intermediate, and long run for primary, secondary, and delivered energy.

Table 1: Demand Elasticities for Total Energy

S	Product		Psr	Pir	Plr	Yir*
1	E	Avg	−0.32	−0.24	−0.47	0.67
		Std	0.19	0.00	0.43	0.32
		Min	−0.52	−0.24	−1.75	0.27
		Max	−0.09	−0.24	−0.04	1.02
		#	4	1	24	5
2	E-i	Avg	−0.12	−0.46	−0.43	0.71
		Std	0.03	0.14	0.19	0.23
		Min	−0.15	−0.60	−0.75	0.31
		Max	−0.09	−0.31	−0.24	0.99
		#	2	2	4	5
3	E-r	Avg	−0.12	−0.15	−0.44	0.96
	E-r&c	Std	0.00	0.00	0.17	0.22
	E-c	Min	−0.12	−0.15	−0.70	0.73
		Max	−0.12	−0.15	−0.17	1.18
		#	1	1	5	2

2 In this survey a smaller or lower elasticity is one that is less elastic. For demand elasticities a smaller elasticity would be a larger number or one closer to zero.

Summarized from Taylor (1977), Energy Modeling Forum (1981), and Kouris (1983).
* The income elasticities in Kouris have not been designated as long or short run and have been labelled intermediate run here.

Sweeney (1983) does not survey specific models but comes to a number of conclusions about energy demand from the Energy Modeling Forum (1981) and other studies. Since his conclusions provide a useful comparison and a benchmark from which to compare later work, I will summarize some of them here. As of 1983, he concludes that demand responses to higher energy prices include substitution across other factors, substitution within different fuels, and energy conservation with the exact quantity of these effects unknown. Energy demand, which is a derived demand is used in every activity but to widely varying degrees. Since most energy using equipment has a fairly long life, long run price elasticities tend to be much larger than short run ones but the adjustment could be slow with the precise time paths unknown. Energy price changes may cause locational shifts of economic activity but not necessarily the total amount of energy consumed implying that international cross sections overstate long run price elasticities to a general increase in price levels.

Elasticities vary depending on where they are measured and get larger the further down the delivery stream from primary to secondary to delivered energy. Estimates for secondary energy price elasticities may be from -0.4 to -0.7. Those for primary energy may be as low as -0.12, while those for delivered energy are probably between -0.5 and -1.

In the immediate post 1979 period, it was hard to distinguish between the effect of recession, lagged response to higher prices, and government policy on reducing energy demand, but at least 80% of the adjustment is thought to have come from responses to price and economic activity. The aggregate demand elasticity should be less than the weighted average of the fuel specific elasticities because of interfuel substitution.

Kouris (1983) specifically breaks studies down into final energy and useful energy. I find that there is a faint suggestion that final energy consumption may have a higher price elasticity than primary energy consumption, whereas the reverse is true for the income elasticity.

He finds some evidence that price response may be more elastic the longer the time period, particularly when post 1973 data is included. He argues that although these estimates are considered long run there is no indication of how long that time period would be and, hence, they are useless for policy evaluation and forecasting. I would argue that if we truly believe these estimates to be long run, they may be useful for long run forecasting and might be modified by judgement for shorter periods. More serious is the issue of whether or not they are truly measuring long term income and price effects rather than other non included variables or locational effects.

In his survey of studies on residential and commercial demand for cross section time series he finds price elasticities generally greater. He cautions on the interpretation of these elasticities since they often include miscellaneous demands such as for the government and agriculture. One of the studies put in agricultures share of GDP in the estimation and found that income elasticity dropped and the price elasticity rose.

Kouris (1983) concludes that the use of BTU's in aggregating, which is the most commonly used approach, appears to be a simple and adequate procedure. However, we should note that Energy Modeling Forum (1981) above found this aggregation provided different elasticity approaches than for other approaches. Whether this matters to the overall analysis if all of the steps use a consistent approach is unclear. He favors Koyck or PDL dynamic specification over translog or other partial adjustment hypotheses. However, we will find later that these types of specifications provide rather unstable long run estimates.

In Taylor (1977) the debate is on whether capital and energy are complements or substitutes. Apostolakis (1990b) surveys a variety of the studies that consider substitution across energy and capital and finds 12 studies that support capital and energy complementarity and 9 studies that support substitutability. Few of these studies include data beyond the late 1970's. In general, he finds that time series estimates tend to more often favor the complementarity argument while cross sections tend to more often favor substitutability. Various explanations have been offered to explain this dichotomy: inadequate econometric techniques, omission of materials from the production function, the difference between gross and net complements. As of the latest study in his survey, no generally accepted explanation had been found.

II.2 New Studies of US Energy Demand. Moving on we consider studies done since 1981 to determine what they imply about the total elasticity for energy demand. Table 2 contains post 1980 studies summarized for the US. There are three econometric studies for total energy demand in category 1 (C1) with an average intermediate run price elasticity of -0.18 and an intermediate run income elasticity near 1.

Rei86[3] considers energy demand from a slightly different point of view in C2. He starts with a CES production function of fossil fuels, electricity, capital, and labor and uses backcasting on aggregate time series to estimate price elasticities assuming different life lengths (Klf) for capital. His average price elasticity is -0.7 with higher price elasticities estimated the longer the assumed capital life.

There are two studies that consider total residential demand in C3. Uris83b uses a dynamic model (PDL) on aggregate census region data and finds a long run price and income elasticities of -0.35 and 1.45 whereas the HGC82 study on household data does not support these estimates, since they find higher average intermediate run price elasticities averaging -0.53 and much lower income elasticities averaging 0.08. HGC82 also find less price elasticity for residential energy for heating than for total residential heating with the same low income elasticities on disaggregate data in C5.

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3 All references to the Table will be abbreviated as in the Table. References in the Table are abbreviated as the first three letters of the last name of one author, the first initial for the first author followed by & and the first initial of the second author for two authored pieces, and the first three initials of the first three authors for pieces with more than two coauthors. Only first initials of authors names are capitalized. The three letter abbreviations are followed by the last two digits of the year of publication. A q signifies that the estimates were quoted from a secondary source. The source is designated after the reference in the bibliography.

Table 2: New Studies of Demand for Total Energy

C	Ref	Product	Sample	y1	y2	Ty	Psr	t(p)	Pir	Plr	Ysr	t(Y)	Yir	Ylr	Q(-1)	t(Q-1)	Model	ET
1	Cri83	E	US	68	78	T		-1.00	-0.10			2.50	0.94				Stat	OLS?
1	Dev88	E	US	60	82	T		-4.66	-0.36			13.64	1.11				Stat	GLS-s
1	Dev88	E	US	61	82	T		-2.77	-0.22			8.41	1.02				Stat	GLS-s
1	MCP87	E	US	61	75	T		-2.30	-0.03			15.30	1.14				Stat	OLS
					Avg				-0.18				1.05					
					Std				0.12				0.08					
					Min				-0.36				0.94					
					Max				-0.03				1.14					
					#				4				4					
2	Rei86	E	US	60	82	T				-1.04								CES bkcs Klf=30
2	Rei86	E	US	60	82	T				-1.01							CES bkcs Klf=28	
2	Rei86	E	US	60	82	T				-0.97							CES bkcs Klf=26	
2	Rei86	E	US	60	82	T				-0.92							CES bkcs Klf=24	
2	Rei86	E	US	60	82	T				-0.89							CES bkcs Klf=23	
2	Rei86	E	US	60	82	T				-0.87							CES bkcs Klf=22	
2	Rei86	E	US	60	82	T				-0.84							CES bkcs Klf=21	
2	Rei86	E	US	60	82	T				-0.82							CES bkcs Klf=20	
2	Rei86	E	US	60	82	T				-0.79							CES bkcs Klf=19	
2	Rei86	E	US	60	82	T				-0.77							CES bkcs Klf=18	
2	Rei86	E	US	60	82	T				-0.74							CES bkcs Klf=17	
2	Rei86	E	US	60	82	T				-0.72							CES bkcs Klf=16	
2	Rei86	E	US	60	82	T				-0.69							CES bkcs Klf=15	
2	Rei86	E	US	60	82	T				-0.66							CES bkcs Klf=14	
2	Rei86	E	US	60	82	T				-0.61							CES bkcs Klf=13	
2	Rei86	E	US	60	82	T				-0.56							CES bkcs Klf=12	
2	Rei86	E	US	60	82	T				-0.50							CES bkcs Klf=11	
2	Rei86	E	US	60	82	T				-0.44							CES bkcs Klf=10	
2	Rei86	E	US	60	82	T				-0.33							CES bkcs Klf=8	
2	Rei86	E	US	60	82	T				-0.26							CES bkcs Klf=6	
2	Rei86	E	US	60	82	T				-0.22							CES bkcs Klf=4	
				Avg						-0.70								
				Std						0.23								
				Min						-1.04								
				Max						-0.22								

Table 2 (continued): New Studies of Demand for Total Energy

C	Ref	Product	Sample	y1	y2	Ty	Psr	t(p)	Pir	Plr	Ysr	t(Y)	Yir	Ylr	Q(-1)	t(Q-1)	Model	ET
3	Uri83b	E-r	US-rCs	47	78	CT	-0.15	-5.81		-0.35	1.17	47.43		1.45			PDL	GLS-s
3	HGC82	E-r	US-h	78	79	CT			-0.65				0.08				Stat	OLS?
3	HGC82	E-r	US-h	78	79	CT			-0.37				0.08				Stat	OLS?
3	HGC82	E-r/sf	US-h	78	79	CT			-0.66				0.08				Stat	OLS?
3	HGC82	E-r/sf	US-h	78	79	CT			-0.44				0.08				Stat	OLS?
				Avg			-0.15		-0.53	-0.35	1.17		0.08	1.45				
				Std			0.00		0.13				0.00					
				Min			-0.15		-0.66				0.08					
				Max			-0.15		-0.37				0.08					
				#			1		4	1	1		4	1				
4	AWK85	E-r&c	US	70	82	T	-0.16	-2.60		-0.24	0.49	2.50		0.74	0.34	1.40	LE	GLS-s
4	AWK85	E-r&c	US	70	82	T	-0.14	-2.50		-0.28	0.44	2.30		0.88	0.50	2.60	LE	GLS-s
				Avg			-0.15			-0.26	0.47			0.81	0.42			
				Std			0.01			0.02	0.02			0.07	0.08			
				Min			-0.16			-0.28	0.44			0.74	0.34			
				Max			-0.14			-0.24	0.49			0.88	0.50			
				#			2			2	2			2				
5	HGC82	E-r-ht	US-h	78	79	CT			-0.25				0.06				Stat	OLS?
5	HGC82	E-r-ht	US-h	78	79	CT			-0.39				0.05				Stat	OLS?
5	HGC82	E-r-ht/sf	US-h	78	79	CT			-0.40				0.07				Stat	OLS?
5	HGC82	E-r-ht/sf	US-h	78	79	CT			-0.20				0.05				Stat	OLS?
				Avg					-0.31				0.06					
				Std					0.09				0.01					
				Min					-0.40				0.05					
				Max					-0.20				0.07					
				#					4				4					
6	And81	E-i	US	48	71	T			-0.28								TlKLEM	ISUR
6	Con89a	E-i	US	58	81	T			-0.01								LgKLEM	FIML
6	Con89a	E-i	US	58	81	T	-0.03			-0.13							LgKLEM	FIML
6	Con89a	E-i	US	58	81	T			0.23								TIKLEM	FIML
6	Mor88	E-i	US	52	81	CT	-0.13	-6.55		-0.55	0.38	7.53		1.00			Gl2KLEM	I3S
6	Mor88	E-i	US	52	81	CT	-0.20	-8.65		-0.37	0.31	6.40		1.00			Gl3KLEM	I3S
6	Mor88	E-i	US	52	81	CT	-0.29	-11.15		-0.32	0.57	7.73		1.00			Gl2KLEM	I3S

6	KBP86	E-i	US	60	82	CT	-0.14				Tl2KLE	ISUR
6	Kol86	E-i	US	60	82	CT	-0.06				Tl2KLE	ISUR
6	Kol87?	E-i	US	60	82	CT				-0.41	TlKLE	ISUR
6	P&R83	E-i	US	48	71	T	-0.36		-0.58	-0.99	Tl3KLEM	3S

Table 2 (continued): New Studies of Demand for Total Energy

C	Ref	Product	Sample	y1	y2	Ty	Psr	t(p)	Pir	Plr	Ysr	t(Y)	Yir	Ylr	Q(-1)	t(Q-1)	Model	ET
6	P&R83	E-i	US	48	71	T	-0.66			-0.93							Tl3KLEM	3S
6	AWK85	E-i	US	70	82	T		-9.30	-0.28			15.00	0.69				LE	GLS-s
6	AWK85	E-i	US	70	82	T		-9.00	-0.28			16.20	0.77				LE	GLS-s
						Avg	-0.23		-0.20	-0.53			0.73	1.00				
						Std	0.19		0.25	0.30			0.04	0.00				
						Min	-0.66		-0.58	-0.99			0.69	1.00				
						Max	-0.03		0.23	-0.13			0.77	1.00				
						#	8		7	7			2	3				
7	GKS89	E-ag	US	82	82	C		-6.41	-0.63								TlKLED	3S
7	Gop87	E-ag	US-sW	78&82		CT		-0.11	-0.85			0.27	0.89				TlEKLIDY	ISUR
7	DFW81	E-ap	US	48	71	T	-0.01			-0.36							Tl3KLEM	NL3S
7	DFW81	E-ch	US	48	71	T	-0.15			-0.15							Tl3KLEM	NL3S
7	C&E87	E-ct	US	47	80	T		-23.14	-0.70								TlKLEM	3S
7	DFW81	E-fd	US	48	71	T	-0.57			-0.57							Tl3KLEM	NL3S
7	DFW81	E-fu	US	48	71	T	-0.08			-0.16							Tl3KLEM	NL3S
7	DFW81	E-in	US	48	71	T	-0.50			-0.59							Tl3KLEM	NL3S
7	DFW81	E-ma	US	48	71	T	-0.11			-0.16							Tl3KLEM	NL3S
7	DFW81	E-me	US	48	71	T	0.00			-0.01							Tl3KLEM	NL3S
7	DFW81	E-mf	US	48	71	T	0.00			-0.25							Tl3KLEM	NL3S
7	DFW81	E-mt	US	48	71	T	-0.55			-0.65							Tl3KLEM	NL3S
7	D&C84	E-mt	US-s	74	77	CT			-0.97								Sh-2Eq	SUR
7	D&C84	E-mt	US-s	67&71		CT			-1.04								Sh-2Eq	SUR
7	D&C84	E-mt	US-s	75	77	CT	-0.30			-1.02							Sh-2Eq	SUR
7	DFW81	E-nm	US	48	71	T	0.00			-0.38							Tl3KLEM	NL3S
7	DFW81	E-pa	US	48	71	T	-0.61			-0.73							Tl3KLEM	NL3S
7	DFW81	E-pr	US	48	71	T	-0.48			0.00							Tl3KLEM	NL3S
7	DFW81	E-rb	US	48	71	T	-0.50			-0.51							Tl3KLEM	NL3S
7	DFW81	E-tb	US	48	71	T	0.00			-0.01							Tl3KLEM	NL3S
7	DFW81	E-te	US	48	71	T	-0.30			-0.35							Tl3KLEM	NL3S
7	DFW81	E-te	US	48	71	T	-0.13			-0.13							Tl3KLEM	NL3S
7	DFW81	E-tx	US	48	71	T	-0.18			-0.19							Tl3KLEM	NL3S
7	DFW81	E-wd	US	48	71	T	-1.09			-1.10							Tl3KLEM	NL3S
						Avg	-0.29		-0.84	-0.39			0.89					
						Std	0.29		0.15	0.32			0.00					
						Min	-1.09		-1.04	-1.10			0.89					

Max	0.00		-0.63	0.00			0.89
#	19		5	19			1

When AWK85 add commercial to residential use on aggregate data in C4 and use a LE model, they tend to find lower elasticities especially for income than Uri83b got for just the residential sector.

There are eight studies for industrial energy demand in Table 2, C6 on a variety of models and over a variety of samples. Not surprisingly, they find a variety of results with more variation across price elasticities than for the earlier survey work. And81 finds a price elasticity of -0.28 on data from 1948 to 1971 using a translog while Con89a finds a positive price elasticity on the same model from 1958 to 1981, but a small negative response on a logit model. Mor88 finds long run price elasticities between -0.32 and -0.55 on 2nd and 3rd generation dynamic generalized Leontief models for 1952 to 1981, while Kol87's results on a translog support those of Mor88. P&R83 find price elasticities near -1 on a third generation translog for data from 1947 to 1971. A&W85 find average intermediate income elasticity of 0.73, which is very near to the earlier studies, while Mor88 constrains her long run elasticity to be 1 for her three specifications.

From these studies on industrial demand it appears that estimates for price elasticity on CT data are more elastic than those on T data and that price elasticities are less elastic, the more recent the data. Although the average long run price elasticity at -0.53 is higher than for earlier studies, if we ignore the studies on early data, the price elasticity appears to be lower than for the earlier surveys, whereas there is no evidence that income elasticity has changed.

There are 5 studies that include estimates for individual industries in Table 2, C7. DFW81 include data only through 1971 by industry using a 3rd generation translog model. They find an average price elasticity for all industries of -0.39, which does not support the much more elastic response near -1 of P&R83 on aggregate energy on a similar model and sample years. Estimates on simpler translog or share models and more recent data for cement, agriculture and metals are rather more elastic averaging -0.84.

The new studies on total energy demand vary rather widely across techniques, samples, and energy categories; most suggest that the price elasticity of energy demand is inelastic and probably less elastic than -0.6 for most sectors. Industrial energy demand overall may be less elastic than for other sectors, but studies on individual industries - agriculture, cement, and metals - suggested that their response was more price elastic.

Most estimates seem to suggest that income elasticity is still below 1. The high income elasticity using the PDL for the residential sector is an interesting result and suggests that more work might be done systematically comparing dynamic models to see what they imply about elasticities and adjustment patterns. The almost nonexistent income elasticity on household data compared to estimates on aggregate data may be the result of other variables picking up the effects of income, the fact that income reported in expenditure surveys tends to lag the other variables, and that aggregate data may be attributing some of the demographic effects of new household formation to increases in income. This result, which we will see again and again in the energy product sections, could bear closer scrutiny in future studies.

III. Demand for Electricity

III.1 Previous Surveys. Given the quality and quantity of data on electricity consumption, it has been one of the most heavily studied energy products and also has the most pre 1973 demand studies. The two most important special issues in electricity demand are decreasing block pricing and the lack of storability. The first of these issues results in the debate about whether to use average, marginal, infra marginal, or some combination of them as the price variable. Nonstorability leads to issues of switching peak and time of day demand studies, which I consider in the next section.

Taylor (1975) surveys 10 studies, which are summarized at the top of Table 3, S4–S6. All studies are on aggregate data. In most cases the average price is used, in a couple of cases marginal price is used. More of the studies tend to be on C or CT data than on T data. He finds large differences between long run and short run elasticities. He concludes that long run price elasticities are between −1 and −2 while long run income elasticity results are mixed with one negative elasticity and the rest varying from 0 and 2 depending on model type. He urges more work dealing with decreasing block pricing and using actual rate schedules.

Taylor (1977) extends this survey with an additional 8 studies. Improvements in these studies include better dynamic modeling of electricity demand by considering appliance choices; using smaller geographical areas to reduce aggregation bias; and more focus on interfuel substitution. These studies are summarized at the bottom of Table 3, S7–S9.

In this later study he concludes in favor of a somewhat lower long run price elasticity. He suggests a maximum price elasticity of 1 in absolute value for residential demand from studies that use marginal rather than actual price. He finds the demands for industrial and commercial electricity demand still under researched.

He concludes that the overall short run price elasticity for electricity is −0.2 and the long run elasticity is between −0.7 and −0.9. Excluding studies on monthly data, the long run income elasticity varies somewhat less than in his earlier survey from 0.23 to 1.63, but he concludes that they still vary rather too much within the residential, commercial, and industrial categories to make generalizations possible.

Table 3: Demand for Electricity Surveyed by Taylor (1975,1977).
Taylor (1975), Table 4, p. 101.

S			Psr	Pir	Plr	Ysr	Yir	Yls*
4	El−r	Avg	−0.44	−0.90	−1.21	0.31	−0.20	0.92
		Std	0.37		0.66	0.43		0.77
		Min	−0.90		−2.00	0.02		0.00
		Max	−0.13		0.00	1.16		1.94
		#	5		6	5	1	5
5	El−c		−0.17	−2.1	−1.36	0.11		0.86
		#	1	1	1	1		1
6	El−i	Avg	−0.22	−1.40	−1.63			
		Std			0.27			
		Min			−1.94			
		Max			−1.25			
		#	1	1	4			

Taylor (1977), Table 1.1, p. 6

S			Psr	Pir	Plr	Ysr	Yir	Yls
7	El−r	Avg	−0.30	−0.62	−1.28	0.15	0.71	0.72
		Std	0.20	0.25	0.32	0.10	0.68	0.40
		min	−0.61	−1.00	−1.66	0.04	0.16	0.12
		max	−0.07	−0.34	−0.81	0.30	1.87	1.10
		#	4	4	4	4	4	4

8	El-c	Avg	-0.37	-0.98	0.56	1.28
		Std	0.12	0.17	0.32	0.76
		min	-0.54	-1.22	0.10	0.23
		max	-0.24	-0.85	0.79	1.98
		#	3	3	3	3
9	El-i	Avg	-0.26	-0.22	0.82	1.38
		Std	0.08	0.89	0.50	0.91
		Min	-0.35	-1.00	0.14	0.50
		Max	-0.15	1.03	1.32	2.63
		#	3	3	3	3

He divides the studies into reduced form models (static or dynamic), structural models (Struct), or fuel share models (FShare) with substratifications across aggregate data (Agg), disaggregate data (Disag), and data by industry (El-ii) and

Bohi (1981) has the advantage of a somewhat larger sample of studies to draw from and does a somewhat more extensive survey of electricity demand. He begins with 25 studies of residential demand for electricity, which are summarized below in Table 4, S10-S16.

He divides the studies into reduced form models (static or dynamic), structural models (Struct), or fuel share models (FShare) with substratification across aggregate data (Agg), disaggregate data (Disag), and data by indsutry (El-ii) and whether the price variable is average or marginal.

He notes the overall wide disparity across elasticities with short run elasticities varying from -0.03 to -0.54, some short run elasticities exceeding other long run elasticities, long run price elasticities varying from -0.45 to -2.10, and both short run and long run income elasticities varying from 0 to 2.

He concludes that the dynamic models give the largest disparities in estimates. Long run price elasticities derived from aggregate data are larger than those from disaggregated data, whereas the reverse is true for the short run price elasticities. Hence, the different studies have different implications on total adjustment as well as its time path.

Models using marginal prices tend to find smaller elasticities in absolute value than those using average prices. However, large variation in each subcategory led me to combine them here. Income elasticity estimates tend to be rather erratic except that fuel share models tend to find income not very significant. Rather, these share studies suggest that income is important in determining overall energy consumption but that prices are more important in determining fuel choice.

The structural models reviewed include those on aggregate data that consider the affect of energy prices on appliance stocks, along with one on disaggregate data that finds the short run from an appliance utilization model and the long run from the sum of the utilization rates and appliance saturation from a logit model. Bohi finds this to be the preferred specification since it has the theoretical appeal of separating utilization rates from appliance choice, it has the econometric appeal of using disaggregate data, it is internally consistent, and it agrees with other model results that he finds credible. It finds an inelastic long run price response as do those models that use marginal price. The direct income elasticity is low, while the indirect effect through the appliance stock and dwelling size is important. The cross price elasticity of natural gas is measured as in the fuel share models.

He finds only a few studies on commercial energy demand, summarized in Table 4, S17. Since they all use reduced form, aggregate data, and average price they tend to find fairly consistent results. Demand appears to be price elastic in the long run, but the effect of income is unclear. Dynamic models are still highly erratic as are the coefficients on climatic and demographic characteristics.

There are two types of studies done on industrial consumption both summarized in Table 4, S18. Those that look at aggregate industrial demand are similar to those for the commercial sector and also come up with inconclusive results. Some on regional data try to account for locational bias introduced by electricity intensive industries locating in areas of cheaper electricity prices.

Table 4: Demand for Electricity Surveyed by Bohi (1981), Tables 3-1, 3-2, 3-3, 3-4, P. 56-59, 80, 84,86.

S			Psr	Pir	Plr	Ysr	Yir	Yls*
10 El-r	Static	Avg	-0.23		-1.13	0.49		0.74
	Agg Data	Std	0.14		0.29	0.83		0.22
		Min	-0.45		-1.53	-0.32		0.48
		Max	-0.08		-0.48	1.87		1.06
		#	4		8	4		6
11 El-r	Static	Avg	-0.14		-0.70	0.07		0.40
	Disag	#	1		1	1		1
	Data							
12 El-r	Dynamic	Avg	-0.18		-0.95	0.23		0.86
	Agg Data	Std	0.13		0.41	0.49		0.73
		Min	-0.49		-1.89	0.02		0.12
		Max	-0.03		-0.44	2.00		2.20
		#	14		13	14		13
13 El-r	Dynamic	Avg	-0.16		-0.45	ns		ns
	Disag	#	1		1	1		1
	Data							
14 El-r	FShare	Avg	-0.30		-1.29	0.40		
	Static&	Std	0.17		0.52			0.00
	Dynamic	Min	-0.54		-2.10			0.40
	Agg	Max	-0.18		-0.72			0.40
	Data	#	3		4			1
15 El-r	Struct	Avg	-0.16		-0.70	0.22		0.68
	Agg Data	Std			0.51			0.42
		Min			-1.28			0.00
		Max			0.00			1.06
		#	1		4	1		4
16 El-r	Struct	Avg	-0.25		-0.66	0.21		0.39
	Disag	#	1		1	1		1
	Data							
17 El-c	Dynamic	Avg	-0.46		-1.23	0.23		0.85
	Agg	Std	0.36		0.32	0.28		0.43
	Data	Min	-1.18		-1.60	0.00		0.00
		Max	-0.17		-0.56	0.72		1.38
		#	6		8	4		6
18 El-i	Dynamic	Avg	-0.28		-1.21	0.27		0.55
	Agg	Std	0.39		0.47	0.32		0.25
	Data	Min	-1.36		-1.82	0.00		0.00
		Max	-0.04		-0.51	0.87		0.73
		#	9		9	6		6
19 E-ii	Static	Avg			-1.06			
	By Industry	Std			0.63			
		Min			-2.60			
		Max			-0.08			

#	57

* The original survey interpretations of short run, intermediate run, and long run have been maintained.

Studies on various industries (El-ii in S19) all using pre 1973 data find substantial agreement between overall price elasticities whether on aggregate or disaggregate data with a consensus estimate of -1.3. However, the instability across time and industry leads Bohi to conclude that overall estimates are subject to aggregation and locational biases and he concludes in favor of a less elastic demand response. Further, he feels that the studies fail to adequately measure the effects of economic activity, technical change, or structural change on industrial energy demand.

Kirby (1983) surveys 10 studies on residential demand for electricity. Since most of these articles have been surveyed elsewhere, I combine the only new study with the articles surveyed by Bohi and Zimmerman (1984) in Table 5. As in other studies she finds wide variation in elasticities, more elastic response on aggregate data, particularly for income, and wide variation in elasticities for dynamic models.

Other observations made by Kirby from individual studies include: little difference found between the use of average or marginal price in the regression; the elasticity for electric heating and cooling systems higher than for other uses; generalized least squares (GLS) and random coefficient models (RC) not performing as well as ordinary least squares (OLS) or error components (EC); satisfactory results from a lagged endogenous but insignificant results from a Balestra-Nerlove (BN), Houthakker-Taylor (HT), and a first differenced model; estimates varying considerable across OLS and 2S; and implied discount rates higher at lower incomes.

Bohi and Zimmerman (1984) provide the most recent survey work on overall electricity demand elasticities. The advantages of their survey is that the studies include more post 1973 data and use more detailed household data from household surveys such as the National Interim Energy Consumption Survey (1978-1979) (NIECS) and the Washington Center for Metropolitan Studies (WCMS) (1973-1975), which contain more demographic and appliance choice information.

Table 5: Demand for Electricity Surveyed by Bohi and Zimmerman (1984), Table 1, 4, and 5, Pages 118, 119, 130, 131.

S			Psr	Pir	Plr	Ysr	Yir	Ylr**
20	El-r	Avg		-0.69	-0.32		0.87	
	Stat, Agg	Std		0.63	0.14		1.09	
		Min		-1.57	-0.52		-2.14	
		Max		0.00	-0.18		1.79	
		#		11	3		12	
21	El-r*	Avg		-0.63	-0.48		0.14	
	Stat, Disag	Std		0.08	0.30		0.01	
		Min		-0.71	-0.71		0.12	
		Max		-0.55	-0.05		0.16	
		#		2	3		4	
22	El-r	Avg	-0.14		-1.06	0.23		0.99
	Dyn, Agg	Std	0.08		0.67	0.43		0.81
		Min	-0.35		-2.50	0.00		0.00
		Max	0.00		-0.26	2.00		3.00
		#	21		19	21		17

23 El-r		Avg	ns		ns			
	StatSk, Agg	#	1		1			
24 El-r*		Avg	-0.48			0.26		
	StatSk	Std	0.16			0.11		
	Disag	Min	-0.76			0.11		
		Max	-0.20			0.42		
		#	12			10		

Table 5: (continued) Demand for Electricity Surveyed by Bohi and Zimmerman (1984)

S			Psr	Pir	Plr	Ysr	Yir	Ylr
28 El-i		Avg			-1.65			
	Stat	Std			0.13			
	Disag Data	Min			-1.83			
		Max			-1.54			
		#			3			
25 El-r		Avg	-0.21		-1.46	0.06		0.39
	Struct	Std	0.22		0.05	0.04		0.02
	Disag	Min	-0.67		-1.51	0.01		0.36
		Max	0.04		-1.40	0.13		0.41
		#	7		2	8		2
26 El-c		Avg	0.00	-1.61	-0.26	-0.03		-0.58
	Stat, Dyn	Std	0.00	2.00	0.45	0.06		0.82
	Agg,Disag	Min	0.00	-4.56	-1.05	-0.15		-1.73
		Max	0.00	0.00	0.00	0.00		0.00
		#	3	3	4	5		3
27 El-i		Avg		-1.90				
	Stat, Agg,	Std		1.63				
		Min		-3.52				
		Max		-0.27				
		#		2				
29 El-i		Avg			-1.13			0.64
	StatSk	Std			0.37			0.26
	Disag	Min			-1.77			0.30
		Max			-0.61			1.04
		#			8			8
30 El-i		Avg	-0.11		-3.26	0.01		0.33
	Dyn, Agg	Std	0.01		0.29	0.02		0.47
		Min	-0.12		-3.55	0.00		0.00
		Max	-0.10		-2.97	0.04		1.00
		#	3		2	3		3

*One study included from Kirby (1983).
** The original survey interpretations of short run, intermediate run, and long run have been maintained.

They consider 18 studies for residential electricity demand (El-r) with models stratified by the following model type: static reduced form (Stat), dynamic reduced form (Dyn), static stock models (StatSk) which include some measure of the stock of electricity using appliances (which they call use models) and structural models (Struct) which include some modeling of both the use of appliances as well as appliance choice. Studies are also substratified by whether the data is aggregate or disaggregate and whether the marginal or average price is used. These studies are summarized in Table 5, S20-S25.

Structural and static stock models showed little sensitivity to the price variable chosen. Static and dynamic reduced form models using the average price tend to find a more elastic price response and a less elastic income response. However, since there was such wide variation of elasticities within model classes, it is not clear that the price difference is meaningful. Therefore, I aggregated models across the two price definitions.

The studies using static models on aggregate data showed a fair amount of regional variation in elasticities as well as variation across studies. In general, the elasticities for aggregate data tended to be higher than those on disaggregate data and they found it hard to come to any general conclusion on elasticities from studies on aggregate data.

The studies on reduced form static models on household data (Disag) in S21 had less variation across studies with all price elasticities below -0.71 and all income elasticizes below 0.16. The low income elasticity may be the result of income related variables in most equations picking up some of the income effect, or models on aggregate data picking up some of the demographic effects such as household formation, which may be related to both population and income. Low elasticities were obtained when both average and marginal price were included in the model, while the study that did a comparison found little difference between the two measures when they were included separately. These studies also have a lot of detailed information on the seasonal, demographic, and housing characteristic effects on demand.

All of the dynamic reduced form models in S22 were on aggregate data. The variation across short run price (-0.00/-0.35) is less than the variation across short run income (0.00/2.) Variation across the long run estimates are very large for both price and income elasticities as the result of the instability of the estimate on the lagged endogenous variable. Where price elasticities are greater than 2 in absolute value, the income elasticity tends to be low and the coefficient on the lagged endogenous variable is high. These correlations make it hard to conclude whether the long run price elasticities are elastic or inelastic and should be viewed with more than a healthy amount of skepticism. The results in these models do not change much across estimation method or between rural and nonrural data.

In the static stock or end-use models, the one on aggregate data in S23 obtains statistically insignificant estimates, while the 12 estimates on disaggregate data (S24) find more consistent results (-0.2/-0.76 and 0.11/0.42). Since appliance stocks of some sort are included in the models these results are considered short run. The results do not seem to be dependent on the choice of the price variable or upon the inclusion of exclusion of pre 1973 data.

There are three studies using structural models all on household data in S25. The two that explicitly include long run elasticities find an elastic long run price but inelastic income response. The study favored by the survey authors, which is the most detailed, has an appliance choice model and an electricity demand equation and only reports short run elasticities. The more detailed study also shows short run elasticities that appear to be somewhat smaller than for the other two studies.

They find only a limited number of commercial and industrial electricity demand studies in S26. Because of the lack of detailed data, most of the studies are on some type of reduced form model and all employ the average price. The commercial demand studies (El–c) all on reduced form static or dynamic models are particularly erratic and are all aggregated together. Price elasticities vary from insignificant to –4.56. Income elasticities are not reported, are insignificant, or are negative. All elasticities on dynamic models are either insignificant, and entered here as 0, or are of the wrong sign.

The industrial studies (El–i), summarized in Table 5, S27–S30 are a bit less erratic than those on the commercial sector. Most studies suggest an elastic price and an inelastic income response. A static study on aggregate data for US regional data finds wide variation across regions. The survey authors interpret the elasticities from the static stock models as long run because cross sectional data are used. This is inconsistent with the interpretation of this type of model which is conditional upon the stock of energy using equipment. I enter these elasticities as long run as did the original authors, but feel they might more properly be interpreted as short run. These static stock models on disaggregate data tend to find an elastic response to price with process heat and driving motors having a more price elastic demand than for lighting and space conditioning. They find that total elasticities from taking a weighted average are smaller than the results obtained from their reduced form model. This may display aggregation bias or could merely reflect the fact that they only considered a small range of end uses. The dynamic models (S30) estimated on aggregate annual data obtain excessively high price elasticities compared to the static and static stock models on disaggregate data (S28,S29).

The overall conclusions of Bohi and Zimmerman (1984) are that the short and long run price elasticities for the residential sector are –0.2/–0.7, respectively. However, the wide variance of the estimates make it difficult to report the price and income elasticity of demand for industrial and commercial users. I would take a somewhat less pessimistic point of view and hazard a guess that the industrial demand is price elastic and income inelastic.

III.2 New Studies on US Electricity Demand. Table 6 has summaries of some post 1980 studies found for electricity demand in the US. In C8, Hogan (1989) treats gross economic output as a function of electricity, nonelectric energy other than transport fuels, transport fuels and all other inputs. He compares a translog estimate with those derived from a symmetric generalized McFadden cost function (Sg) that explicitly allows capital to be fixed in the short run but not in the long run. His ex post or short run elasticity is estimated as –0.05, but his ex ante or long run elasticity is –0.99. The ex ante estimate on the translog model is higher at –1.31.

Rei86 in a less traditional approach assumes a CES model and backcasts to estimate price elasticities and finds a somewhat similar aggregate elasticity of –0.99. He finds that total electricity demand is more elastic the longer the assumed life of capital and is in the elastic region for a capital stock life greater than 14 years. Both types of study in C8 suggest a long run price elasticity that is near to 1, but neither has any information on the income elasticity of demand.

Studies for residential demand in Table 6 are divided into those done on aggregate data (C9) and those on disaggregate or household data (C10). Since I designate static models as yielding intermediate run elasticities and dynamic models as yielding long and short run estimates, they can be combined into one category with their elasticities still aggregated separately. Although all studies have been published after 1980, only a few have data that extend beyond the late 1970's.

Beginning with C9 there are 16 studies on some form of aggregate data. The averages over all studies suggest that all price and income elasticities are inelastic on average with short, intermediate, and long run price elasticities of -0.22, -0.65, and -0.91 and short, intermediate, and long run income elasticities more inconsistent at 0.18, 0.87, and 0.49. However, there are wide disparities in estimates across studies.

On strict cross sectional data for a small geographical area Wil81 finds intermediate price elasticities averaging near -0.3 with all electric homes having less than half the elasticity of homes that also use another fuel. Income elasticities, which are unclear in Wil81 and are not included here, appear to be small. Bad92 and Hen83 find a more elastic price/income response on cross sections for the whole US near -0.83/0.69.

The seven studies using a LE model on CT for US states in C9 show wide disparities across studies, across regions, and across time. BDM81 report very high price elasticities, coefficients of over 0.9 on the lagged endogenous variable, and almost no income response. BTR83 with a sample that includes relatively more data in the 1960s and variables to account for shortages report very high coefficients on the lagged endogenous model but price income elasticities are more reasonable (-1.12/0.76).

Table 6: New Studies of Demand for Electricity.

C	Ref	Product	Sample	y1	y2	Typ	Psr	t(p)	Pir	Plr	Ysr	t(Y)	Yir	Ylr	Q(-1)	t(Q-1)	Model	ET
8	Hog89	El	US	60	84	T		-12.07		-1.31							TlElNelOtrOth	ML
8	Hog89	El	US	60	84	T		-8.27		-0.99							SgElNelOtrOth	ML
8	Hog89	El	US	60	84	T	-0.05	-0.69									SgElNelOtrOth	ML
8	Rei86	El	US	60	82	T				-1.15							CES bkct Klf=30	
8	Rei86	El	US	60	82	T				-1.13							CES bkct Klf=28	
8	Rei86	El	US	60	82	T				-1.11							CES bkct Klf=26	
8	Rei86	El	US	60	82	T				-1.09							CES bkct Klf=24	
8	Rei86	El	US	60	82	T				-1.08							CES bkct Klf=23	
8	Rei86	El	US	60	82	T				-1.08							CES bkct Klf=22	
8	Rei86	El	US	60	82	T				-1.07							CES bkct Klf=21	
8	Rei86	El	US	60	82	T				-1.07							CES bkct Klf=20	
8	Rei86	El	US	60	82	T				-1.06							CES bkct Klf=19	
8	Rei86	El	US	60	82	T				-1.06							CES bkct Klf=18	
8	Rei86	El	US	60	82	T				-1.05							CES bkct Klf=17	
8	Rei86	El	US	60	82	T				-1.04							CES bkct Klf=16	
8	Rei86	El	US	60	82	T				-1.03							CES bkct Klf=15	
8	Rei86	El	US	60	82	T				-1.02							CES bkct Klf=14	
8	Rei86	El	US	60	82	T				-0.99							CES bkct Klf=13	
8	Rei86	El	US	60	82	T				-0.96							CES bkct Klf=12	
8	Rei86	El	US	60	82	T				-0.92							CES bkct Klf=11	
8	Rei86	El	US	60	82	T				-0.86							CES bkct Klf=10	
8	Rei86	El	US	60	82	T				-0.75							CES bkct Klf=8	
8	Rei86	El	US	60	82	T				-0.68							CES bkct Klf=6	
8	Rei86	El	US	60	82	T				-0.61							CES bkct Klf=4	
						Avg	-0.05			-1.00								
						Std	0.00			0.56								
						Min	-0.05			-1.31								
						Max	-0.05			-0.61								
						#	1			23								
9	Wil81	El-r	US-utMA	75	75	C			-0.27								Stat	GLS-h
9	Wil81	El-r-ae	US-utMA	75	75	C			-0.18								Stat	GLS-h
9	Wil81	El-r-nae	US-utMA	75	75	C			-0.52								Stat	GLS-h
9	Bad92	El-r	US-s	88	88	C		-3.27	-0.76			2.56	0.72				Stat	2S-all
9	Bad92	El-r	US-s	88	88	C		-5.96	-1.02			1.13	0.76				Stat	2S-sect
9	Hen83	El-r	US-ut	70	70	C		-3.46	-0.73			1.60	0.58				Stat	OLS

9	BDM81	El-r	US-s9	67	77	CT	-0.11	-3.15		-1.87	0.02	1.46		0.26	0.94	51.51	LE	OLS
9	BDM81	El-r	US-s9	67	77	CT	-0.11	-4.46		-2.20	0.00	0.55		0.08	0.95	66.33	LE	EC
9	BDM81	El-r	US-s9	67	77	CT	-0.09	-3.88		-2.19	-0.00	-0.07		-0.01	0.96	0.01	LE	EC-SUR
9	BTR83	El-r	US-s48	60	75	CT	-0.10	-8.61		-1.05	0.08	3.08		0.79	0.90	99.70	LE	EC
9	BTR83	El-r	US-s48	60	75	CT	-0.09	-8.19		-1.20	0.05	2.43		0.73	0.93	109.50	LE	EC

Table 6 (continued): New Demand for Electricity Studies.

C	Ref	Product	Sample	y1	y2	Typ	Psr	t(p)	Pir	Plr	Ysr	t(Y)	Yir	Ylr	Q(-1)	t(Q-1)	Model	ET
9	C&B88	El-r	US-s	55	78	CT	-0.12	-8.72		-0.73	0.14	6.88		0.85	0.84	90.20	LE	2S
9	C&B88	El-r	US-s	55	64	CT	-0.80	-10.10		-1.36	0.80	1.86		1.37	0.41	10.90	LE	2S
9	C&B88	El-r	US-s	56	65	CT	-0.73	-9.01		-1.29	0.07	1.50		0.11	0.43	11.30	LE	2S
9	C&B88	El-r	US-s	57	66	CT	-0.68	-7.98		-1.32	-0.01	-0.16		-0.02	0.48	13.10	LE	2S
9	C&B88	El-r	US-s	58	67	CT	-0.60	-7.20		-1.21	0.03	0.52		0.05	0.50	13.80	LE	2S
9	C&B88	El-r	US-s	59	68	CT	-0.57	-8.20		-1.11	0.08	1.52		0.15	0.49	14.70	LE	2S
9	C&B88	El-r	US-s	60	69	CT	-0.53	-9.45		-1.05	0.14	3.09		0.28	0.49	15.50	LE	2S
9	C&B88	El-r	US-s	61	70	CT	-0.43	-9.32		-1.01	0.17	4.41		0.40	0.57	19.60	LE	2S
9	C&B88	El-r	US-s	62	71	CT	-0.25	-6.79		-0.91	0.22	6.82		0.82	0.73	30.30	LE	2S
9	C&B88	El-r	US-s	63	72	CT	-0.22	-7.87		-0.95	0.20	6.38		0.85	0.77	40.20	LE	2S
9	C&B88	El-r	US-s	64	73	CT	-0.14	-5.00		-0.76	0.13	4.39		0.71	0.82	46.30	LE	2S
9	C&B88	El-r	US-s	65	74	CT	-0.19	-9.25		-0.84	0.21	6.44		0.92	0.78	50.60	LE	2S
9	C&B88	El-r	US-s	66	75	CT	-0.14	-6.82		-0.65	0.17	5.13		0.83	0.79	49.90	LE	2S
9	C&B88	El-r	US-s	67	76	CT	-0.11	-6.19		-0.49	0.17	5.20		0.75	0.77	47.50	LE	2S
9	C&B88	El-r	US-s	68	77	CT	-0.11	-5.94		-0.44	0.17	5.51		0.70	0.76	43.30	LE	2S
9	C&B88	El-r	US-s	69	78	CT	-0.11	-6.14		-0.42	0.16	5.03		0.60	0.73	37.90	LE	2S
9	C&B88	El-r	US-s	55	68	CT	-0.48	-8.08		-1.20	0.05	1.45		0.13	0.60	21.90	LE	2S
9	C&B88	El-r	US-s	69	78	CT	-0.11	-6.14		-0.42	0.16	5.03		0.60	0.73	37.90	LE	2S
9	C&B88	El-r	US-s	55	69	CT	-0.41	-8.31		-1.16	0.07	2.05		0.19	0.64	26.50	LE	2S
9	C&B88	El-r	US-s	70	78	CT	-0.13	-6.26		-0.42	0.15	4.48		0.48	0.69	28.80	LE	2S
9	C&B88	El-r	US-s	55	70	CT	-0.32	-7.55		-1.06	0.10	3.28		0.33	0.70	31.90	LE	2S
9	C&B88	El-r	US-s	71	78	CT	-0.13	-4.97		-0.36	0.14	3.88		0.40	0.65	21.50	LE	2S
9	C&B88	El-r	US-s	55	71	CT	-0.25	-6.83		-0.96	0.12	4.24		0.46	0.74	37.20	LE	2S
9	C&B88	El-r	US-s	72	78	CT	-0.16	-5.73		-0.38	0.06	1.49		0.25	0.76	17.20	LE	2S
9	C&B88	El-r	US-s	55	72	CT	-0.22	-6.12		-0.92	0.12	4.30		0.50	0.77	41.50	LE	2S
9	C&B88	El-r	US-s	73	78	CT	-0.20	-5.91		-0.38	-0.02	-0.44		-0.04	0.47	11.79	LE	2S
9	D&S88	EL-r	US-s	71	74	CT	-0.17	-6.86		-1.05	*				0.84	36.70	LE	EC
9	D&S88	El-r	US-s	78	82	CT	-0.17	-6.19		-1.11	*				0.84	30.96	LE	EC
9	MCR83	El-r-ru	US-sNE	69	78	CT	-0.20	-5.30		-0.47	0.42	4.94		0.98	0.57	10.24	LE	2S
9	MCR83	El-r-ru	US-sSE	69	78	CT	-0.23	-5.77		-0.50	0.32	4.69		0.70	0.55	6.77	LE	2S
9	MCR83	El-r-ru	US-sNC	69	78	CT	-0.21	-3.75		-0.93	0.03	1.20		0.15	0.77	9.40	LE	2S

9	MCR83	El-r-ru	US-sSW	69	78	CT	-0.16	-3.50		-0.74	0.12	1.39		0.53	0.78	17.27	LE	2S
9	MCR83	El-r-ru	US-sW	69	78	CT	-0.13	-2.34		-0.26	0.18	3.61		0.37	0.50	13.80	LE	2S
9	MCR83	El-r-ru	US-sNE	69	78	CT	-0.18	-4.47		-0.62	0.19	2.76		0.66	0.71	16.68	LE	2S
9	MCR83	El-r-ru	US-sSE	69	78	CT	-0.10	-1.04		-0.24	0.25	0.14		0.58	0.58	5.43	LE	2S
9	MCR83	El-r-ru	US-sNC	69	78	CT	-0.25	-3.83		-0.71	-0.00	-0.07		-0.01	0.64	8.75	LE	2S
9	MCR83	El-r-ru	US-sSW	69	78	CT	-0.10	-1.91		-0.26	0.30	2.70		0.76	0.60	9.63	LE	2S
9	MCR83	El-r-ru	US-sW	69	78	CT	-0.06	-1.49		-0.33	0.24	2.98		1.23	0.81	12.92	LE	2S
9	Shi85	El-r	US-utOH	60	80	CT	-0.14	-6.00		-0.46	0.17	4.06		0.56	0.69	17.33	Stat	GLS-h
9	Shi85	El-r	US-utOH	60	80	CT	-0.12	-4.52		-0.40	0.19	4.30		0.62	0.70	17.40	Stat	GLS-h

Table 6 (continued): New Demand for Electricity Studies.

C	Ref	Product	Sample	y1	y2	Typ	Psr	t(p)	Pir	Plr	Ysr	t(Y)	Yir	Ylr	Q(-1)	t(Q-1)	Model	ET
9	Sut83b	El-r	US-s48	61	73	CT				-1.73				0.31			PDL	2S
9	Sut83b	El-r	US-s48	74	80	CT				0.77				-0.09			PDL	2S
9	Sut83b	El-r	US-s48	61	80	CT				-1.53				0.33			PDL	2S
9	Sut83b	El-r	US-s48	61	73	CT				-1.22				0.53			LE	2S
9	Sut83b	El-r	US-s48	74	80	CT				-1.05				0.39			LE	2S
9	Sut83b	El-r	US-s48	61	80	CT				-1.18				0.24			LE	2S
9	Sut83b	El-r	US-s48	61	73	CT				-1.12				0.38			DL	2S
9	Sut83b	El-r	US-s48	74	80	CT				-1.08				0.17			DL	2S
9	Sut83b	El-r	US-s48	61	80	CT				-1.08				0.50			DL	2S
9	Uri83b	El-r	US-rNE	47	78	T			-0.92								TlNgOEl	SUR-s
9	Uri83b	El-r	US-rMAt	47	78	T			-0.74								TlNgOEl	SUR-s
9	Uri83b	El-r	US-rENC	47	78	T			-0.73								TlNgOEl	SUR-s
9	Uri83b	El-r	US-rWNC	47	78	T			-0.68								TlNgOEl	SUR-s
9	Uri83b	El-r	US-rSAt	47	78	T			-0.53								TlNgOEl	SUR-s
9	Uri83b	El-r	US-rESC	47	78	T			-0.50								TlNgOEl	SUR-s
9	Uri83b	El-r	US-rWSC	47	78	T			-0.57								TlNgOEl	SUR-s
9	Uri83b	El-r	US-rMt	47	78	T			-0.68								TlNgOEl	SUR-s
9	Uri83b	El-r	US-rPc	47	78	T			-0.65								TlNgOEl	SUR-s
9	Uri83b	El-r	US	47	78	Avg			-0.71								TlNgOEl	computed
9	LCC87	El-r	US	60	83	T	-0.16			-1.19	0.10			0.69	0.85		LE	EC-SUR
9	YSW83	El-r	US	37	77	T		-49.00	-0.98			49.50	0.99				Stat	RIDGE
9	YSW83	El-r	US	37	77	T		-29.67	-0.89			33.33	1.00				Stat	RIDGE
9	YSW83	El-r	US	37	77	T		-49.00	-0.49			25.50	0.51				StatAsym	RIDGE
9	YSW83	El-r	US	37	77	T			-0.97				1.02				Pcut,Yrec	
9	YSW83	El-r	US	37	77	T		-14.33	-0.43			25.50	0.51				StatAsym	RIDGE
9	YSW83	El-r	US	37	77	T			-0.92				1.00				Pcut,Yrec	

9	YSW83	El-r	US	37	77	T		-31.07	-0.93			34.60	1.04				Stat	RIDGE
9	YSW83	El-r	US	37	77	T		-23.80	-0.48			27.25	0.55				StatAsym	RIDGE
9	YSW83	El-r	US	37	77	T			-0.93				1.08				Pcut,Yrec	
9	YSW83	El-r	US	37	77	T		-4.96	-0.397			5.26	0.58				StatAsym	RIDGE
9	YSW83	El-r	US	37	77	T			-0.903				1.16				Pcut,Yrec	
9	YSW83	El-r	US	37	77	T		-16.12	-0.81			18.08	1.09				Stat	RIDGE
9	YSW83	El-r	US	37	77	T		-9.53	-0.38			13.60	0.54				StatAsym	RIDGE
9	YSW83	El-r	US	37	77	T			-0.86				1.06				Pcut,Yrec	
9	YSW83	El-r	US	37	77	T		-2.40	-0.288			5.83	0.58				StatAsym	PrinCom
9	YSW83	El-r	US	37	77	T					-0.788					1.20	Pcut,Yrec	

Table 6 (continued): New Demand for Electricity Studies.

C	Ref	Product	Sample	y1	y2	Typ	Psr	t(p)	Pir	Plr	Ysr	t(Y)	Yir	Ylr	Q(-1)	t(Q-1)	Model	ET
9	L&D82	El-r	US	60	80	Tq	ns				0.93			1.64			HT	OLS?
9	L&D82	El-r	US	60	80	Tq			-0.46				1.35				Ex-AIDS	ML
9	Sut83a	El-r	US	61	80	Tq	0.57	3.10		-2.20	0.77	3.68		0.33			Stat	2S
9	Rot81	El-r	US-utSW	74:	77:	Tm		-1.17	-0.11								Stat	OLS
						Avg	-0.22		-0.65	-0.91	0.18		0.87	0.49	0.70			
						Std	0.22		0.24	0.53	0.20		0.27	0.35	0.14			
						Min	-0.80		-1.11	-2.20	-0.02		0.51	-0.09	0.41			
						Max	0.57		-.11	0.77	0.93		1.35	1.64	0.96			
						#	48		34	56	46		20	55	46			
10	GSG86	El-r	US-h	78	78	C		8.00	-0.64			7.90	0.20				Stat	OLS
10	GSG86	El-r	US-h	74	74	C		10.20	-0.97			5.90	0.15				Stat	OLS
10	GSG86	El-r	US-h	76	76	C		8.70	-0.86			7.30	0.18				Stat	OLS
10	GSG86	El-r	US-h	79	79	C		8.00	-0.78			5.90	0.19				Stat	OLS
10	GSG86	El-r	US-h	77	77	C		9.40	-0.46			5.90	0.16				Stat	OLS
10	GSG86	El-r	US-h	75	75	C		4.40	-0.38			5.60	0.16				Stat	OLS
10	GSG86	El-r	US-h	74	79	CT		18.90	-0.62			15.10	0.17				Stat	OLS
10	Poy86	El-r-bl	US-h	80-&83		CT				-0.38				0.22			ExpL-Dyn	NL
10	Poy86	El-r-nbl	US-h	80-&83		CT				-0.48				0.22			ExpL-Dyn	NL
10	HGC82	El-r	US-h	78	79	CT			-0.71				0.12				Stat	OLS?
10	HGC82	El-r	US-h	78	79	CT			-0.67				0.16				Stat	OLS?

10	Gar83b	El-r	US-h	78	79	CTm		-2.73	-0.05			8.40	0.14			
10	Gar83c	El-r	US-h	78	79	CTm	-0.19			-1.40	0.10			0.41	Stat3Eq	2S
10	Gar86	El-r	US-h	78	79	CTm	-0.17				0.02				Stat3Eq	2S
10	Gar86	El-r	US-h-rNC	78	79	CTm	-0.97				0.12				Stat3Eq	2S
10	Gar86	El-r	US-h-rNE	78	79	CTm	-0.97				0.01				Stat3Eq	2S
10	Gar86	El-r	US-h-rS	78	79	CTm	-0.60				0.27				Stat3Eq	2S
10	Gar86	El-r	US-h-rW	78	79	CTm	-0.02				0.07				Stat3Eq	2S
Disag						Avg	-0.49		-0.63	-0.75	0.10		0.17	0.28		
						Std	0.39		0.24	0.46	0.09		0.03	0.09		
						Min	-0.97		-0.97	-1.40	0.01		0.12	0.22		
						Max	-0.02		-0.05	-0.38	0.27		0.21	0.41		
						#	6		12	3	6		12	3		

* income was found insignificant and was omitted from the estimation.

The instability of the lagged endogenous model is further demonstrated by C&B88, who systematically change the sample and find the coefficient on the lagged endogenous variable varies from 0.41 to 0.84. They find that price appears to be more inelastic in the 1970s than the 1950s and 1960s. Income elasticities appear to be rather erratic from correlation between income, the lagged endogenous variable, and the number of customers. Demand is income elastic on a sample from 1955 to 1964, drops to insignificance on a sample from 1956 to 1965, then gradually increases as a ten year sample is sequentially moved a year at time through a sample from 1965 to 1974 increasing to 0.92, then falling off again, until it has fallen to insignificance again on a sample from 1973 to 1978.

However, if one regresses the coefficient on the lagged endogenous variable $\varepsilon(Q_{t-1})$ on the short run price elasticity $\varepsilon(Psr)$ there is the following strong positive relationship:

$$\varepsilon(Q_{t-1}) = -1.25 + 1.421\ \varepsilon(Psr)$$

t statistic (8.31)

$R^2 = 0.74$

These results lead one to continue to question the lagged endogenous model and wonder whether these results have an economic or a statistical cause and to urge more work on the most appropriate way to make models dynamic.

D&S88 find an elastic long run price response from 1971 to 1974 and 1978 to 1982 but find the income response insignificant. MCR83 looked at rural data by regions. Their long run price and income elasticities average −0.51 and 0.47, which is not too different from a similar sample and model for all residential consumption. However, there appears to be wide variations across regions, particularly for income. This might be the result of the correlation between income and the variable used to measure farming activity (acres per farm or grain per farm.) Shi85 finds similar price and income elasticities on aggregate state data from 1960 to 1980.

Sut83b considers demand across time periods and across dynamic models. His long run price response averages greater than 1 in absolute value and his long run income response is less than 0.5. His PDL performs poorly on data from 1974 to 1980 with a positive price elasticity and a negative income elasticity but otherwise he tends to find higher price elasticities. Excluding the PDL estimates from 1974 to 1980, his three models PDL, LE, and DL tend to find fairly similar results across models and time periods. We do not see the same swings in elasticity across time periods as we did in the earlier study by C&B88, which lends support to the hypothesis that collinearity between # of customers and income might be causing the unstable results in their study. The comparison between these studies also suggests that continued work to study the relative roles of demographics, structural effects, and income might be fruitful.

There are three studies on annual time series data. Uri83b finds an intermediate price elasticity averaging −0.71 on a translog model using state data by regions. The variation in price elasticities across regions is not as large as in MCR83 on rural data. LCC87 using a bit more recent data finds an elastic price and an inelastic income response.

Y&S83 uses the longest time series, 1937 to 1977. On symmetric models, their price and income elasticities are near 1 in absolute value. However, when on their asymmetric model, they find that the elasticity for price cuts (Pcut) below previous minimums and income increases above previous maximums (Ymax) have price and income elasticities near those for a symmetric model, (See equations 36-38 in Section I) but other price and income changes have roughly half these responses. The three studies using quarterly or monthly data find rather erratic results and do not shed much light on the issue.

Moving on, the studies of disaggregate data for residential electricity demand are in Table 6, C10. As for the aggregate data, the price and income elasticities are both on average inelastic and there is wide variation across the price elasticities in each category. Income elasticities vary less and are on average much lower than for the aggregate data. However, some of the studies on aggregate data suggest that the income elasticities after 1974 have fallen. Gar83c using a 3 equation structural model that explicitly includes the appliance stock finds a long income elasticity of 0.41 which is now near the long run average for the aggregate data. His long run price elasticity lends support to those studies that find an elastic long run price response, whereas Poy86's study using a dynamic expenditure system does not.

There are two studies that consider demand elasticities for electricity by appliance stock. H&W81 uses state data and B&G82 uses household data. Their equations are summarized in Table A1 in the appendix with the results of their equation summarized in Table 7. Since both models include stock variables, these elasticities do not measure a purchase decision for electrical equipment but utilization along with the size and characteristics of the specific equipment choice.

Table 7: Comparison of Short Run Electricity Elasticities* by Appliance Stock for Household (h) and State Data (s)

		Price		Income	
C	Data	s	h	s	h
11	Cooking (ck)	-3.85	ns	ns	-1.18
11	Room Air conditioner (rac)	-1.68	-1.77	ns	0.20
11	Central air conditioner (cac)	ns	-1.24	ns	0.38
11	Clothes drying (cd)	ns	-1.54	ns	0.65
11	Color TV (ctv)	--	ns	--	ns
11	Clothes wash (cw)	9.07	--	ns	--
11	Dishwasher (dw)	--	ns	--	ns
11	Freezer (fr)	ns	--	ns	--
11	1 refrigerator (rf1)	--	-0.77	--	.09
11	2 refrigerator (rf2)	--	-3.14	--	ns
11	heating (ht)	-0.86	-1.06	ns	ns
11	water heat (wh)	-0.72	ns	ns	ns
11	total residential (r)	-0.40!	-0.72!!	ns!	0.20!!

*Elasticities are averages of significant elasticities with summaries of the studies are given in the appendix in Table A1.

! estimated by a regression.

!! weighted average of the elasticities by appliance stock.

There is not close agreement between the two studies with the aggregate data by states appearing to perform the more poorly. On state data, H&W81 find a significant negative price response for cooking, room air conditioning, heating and water heating, an immensely positive price response to clothes washing (9.07), but income elasticities to always be insignificant. On household data, B&G82 find a significant negative price response for room and central air conditioning, clothes drying, a first refrigerator, a second refrigerator, and for heating. They estimate a negative income response for cooking but positive income responses for central and room air conditioning, clothes drying, and a first refrigerator. Both studies find somewhat similar elasticities for room air conditioning and space heating.

Both authors compute overall elasticities for residential electricity demand. B&G82 find the residential price elasticity from a weighted average of their individual appliance elasticities to be −0.72, which is near the intermediate and long run averages in C9 and C10, while H&W81 find a price elasticity around half of this using a regression. B&G82 find an income elasticity of 0.20, which is consistent with the averages in C10 also on household data.

The rest of the residential electricity demand studies look at demand by season. These studies (Gar83, Gar84b, A&F82), which are high lighted here, are included by equation in the Appendix in Table A2. Gar83 and Gar84b finds summer elasticities much lower than winter elasticities (−0.27 versus −1.30), suggesting the demand for air conditioning with fewer substitutes is less elastic than the demand for heating with more substitutes. This result, however, does not agree with the appliance stock elasticity results in Table 7. Urban areas with better access to natural gas for heating have a more elastic demand than rural areas in the winter but not in the summer. The south has the least elastic demand in the summer but the most elastic demand in the winter, while the situation is reversed for the West. There are a number of inexplicable negative income elasticities in the seasonal estimates.

The monthly elasticities tend to mimic the more aggregate seasonal estimates with highest elasticities in November, January, and February and the lowest elasticities in June, July, and August. The one exception is that December shows the least elastic price response of any month. Perhaps 'tis the season to be electrical as well as jolly.' Variance in price elasticity estimates across regions also tends to be highest in winter months, except for December, and lowest in summer months.

Moving on to commercial demand, C12 in Table 8, all are on aggregate data. Results on static models are reasonable with price elasticities averaging −0.74 and income elasticities averaging 1.26.

Results on dynamic models are as wild as ever. On cross section times series, BDM82 find small price elasticities, negative income elasticities, and coefficients on the lagged endogenous model of 0.9 or greater. Sut83a finds very different price elasticity results on quarterly time series (−2.24) than Sut83b finds on annual time series for the same years (−1.05). He also finds his PDL and LE model very unstable across different time periods. As with economists, if you laid these elasticities end to end, you would have trouble coming to a conclusion.

The 12 studies on aggregate data for industrial demand in Table 8, C13 have more well behaved averages than for the commercial sector and suggest an elastic price and inelastic income response, but there is considerable variation across all categories of elasticities.

On CT data, BDM81 find very different results on a LE when they use OLS than when they use EC or EC-SUR. Most LE models suggest an elastic price response, but they find a widely varying income response from −0.33 to 1.34. Estimates using a PDL and DL also tend to favor an elastic price response but appear to be even more unstable than the LE model.

Models that measure more interfuel substitution, however, do not support the elastic price response of the LE model. K&L92 pick up very little price elasticity using translog and two dynamic variants of the translog with capital, labor, electricity, and fossil fuels on CT data for the US and a number of other OECD countries from 1960-1989, whereas the long run elasticity on an earlier study Kol86 using a dynamic translog with coal, oil, gas, and electricity through only 1982 found a long run price elasticity of −0.91.

Static logit models find an inelastic price response as well. As in the commercial sector it is difficult to come up with any meaningful estimates of price and income elasticities.

C14 in Table 8 contains demand studies by industry El-ii. Mcd91, a unique translog study that includes coal, oil natural gas, nuclear, hydro, and wholesale power purchases by electric utilities, is not included in the averages but finds a price elasticity of −0.34. For the other studies, the long run averages suggest an elastic price and an inelastic income response. The variance across industries is wide but is not wider than across earlier studies estimated on aggregate data in C13. In estimates on CT data by industry, D&C84 find a lower price elasticity on a static share model on CT data for 1974 through 1977 on the metal industry than on data for 1967 and 1971, but both are in the elastic range. However, estimates on a LE model yield a long run price elasticity of only −0.69. Other fuel share models find estimates on agriculture and food industries to be inelastic. The LE models tend to find widely varying long run elasticities across and within industries.

Table 8: New Demand for Commercial and Industrial Electricity Studies.

C	Ref	Product	Sample	y1	y2	Typ	Psr	t(p)	Pir	Plr	Ysr	t(Y)	Yir	Ylr	Q(−1)	t(Q−1)	Model	ET
12	Bad92	El-c	US-s	88	88	C		−3.82	−0.98			3.97	1.26				Stat	2S-all
12	Bad92	El-c	US-s	88	88	C		−4.73	−0.71			4.33	1.25				Stat	2S-sect
12	Hen83	El-c	US-ut	70	70	C		−5.69	−0.67								Stat	SUR
12	LCC87	El-c	US	60	83	T	−0.28			−1.33	0.26			0.82	0.69		LE	EC-SUR
12	Sut83a	El-c	US-s48	61	80	Tq	−0.82	−2.70		−2.24	−0.45	−1.22		0.37			PDL	2S
12	BDM81	El-c	US-s9	67	77	CT	−0.00	−0.30		−0.04	−0.08	−1.28		−0.82	0.90	45.99	LE	EC-SUR
12	BDM81	El-c	US-s9	67	77	CT	−0.03	−1.17		−0.37	−0.08	−0.73		−0.92	0.92	32.97	LE	OLS
12	BDM81	El-c	US-s9	67	77	CT	−0.01	−0.47		−0.10	−0.15	−1.90		−1.72	0.91	40.10	LE	EC
12	C&M84	El-c	US-s14	64	77	CT	−0.18			−0.92					0.81	40.30	LgElNgOGD	ISUR
12	C&M84	El-c	US-s14	64	77	CT			−0.59								LgElNgOGD	ISUR
12	Sut83b	El-c	US-s48	61	73	CT				3.36				0.26			PDL	2S
12	Sut83b	El-c	US-s48	74	80	CT				−2.00				−0.42			PDL	2S
12	Sut83b	El-c	US-s48	61	80	CT				−1.05				0.34			PDL	2S
12	Sut83b	El-c	US-s48	61	73	CT				−0.28				1.29			LE	2S
12	Sut83b	El-c	US-s48	74	80	CT				−4.74				−21.12			LE	2S
12	Sut83b	El-c	US-s48	61	80	CT				−0.46				0.56			LE	2S
12	Sut83b	El-c	US-s48	61	73	CT				−0.61				0.69			DL	2S

12	Sut83b	El-c	US-s48	74	80	CT				-0.80				1.39			DL	2S
12	Sut83b	El-c	US-s48	61	80	CT				-0.74				0.98			DL	2S
						Avg	-0.22		-0.74	-0.82	-0.10		1.26	-1.31	0.84			
						Std	0.29		0.15	1.60	0.23		0.00	5.56	0.09			
						Min	-0.82		-0.98	-4.74	-0.45		1.25	-21.12	0.69			
						Max	-0.00		-0.59	3.36	0.26		1.26	1.39	0.92			
						#	6		4	15	5		2	14	5			
13	Bad92	El-i	US-s	88	88	C		-2.05	-0.86			6.95	0.57				Stat	2S-sect
13	Bad92	El-i	US-s	88	88	C		-2.07	-0.83			6.96	0.56				Stat	2S-alls
13	Hen83	El-i	US-ut	70	70	C		-8.82	-1.73				0.09				Stat	SUR
13	BDM81	El-i	US-s9	67	77	CT	-0.12	-4.44		-3.55	0.01	0.70		0.44	0.97	60.45	LE	EC
13	BDM81	El-i	US-s9	67	77	CT	-1.03	-24.89		-1.15	0.02	0.47		0.02	0.10	3.87	LE	OLS
13	BDM81	El-i	US-s9	67	77	CT	-0.12	-5.53		-2.97	0.04	2.23		1.00	0.96	70.07	LE	EC-SUR
13	KBP86	El-i	US	60	82	CT	-0.14										Tl2COElNg	ISUR
13	Kol86	El-i	US	60	82	CT	-0.01										Tl2COElNg	ISUR
13	Kol87	El-i	US	60	82	CT				-0.91							Tl2COElNg	ISUR
13	K&L92	El-i	US	60	89	CT		1.10		0.12							Tl3KLFfEl	FIML
13	K&L92	El-i	US	60	89	CT		0.06	0.01								TlKLFfEl	FIML
13	K&L92	El-i	US	60	89	CT		-3.91		-0.27							Tl2KLFfEl	FIML
13	Sut83b	El-i	US-s48	61	73	CT				17.40*				0.09			PDL	2S
13	Sut83b	El-i	US-s48	74	80	CT				-0.78				-1.01			PDL	2S
13	Sut83b	El-i	US-s48	61	80	CT				-1.12				0.47			PDL	2S
13	Sut83b	El-i	US-s48	61	73	CT				-1.26				0.65			LE	2S
13	Sut83b	El-i	US-s48	74	80	CT				-1.15				1.34			LE	2S
13	Sut83b	El-i	US-s48	61	80	CT				-1.14				-0.33			LE	2S
13	Sut83b	El-i	US-s48	61	73	CT				-2.23				1.44			DL	2S

Table 8: New Demand for Commercial and Industrial Electricity Studies.

C	Ref	Product	Sample	y1	y2	Typ	Psr	t(p)	Pir	Plr	Ysr	t(Y)	Yir	Ylr	Q(-1)	t(Q-1)	Model	ET
13	Sut83b	El-i	US-s48	74	80	CT				-1.32				-0.44			DL	2S

```
13 Sut83b El-i    US-s48  61 80 CT                     -1.56                    0.73
             DL       2S
13 Con89b El-i    US      70 85 T                -0.41
              TlCONgEl FIML
13 Con89b El-i    US      70 85 T                -0.38
              LgCONgElFIML
13 Con89b El-i    US      70 85 T                -0.51
              TlCONgEl FIML
13 Con89b El-i    US      70 85 T                -0.49
              LgCONgEl FIML
13 Con89b El-i    US      70 85 T                -0.39
              TlCO+tNgEl FIML
13 Con89b El-i    US      70 85 T                -0.40
              LgCO+tNgEl FIML
13 Hal86b El-i    US      60 79 T         -6.43  -0.50
              TlCOElNg ISUR
13 Hal86b El-i    US      60 79 T         -5.16  -0.14
              TlCOElNg ISUR
13 LCC87  El-i    US      60 83 T  -0.39               -1.16  0.28              0.84
 0.67        LE       EC-SUR
13 M&K86  El-i    US      59 77 T         -3.98  -0.40
              TlElFfMKLISUR
13 Sut83a El-i    US-s48  61 80 Tq  0.06   0.82        -0.85  0.17  2.41         0.08
             PDL      2S
                                Avg-0.25         -0.54 -1.33  0.10         0.40  0.38
 0.67
                                Std 0.34          0.41  4.49  0.10         0.23  0.67
 0.35
                                Min-1.03         -1.73 -3.55  0.01         0.09 -1.01
 0.10
                                Max 0.06          0.01 17.40  0.28         0.57  1.44
 0.97
                                #      7            13    17     5            3    14
    4

14 Mcd91* El-e-whsUS-ut82 87 87 C                -0.34
           TlCONgNHyElws ISUR
14 Uri88a El-ag   US-s    78 80 CT               -0.76
           TlGDLpFoNgEl SUR
14 C&C81  El-ch   US      59 76 T  -0.58  -3.03        -1.46  0.33  5.42         0.82
 0.61  12.10 LE       3S
14 C&C81  El-ct   US      59 76 T  -0.09  -0.73        -0.11  0.82  7.41         1.02
 0.20   2.02 LE       3S
14 C&C81  El-fd   US      59 76 T  -1.46  -8.13        -2.50  0.28  4.60         0.47
 0.42   5.19 LE       3S
14 L&L84  El-fd   US      54 76 CT               -0.29                     0.93
              Lg-ONgCElML
14 L&L84  El-fd   US      54 76 T                -0.58                     0.86
              Tl-ONgCElML
14 C&C81  El-gl   US      59 76 T  -1.07  -5.63        -1.28  0.21  1.77         0.25
 0.17   2.10 LE       3S
14 C&C81  El-gr   US      59 76 T  -0.23  -1.15        -1.62  0.10  2.50         0.71
 0.86   8.59 LE       3S
14 D&C84  El-mt   US-s    75 77 CT -0.27               -0.69
              Sh-LE    SUR
14 D&C84  El-mt   US-s    74 77 CT               -1.10
              Sh-2Eq   SUR
14 D&C84  El-mt   US-s    67&71 CT               -1.30
              Sh-2Eq   SUR
```

14	C&C81	El-mt	US	59	76	T	−0.46	−1.10		−2.00	0.38	2.90	1.63	0.77	7.68	LE	3S
14	C&C81	El-mt	US	59	76	T	−0.65	−2.82		−1.03	0.60	5.42	0.94	0.37	4.59	LE	3S
14	C&C81	El-mt	US	59	76	T	−0.43	−3.10		−0.95	0.39	6.45	0.84	0.54	10.82	LE	3S
14	C&C81	El-pl	US	59	76	T	−0.22	−1.35		−0.40	0.43	4.77	0.79	0.46	5.08	LE	3S
14	C&C81	El-rf	US	59	76	T	−0.03	−0.41		−0.19	0.18	4.55	1.03	0.82	20.58	LE	3S
14	C&C81	El-te	US	59	76	T	−1.51	−4.86		−1.66	0.46	7.65	0.51	0.10	1.06	LE	3S
14	C&C81	El-tx	US	59	76	T	−1.00	−5.01		−1.86	0.48	4.40	0.90	0.46	9.20	LE	3S
14	C&C81	El-tx	US	59	76	T	−0.13	−1.83		−0.17	0.46	15.43	0.62	0.25	5.06	LE	3S
						Avg	−0.58		−0.81	−1.14	0.39		0.81	0.46			
						Std	0.48		0.36	0.73	0.18		0.32	0.24			
						Min	−1.51		−1.30	−2.50	0.10		0.25	0.10			
						Max	−0.03		−0.29	−0.11	0.82		1.63	0.86			
						#	14		5	14	13		13	13			

* not included in the average.

Given the large variance in estimates for all three consuming sectors one is rather cautious in coming to overall conclusions. However, I venture to make the following observations. Studies for aggregate electricity demand suggest that the long run price elasticity might be near −1. If we look at averages across categories in the household sector, price and income elasticities are inelastic, with less income elasticity picked up on disaggregate data than on aggregate data. The long run price elasticity averages of −0.91 and −0.75 are near the numbers selected by earlier researchers. However, there is wide variation across studies. There is some evidence that price elasticity is lower in the 1970s than in the 1950s and 1960s, whereas income elasticities appear to drop off after 1974. There is also some evidence that the elasticity for price cuts (Pcut) below previous minimums and income increases above previous maximums (Ymax) have larger price and income elasticities than for other price and income changes (See equations 36-38 in Section I. Summer price elasticities appear to be lower than those in the winter and there is a fair amount of variance in elasticity estimates across regions. All models that consider long run adjustment by using lagged variables appear to show significant instability in estimates.

As was concluded in earlier surveys, studies on the commercial and industrial sector are even more puzzling. If we eliminate the obviously peculiar estimates in these two categories long run price is elastic and income is inelastic. However, the variation across the dynamic models and across time periods would lead one to be very cautious about this interpretation of the results.

There appears to be considerable variation across industries. If this variation is caused by the differences within industries rather than the vagaries of the lagged endogenous variable, then structural change will be important in determining future consumption in the industrial sector.

Poorer data and fewer studies limit our knowledge of the industrial and commercial sector much as was the case for the earlier surveys. Little is still known about the dynamics of adjustment, nor do we have very precise information on the size of the elasticities particularly for the commercial and industrial sector. There is some evidence that there is less price elasticity in the post 1973 period. Since few studies include very recent data, we do not know if lower price elasticities were associated with a response to the energy crisis or whether they persist to the present.

III.3 Time of Day Pricing Studies for Electricity and Peak/OffPeak Elasticities.

With the nonstorability of electricity, uncertainty over fuel prices, concerns over the political acceptability of nuclear energy, and nimby problems in siting new plants, utilities became more concerned about making big up front capital investments in new plants. These concerns led to considering shifting peaks loads and time of day pricing.

An early study by Cargill and Meyer (1971), surveyed by Taylor (1975), looked at monthly observations for each hour of the day from 1965:1 to 1969:12 for two cities. Elasticities for the midwest industrial city vary across the 24 hours of the day from -0.38 to -0.57. They tend to be highest from 7-11 am and from 8-10 pm and lowest from noon to 7 pm and 11-12 pm with the price elasticities significant. They are less elastic and vary more for the west coast city from -0.06 to -0.52 with the price elasticities found to be insignificant. The elasticities are highest from 1-5 am and lowest from 1 pm - 10 pm. Since the price variable is the price of electricity divided by the price of gas the specification forces the electricity and gas price to have equal but opposite effects. Income was not found to be significant in either city. No statistical tests were mentioned to determine if the differences across time periods were significant. Nor was there any consideration of substitution effects across peak and off peak periods.

More recently Hawdon (1992) has considered time of day studies for the residential sector, which explicitly consider substitution across time periods. These studies were made possible by a time of day experiment in the UK in 1967 and 15 studies in the US conducted somewhat later. He notes the advantages for such experimental studies are that they can increase the range of data variation over historical data, they can include policy relevant ranges of variables, and often provide information on the feasibility and cost of implementing a policy.

He notes the disadvantages for them are that they are costly, they usually include side payments that might bias the results of the study, they require loyalty from the participants, there is a temptation to implement the policies before the experiments are complete, and the Hawthorne effect arises, where part of the response may be a result of being in the study rather than an economic response to they economic parameter in question.

Hawdon's overall criticism of the experiments is that they often failed to apply experimental design and optimal sampling strategies. There was a lack of consistency across studies. The studies varied considerably in their time period, tariffs, sample sizes, and peak period length making their results difficult to compare. Only two were based on models of consumer behavior. Some were voluntary, some were not. Since all the studies were temporary they are likely to be capturing short run effects at best.

He then goes on to survey 11 studies that were based on 7 experimental programs. The reported price elasticities are summarized in Table 9.

Table 9: Elasticities for Time of Day Studies Surveyed by Hawdon (1992), Table 3.2, p. 103.

Own price elasticities for Peak (ε_{pk}), Offpeak (ε_{opk}), MidPeak (ε_{mpk}) and Cross Price Elasticity between Peak and Offpeak ($\varepsilon_{pk,opk}$))

S		ε_{pk},	ε_{opk}	ε_{mpk}	$\varepsilon_{pk,opk}$
31	Avg	-0.23	-0.34	-0.39	-0.11

Std	0.43	0.43	0.27	0.26
Min	-0.80	-0.90	-0.70	-0.50
Max	0.80	0.50	0.06	0.30
#	9	8	7	9

Although results are mixed some general conclusions are made by the Hawdon. (Note his Table and his text are not always consistent with larger variation in his Table than in his text. I quote both his Table and text as they are given.) He finds evidence of higher elasticities of substitution across peak and nonpeak for voluntary programs. Own peak elasticities vary from 0.81/-0.26, own off peak elasticities vary from -0.05/-0.27, middle period peak elasticities vary from 0.57/-0.66. Elasticities of substitutions (not reported in Table 9) vary from 0.01/0.37. Although all the reported elasticities of substitution are positive, many of the cross price elasticities are negative as noted in the above Table with averages suggesting that peak and off peak elasticities are gross complements.

Hawdon feels that the results vary because of the quality of the sample design, the length of the peak period, the choice of the demand model, the lack of good data for income, and different representations of household characteristics and appliance stock. He also notes that there tends to be interaction between household characteristics, weather, and appliance stock. Air conditioners have an impact on summer peak while water and space heaters have an impact on winter peaks. Larger household sizes have lower peak price elasticities. Experiments with peak load tariffs found them more successful in shifting summer air conditioning peak utilization than the winter heating peak, but there was the feeling that lack of feedback to customers prevented more shifting from occurring.

The studies that included seasonal tariffs found they had little affect in shifting load. The greatest affect of the pricing change was on peak demand and the effect was to shift it to night time off peak rather than adjacent off peak periods. Overall the studies suggest that peak load pricing is not effective since the change in consumer surplus plus the change in producer revenue are smaller than the increased metering costs.

Looking at additional work, the studies in A2, which include seasonal effects have some information on peak demand. For example, AFM82 find that residential price elasticities are higher during months of peak demand (-0.47) than during off peak months (-0.32).

The most recent time of day pricing study I have found is Tis91. His results, summarized in Table 10, C15 below, are for industrial time of day pricing estimated from two models on two firms A and B, one assuming cost minimization and another assuming profit maximization using Southern California Edison's TOU 8 rate for two firms. He does not assume weak separability from labor and includes it in his estimation equation. He is not very clear about his sample, except that it is monthly data that appears to begin in October of 1977. He finds all own price elasticities to be negative but small varying across models and firms from -0.015 to -0.087. Peak demand elasticities tend to be slightly more elastic than mid or offpeak, which are similar. The cost minimization model shows less elastic own price responses. Cross elasticities between the time periods tend to be even smaller, but are of mixed signs. In the profit maximization model all electricity inputs are complements and in the cost minimization they are all substitutes. His elasticities are smaller than most other estimates for industrial energy demands in C13 and C14.

The overall conclusion from the time of day work suggests that elasticities may vary across time periods but there does not tend to be any sort of consensus, at this point, on whether there is substitution for electricity demand across time periods or not either for the residential or the industrial sector.

Table 10: New Time of Day Industrial Demand for Electricity Studies

C	Ref.	Product	Sample	y1	y2	Type	Pir	Model	Other Cross Prices					
15	Tis91	El-mpk	US-firmB	77:10	?	C-m	-0.016	Cost Min	Ppk	0.002	Popk	0.005	Pl	-0.029
15	Tis91	El-mpk	US-firmA	77:10	?	C-m	-0.041	Cost Min	Ppk	0.014	Popk	0.019	Pl	0.002
15	Tis91	El-mpk	US-firmB	77:10	?	C-m	-0.019	Prof max	Ppk	-0.001	Popk	-0.000	Pl	-0.151
15	Tis91	El-mpk	US-firmA	77:10	?	C-m	-0.063	Prof max	Ppk	-0.004	Popk	-0.002	Pl	0.011
						Avg	-0.035			0.003		0.006		-0.042
						Std	0.019			0.007		0.008		0.065
						min	-0.063			-0.004		-0.002		-0.151
						max	-0.016			0.014		0.019		0.011
						#	4			4		4		4
15	Tis91	El-opk	US-firmB	77:10	?	C-m	-0.024	Prof max	Ppk	-0.002	Pmpk	-0.000	Pl	-0.201
15	Tis91	El-opk	US-firmB	77:10	?	C-m	-0.015	Cost Min	Ppk	0.003	Pmpk	0.006	Pl	-0.022
15	Tis91	El-opk	US-firmA	77:10	?	C-m	-0.058	Prof max	Ppk	-0.008	Pmpk	-0.002	Pl	0.011
15	Tis91	El-opk	US-firmA	77:10	?	C-m	-0.040	Cost Min	Ppk	0.008	Pmpk	0.017	Pl	0.003
						Avg	-0.034			0.000		0.005		-0.052
						Std	0.016			0.006		0.007		0.087
						min	-0.058			-0.008		-0.002		-0.201
						max	-0.015			0.008		0.017		0.011
						#	4			4		4		4
15	Tis91	El-pk	US-firmA	77:10	?	C-m	-0.038	Cost Min	Pmpk	0.087	Popk	0.015	Pl	-0.003
15	Tis91	El-pk	US-firmB	77:10	?	C-m	-0.057	Prof max	Pmpk	-0.003	Popk	-0.006	Pl	-0.276
15	Tis91	El-pk	US-firmA	77:10	?	C-m	-0.087	Prof max	Pmpk	-0.007	Popk	-0.014	Pl	0.011
15	Tis91	El-pk	US-firmB	77:10	?	C-m	-0.043	Cost Min	Pmpk	0.006	Popk	0.007	Pl	0.047
						Avg	-0.056			0.021		0.002		-0.055
						Std	0.019			0.039		0.011		0.129
						min	-0.087			-0.007		-0.014		-0.276
						max	-0.038			0.087		0.015		0.047
						#	4			4		4		4

IV. Demand for Natural Gas

IV.1 Previous Surveys. Natural gas has the same methodological issue associated with decreasing block pricing as for electricity. In addition there are the difficulties in determining the demand elasticities of natural gas because of supply constraints, particularly in the commercial and industrial interstate market. At times there have also been restrictions on new under the boiler use for natural gas. These constraints suggest that historical elasticities may not have much relevance in evaluating current and future natural gas demand elasticities.

Nevertheless, I consider what the historical evidence suggests about the natural gas market. Taylor (1977) surveys 11 studies of natural gas demand. These studies are aggregated and summarized below in Table 11 by end user. All studies were done on aggregate data and used the average price of natural gas (Pa).

Table 11: Demand for Natural Gas Elasticities Surveyed by Taylor (1977), Table 1.3, p. 21.

S			Pir	Plr	Ysr	Ylr
32	Ng-r	Avg	-0.08	-1.47	0.32	1.33
		Std	0.08	0.89	0.01	1.46
		Min	-0.16	-3.00	0.30	-0.23
		Max	0.00	0.00	0.33	3.11
		#	2	6	2	4
33	Ng-c	Avg	-0.38	-1.45	0.73	large
		#	1		1	1
34	Ng-r&c	Avg	-0.14	-0.70	0.03	0.38
		Std		0.00		0.25
		Min		-0.70		0.13
		Max		-0.69		0.62
		#	1	2	1	2
35	Ng-i	Avg	-0.17	-1.59	1.00	0.63
		Std		0.55		0.32
		Min		-2.11		0.21
		Max		-0.58		1.00
		#	1	5	1	3
36	Ng-c&i	Avg		-3.85		-0.29
		#		1		1

He found wide variation in long run price elasticities (0/-3.85). Most studies found the demand for natural gas to be price elastic, while those that used a BN model, that breaks demand into new and old demand, found new gas to have an elasticity of -0.7, but old gas to have an elasticity below -0.05.

Dynamic models find more consistent long run elasticities than is the case for electricity. The commercial sector seems to have a more elastic price response than the residential sector, especially when the estimates are done on disaggregate data. (S32-S34) He finds that for the residential sector a disaggregate model on monthly data finds low price elasticities; two dynamic reduced form models find widely varying income and price elasticities, little difference was found between estimates from OLS, EC, and EC-SUR.

One study found a much more elastic response from a reduced form equation than from an elasticity derived from equations on the ownership of energy using appliances.

There was also wide variation across long run income elasticities (-0.23/3.11) with one estimate on commercial consumption designated as large) although all income elasticities for industrial users were 1 or less. Taylor concludes, that although there is great deal of uncertainly over the actual magnitude of the elasticities, there is strong evidence that demand responds to prices, there is some substitution across fuels, and there is probably some location bias in the price elasticities of industrial users on cross sectional data. He concludes that the short run demand for natural gas is -0.15 and that the long run price elasticity is more elastic than -1.

Bohi (1981) surveys 16 studies for natural gas demand, using a similar stratification to the one he used for electricity. Studies in some categories use marginal price (Pm) and others used average price (Pa) as indicated in the Table 12, which contains summaries of these studies.

Table 12: Demand Elasticities for Natural Gas Surveyed by Bohi (1981), Tables 4-1 and 4-2, pages 94, 95, and 106.

S	Product		Psr	Plr	Ysr	Ylr
37	Ng-r (CS)	Avg		-2.06		1.86
	Stat, Agg, Pa	Std		0.33		0.21
		Min		-2.42		1.59
		Max		-1.54		2.18
		#		4		4
38	Ng-r	Avg		-0.31		0.10
	Stat,Disag,	Std		0.14		0.02
	Pm	Min		-0.45		0.08
		Max		-0.17		0.12
		#		2		2
39	Ng-c Stat	Avg		-1.04		
	Disag, Pm	#		1		
40	Ng-r&c	Avg	-0.10	-0.70	-0.01	0.38
	Dyn,Agg,Pa	Std	0.07	0.00	0.02	0.25
		Min	-0.16	-0.70	-0.03	0.13
		Max	-0.03	-0.69	0.00	0.62
		#	2	2	2	2
41	Ng-r	Avg	-0.32	-0.80		
	Dyn,Agg,Pa	Std	0.13	0.20		
		Min	-0.50	-1.02		
		Max	-0.15	-0.48		
		#	4	4		
42	Ng-r	Avg	-0.28	-0.37	0.05	0.07
	Dyn,Disag,Pa	#	1	1	1	1
43	Ng-r&c Stat	Avg		-1.26	ns	ns
	FShare,Agg	#		1	1	1
44	Ng-r,Ng-c	Avg	-0.27	-1.01	ns	ns
	Ng-r&c	Std	0.09	0.04		
	Dyn,FShare,Agg	Min	-0.34	-1.06		
		Max	-0.15	-0.95		
		#	3	3		

Table 12 (continued): Demand Elasticities for Natural Gas Surveyed by Bohi (1981), Tables 4-1 and 4-2, pages 94, 95, and 106.

S	Product		Psr	Plr	Ysr	Ylr
45	Ng-r	Avg	-0.30	-2.00		
	Struct, Agg	#	1	1		
46	Ng-i	Avg	-0.14	-0.63		
	Dyn,FShare,Agg	Std	0.07	0.18		
		Min	-0.21	-0.81		
		Max	-0.07	-0.45		
		#	2	2		
46	Ng-ii	Avg		-1.44		
	2 digit	Std		0.03		
		Min		-1.47		
		Max		-1.41		
		#		2		
47	Ng-e	Avg	-0.06	-1.43		
	Stat,utility	#	1	1		

Bohi finds that price elasticities estimated from microdata in the residential sector (S38) tend to be much less price and income elastic than those on aggregate data (S37). He dismisses the large income elasticities from some static cross section estimates and concludes that income is not found to be an important variable in natural gas demand. However, he does conclude that the income variable in models is sensitive to whether household characteristics and appliance holdings are included.

The only structural model for the residential sector (S45) has share equations for water heating, space heating, cooling, and clothes drying on cross sectional data. He finds the equations fairly consistent across appliances with a long run elasticity of -2 and cross price elasticities for fuel oil and electricity of 0.43 and 0.28. However, Bohi concludes that the model is not to be believed because the same model performed badly for electricity demand yielding a positive price elasticity. One might note, however, that the price elasticity is surprisingly close to the static estimates on aggregate cross sectional data.

Bohi concludes that residential demand is price inelastic and is likely less elastic than in the electricity sector. His conclusion, however, is based on dismissing out of hand the cross section aggregate results. Although supply constraints may bias long run aggregate elasticities with intrastate markets having less supply constraints, I would still argue that one should rather see if these models perform well in forecasting aggregate responses, not whether they necessarily agree with models on disaggregate data. Further, the structural model supports the large price elasticity on aggregate data and fuel share models tend to put the price response in the slightly elastic range.

Bohi looks at 4 studies for industrial gas demand (S45,S46) and two on electricity generation (S47). For industrial demand, the two studies on more disaggregate data find larger price and cross price elasticities than the two on more disaggregate. The two on electricity generation vary widely because one is on a monthly time series on US data while the other is on a cross section of utilities. In general he finds that there appears to be substitution across fuels but it is difficult to determine whether industrial and electricity generation demand for natural gas is price elastic or inelastic. I would conclude this somewhat more recent and larger sample of models gives somewhat more consistent results that the earlier studies and would urge more work to try explain the large price elasticities on cross sectional data, the medium estimates on fuel share models, and the extremely low elasticities on disaggregate data for the residential sector.

Bohi and Zimmerman (1984) consider 8 more recent studies on natural gas, that are summarized below in Table 13. The study on disaggregate monthly data (S49) finds an average elasticity of −0.32. The two studies using a dynamic model vary widely (S50,S51). The one that includes both marginal, average price and a gas availability parameter find price elasticities similar to those on disaggregate data, but a more significant income response (S51). The study that uses aggregate data and only the average price finds average price elasticities of −3.13 but an insignificant income response (S50). When a static stock model is used no significant price and income elasticities are found. (S52). From the residential studies the authors conclude that the consensus estimate for natural gas price elasticity in the residential sector in the short run is −0.2 and in the long run is −0.3. Although most categories find little income response, the one study that explicitly tries to take supply constraints into account finds a long run income elasticity of 0.63. More work might be done to determine whether earlier low income elasticities are a reflection of supply constraints.

Table 13: Demand Elasticities for Natural Gas Surveyed by Bohi and Zimmerman (1984), Pgaes 124, 133, 134.

S	Product		Psr	Plr	Ysr	Ylr
49	Ng−r,	Avg		−0.32	not reported	
	Stat, Disag, Pm	Std		0.16		
	monthly	Min		−0.60		
		Max		−0.22		
		#		4		
50	Ng−r	Avg	−0.27	−3.13	ns	ns
	Dyn,Agg,Pa	Std	0.05	0.27		
		Min	−0.35	−3.44		
		Max	−0.23	−2.79		
		#	3	3	3	3
51	Ng−r	Avg	−0.04	−0.30	0.09	0.63
	Dyn,Agg,Pm&Pa	Std	0.01	0.03	0.02	0.14
		Min	−0.05	−0.33	0.06	0.48
		Max	−0.03	−0.26	0.11	0.77
		#	2	2	2	2
52	Stat−Sk,Agg, Pa	Avg	ns		ns	
		#	3		3	
53	Ng−c	Avg	−0.22	−1.38	ns	ns
	Dyn,Agg,Pa	Std	0.16	0.99		
		Min	−0.37	−2.27		
		Max	0.00	0.00		
		#	3	3	3	3
54	Ng−i	Avg	−0.62	−2.48	0.74	2.96
	Dyn,Agg,Pa	Std	0.01	0.06	0.03	0.09
		Min	−0.63	−2.54	0.70	2.86
		Max	−0.61	−2.40	0.78	3.08
		#	3	3	3	3
55	Ng−i	Avg		−2.54		
	Stat,FShare,Agg,	Std		0.38		

Pa	Min	-2.92
	Max	-2.16
	#	2

They include only one study on the commercial sector using aggregate data (S53). The price elasticities vary widely being insignificant for OLS but are almost 2 or larger in absolute value using EC or EC-SUR regressions. The income elasticity is insignificant for all three approaches. There are two studies using aggregate data for the US industrial sector, one on a dynamic reduced form (S54) another on a share model (S55). Both suggest that industrial demand is price elastic (-2.5). However, the only study that estimates income elasticities finds noncredible elasticities averaging close to 3 (S54).

Kirby (1983) surveys 5 residential demand studies for natural gas and estimates demand as well. The only new study as well as her estimates, all on household data, support most earlier estimates on household data and suggest a long run price that could be near -0.3 and a long run income elasticity less than 0.4.

IV.2 New Studies on Natural Gas Demand. There is one new study on total demand for natural gas in Table 14, C16 with average intermediate price and income elasticities in the inelastic range (-0.27 and 0.71). However, the price elasticities are considerably lower (-0.05 vs -0.49) when the prices of electricity and fuel oil are included in the estimation.

There are 9 post 1980 studies included on residential demand for natural gas on aggregate data in Table 14, C17. The average short, intermediate, and long run price/income elasticities are all inelastic and appear fairly well behaved (-0.13, -0.62, -0.68/ 0.09, .53, .49) respectively. However, we see wide variations across both the intermediate and long run price elasticities. (1.86/-3.44)

BDM81, has large price elasticities as a result of the large coefficient on the lagged endogenous variable and insignificant income elasticities for nine northeastern states. We see an even larger coefficient on the lagged endogenous variable in D&S88, with included price elasticities insignificant and income elasticities, which were found to be insignificant and were excluded.

BTR83, which include a gas availability variable, and Gra86, who stratifies his samples by gas availability both seem to find reasonably gas price elasticities, although Gra86 finds income to be insignificant. Other studies that do not take gas availability into account, Liu83 and Uri83b, find fairly high variations across regions. All studies suggest that gas response to income is inelastic, although Liu83 does not report income elasticities for his estimates from a linear equation. Comparing these studies to those on households in C18 we see the aggregate data suggests more price and income elasticity (-0.62 vs -0.17 and 0.53 vs 0.10). However, A&W86 divide household dat into those who buy gas in the interstate market (-si) (C20) and those who buy in the intrastate market (-sa) (C19). They find a uniformly low income elasticities as in the other household data studies with income elasticity perhaps slightly higher in the interstate market. They find uniformly elastic price response with perhaps the more elastic response in the interstate market and a higher price elasticity in the interstate market when census division dummy variables are included. Their results are quite interesting because they are on the most recent data and they segregate interstate and intrastate markets. I believe that their elastic price response is the result of not including the price of substitute fuels and would encourage more work to determine if inclusion of the price of substitute fuels would put these results more in line with other studies.

Table 14: New Demand for Total and Residential Natural Gas Studies

C	Ref	Product	Sample	y1	y2	Type	Psr	t(p)	Pir	Plr	Ysr	t(Y)	Yir	Ylr	Q(-1)	t(Q-1)	Model	ET
16	Liu83	Ng	US Stat	67	78	CT		-0.60	-0.07				nr				OLS	

```
16 Liu83  Ng       US       67 78 CT          -8.57 -0.49                           nr
                  Stat    OLS
16 Liu83  Ng       US       67 78 CT          -0.20 -0.03                  7.29   0.62
                  Stat    OLS
16 Liu83  Ng       US       67 78 CT         -13.14 -0.49                 11.35   0.79
                  Stat    OLS
                                Avg                 -0.27                         0.71
                                Std                  0.22                         0.09
                                Min                 -0.49                         0.62
                                Max                 -0.03                         0.79
                                  #                     4                            2

17 BDM81  Ng-r     US-9st   67 77 CT   -0.23  -2.94         -2.79  0.01  0.22
0.13  0.92  51.81  LE      OLS
17 BDM81  Ng-r     US-9st   67 77 CT   -0.24  -4.51         -3.17  0.01  0.23
0.11  0.93  74.60  LE      EC
17 BDM81  Ng-r     US-9st   67 77 CT   -0.35  -7.16         -3.44  0.03  0.89
0.26  0.90  77.36  LE      EC-SUR
17 BTR83  Ng-r     US-s48   61 70 CT   -0.05  -3.05         -0.36  0.12  5.49
0.80  0.86  56.02  LE      EC
17 BTR83  Ng-r     US-s48   61 70 CT   -0.05  -2.85         -0.33  0.11  5.25
0.77  0.85  54.94  LE      EC
17 BTR83  Ng-r     US-s48   61 70 CT   -0.05  -2.80         -0.34  0.11  5.28
0.80  0.86  56.04  LE      EC
17 BTR83  Ng-r     US-s48   61 74 CT   -0.03  -1.98         -0.26  0.06  3.63
0.48  0.88  72.60  LE      EC
17 BTR83  Ng-r     US-s48   61 74 CT   -0.03  -1.98         -0.26  0.06  3.66
0.48  0.88  72.70  LE      EC
17 BTR83  Ng-r     US-s48   61 74 CT   -0.03  -2.05         -0.26  0.06  3.68
0.48  0.88  72.79  LE      EC
17 BTR83  Ng-r     US-s48   61 74 CT   -0.32                -0.39  0.03
0.34               2EqLE   EC
17 D&S88  Ng-r     US-s     71 74 CT    0.02   0.38          1.19
    0.99  59.13  LE      EC
17 D&S88  Ng-r     US-s     78 82 CT   -0.06  -0.68         -0.96
    0.94  35.89  LE      EC
17 Gra86  Ng-r     US-s9    60 78 CT   -0.09  -1.13         -0.16         ns
                  LE      BxCx-h
17 Gra86  Ng-r     US-s7    60 78 CT   -0.14  -2.63         -0.31         ns
                  LE      BxCx-h
17 Gra86  Ng-r     US-s10   60 78 CT   -0.15 -18.17         -0.53         ns
                  LE      BxCx-h
17 Gra86  Ng-r     US-s11   60 78 CT   -0.16  -2.85         -0.86         ns
                  LE      BxCx-h
17 Gra86  Ng-r     US-s8    60 78 CT   -0.16  -2.79         -0.72         ns
                  LE      BxCx-h
17 Gra86  Ng-r     US-s5    60 78 CT   -0.03  -0.59         -0.46         ns
                  LE      BxCx-h
17 Gra86  Ng-r     US-avg              -0.10                -0.40         ns
17 Leb88  Ng-r     US-s7ENC60 82 CT          -10.83 -0.30                  1.89   0.58
                  Stat    GLS-sh
17 LCC87  Ng-r     US       60 83 T    -0.15                -1.22  0.11
0.57  0.82         LE      EC-SUR
17 Liu83  Ng-r     US       67 78 CT          -2.53 -0.54
                  Stat    OLS
17 Liu83  Ng-r     US       67 78 CT          -5.08 -0.39
                  Stat    OLS
17 Liu83  Ng-r     US       67 78 CT          -1.59 -0.49                  3.41   0.55
                  Stat    OLS
```

C	Ref	Product	Sample	y1	y2	Type	Psr	t(p)	Pir	Plr	Ysr	t(Y)	Yir	Ylr	Q(-1)	t(Q-1)	Model	ET
17	Liu83	Ng-r	US	67	78	CT		-4.89	-0.32			5.34	0.46				Stat	OLS
17	Liu83	Ng-r	US-s-r1	67	78	CT				-0.19			nr				DL	OLS
17	Liu83	Ng-r	US-s-r2	67	78	CT				0.33			nr				DL	OLS
17	Liu83	Ng-r	US-s-r3	67	78	CT				-0.93			nr				DL	OLS
17	Liu83	Ng-r	US-s-r4	67	78	CT				-0.65			nr				DL	OLS
17	Liu83	Ng-r	US-s-r5	67	78	CT				-0.56			nr				DL	OLS
17	Liu83	Ng-r	US-s-r6	67	78	CT				-0.75			nr				DL	OLS

Table 14 (continued): New Demand for Total and Residential Natural Gas Studies

C	Ref	Product	Sample	y1	y2	Type	Psr	t(p)	Pir	Plr	Ysr	t(Y)	Yir	Ylr	Q(-1)	t(Q-1)	Model	ET
17	Liu83	Ng-r	US-s-r7	67	78	CT				-0.40			nr				DL	OLS
17	Liu83	Ng-r	US-s-r8	67	78	CT				1.56			nr				DL	OLS
17	Liu83	Ng-r	US-s-r9	67	78	CT				-0.76			nr				DL	OLS
17	Liu83	Ng-r	US-s-r10	67	78	CT				-2.31			nr				DL	OLS
17	Liu83	Ng-r	US-s-r1	67	78	CT			1.86				nr				DL	2S
17	Liu83	Ng-r	US-s-r2	67	78	CT			0.29				nr				DL	2S
17	Liu83	Ng-r	US-s-r3	67	78	CT			-1.04				nr				DL	2S
17	Liu83	Ng-r	US-s-r4	67	78	CT			-0.82				nr				DL	2S
17	Liu83	Ng-r	US-s-r5	67	78	CT			0.52				nr				DL	2S
17	Liu83	Ng-r	US-s-r6	67	78	CT			-0.31				nr				DL	2S
17	Liu83	Ng-r	US-s-r7	67	78	CT			-0.81				nr				DL	2S
17	Liu83	Ng-r	US-s-r8	67	78	CT			-0.83				nr				DL	2S
17	Liu83	Ng-r	US-s-r9	67	78	CT			-2.41				nr				DL	2S
17	Liu83	Ng-r	US-s-r10	67	78	CT			-0.37				nr				DL	2S
17	L&D82	Ng-r	US	60	80	Tq	-0.28			-0.36	0.44				0.70		HT	OLS?
17	Uri83b	Ng-r	US-rNE	47	78	T			-0.45								TlNgOEl	SUR-s
17	Uri83b	Ng-r	US-rMAt	47	78	T			-0.54								TlNgOEl	SUR-s
17	Uri83b	Ng-r	US-rENC	47	78	T			-0.67								TlNgOEl	SUR-s
17	Uri83b	Ng-r	US-rWNC	47	78	T			-0.78								TlNgOEl	SUR-s
17	Uri83b	Ng-r	US-rSAt	47	78	T			-0.84								TlNgOEl	SUR-s

C	Ref	Product	Sample	y1	y2	Type	Psr	t(p)	Pir	Plr	Ysr	t(Y)	Yir	Ylr	Q(-1)	t(Q-1)	Model	ET
17	Uri83b	Ng-r	US-rESC	47	78	T			-0.85								TlNgOEl	SUR-s
17	Uri83b	Ng-r	US-rWSC	47	78	T			-1.90								TlNgOEl	SUR-s
17	Uri83b	Ng-r	US-rMt	47	78	T			-1.41								TlNgOEl	SUR-s
17	Uri83b	Ng-r	US-rPc	47	78	T			-1.23								TlNgOEl	SUR-s
17	Uri83b	Ng-r	US	47	78	Avg			-1.01								TlNgOEl	compute
						Avg	-0.13		-0.62	-0.68	0.09		0.53		0.49	0.89		
						Std	0.10		0.78	1.03	0.11		0.05		0.24	0.04		
						Min	-0.35		-2.41	-3.44	0.01		0.46		0.11	0.82		
						Max	0.02		1.86	1.56	0.44		0.58		0.80	0.99		
						#	21		25	31	12		3		12	12		
18	GSG86	Ng-r	US-h	78	78	C		6.40	-0.22			8.60	0.09				Stat	OLS
18	GSG86	Ng-r	US-h	76	76	C		2.20	-0.08			10.50	0.13				Stat	OLS
18	GSG86	Ng-r	US-h	74	79	CT		10.10	-0.16			22.10	0.10				Stat	OLS
18	GSG86	Ng-r	US-h	77	77	C		7.90	-0.26			8.80	0.09				Stat	OLS

Table 14 (continued): New Demand for Total and Residential Natural Gas Studies

C	Ref	Product	Sample	y1	y2	Type	Psr	t(p)	Pir	Plr	Ysr	t(Y)	Yir	Ylr	Q(-1)	t(Q-1)	Model	ET
18	GSG86	Ng-r	US-h	75	75	C		2.40	-0.10			9.70	0.12				Stat	OLS
18	GSG86	Ng-r	US-h	74	74	C		2.80	-0.12			8.90	0.10				Stat	OLS
18	GSG86	Ng-r	US-h	79	79	C		5.40	-0.22			7.00	0.08				Stat	OLS
						Avg			-0.17				0.10					
						Std			0.06				0.02					
						Min			-0.26				0.08					
						Max			-0.08				0.13					
						#			7				7					
19	A&W86	Ng-r	US-h-sa	81	81	C		-15.00	-1.05			4.00	0.08				Stat	OLS
19	A&W86	Ng-r	US-h-sa	82	82	C		-12.30	-1.23			4.00	0.12				Stat	OLS
19	A&W86	Ng-r	US-h-sa	80	80	C		-12.10	-1.21			2.00	0.06				Stat	OLS
19	A&W86	Ng-r	US-h-sa	80	82	CT		-22.80	-1.14			4.50	0.09				Stat	OLS
						Avg			-1.16				0.09					

						Std			0.07				0.02
						Min			-1.23				0.06
						Max			-1.05				0.12
						#			4				4
20	A&W86	Ng-r	US-h-si	80	82	CT		-75.00	-1.50			13.00	0.13
			Stat	OLS									
20	A&W86	Ng-r	US-h-si	80	80	C		-90.00	-1.80			10.00	0.10
			Stat	OLS									
20	A&W86	Ng-r	US-h-si	81	81	C		-50.67	-1.52			11.00	0.11
			Stat	OLS									
20	A&W86	Ng-r	US-h-si	80	82	CT		-34.00	-1.70			13.00	0.13
			Stat	OLS									
20	A&W86	Ng-r	US-h-si	82	82	C		-31.25	-1.25			9.00	0.18
			Stat	OLS									
20	A&W86	Ng-r	US-h-si	80	80	C		-79.50	-1.59			11.00	0.11
			Stat	OLS									
20	A&W86	Ng-r	US-h-si	82	82	C		-32.60	-1.63			8.50	0.17
			Stat	OLS									
20	A&W86	Ng-r	US-h-si	81	81	C		-60.00	-1.80			12.00	0.12
			Stat	OLS									
20	A&W86	Ng-r	US-h-si	80&82		CT	-0.88	-12.57		-1.49	0.07	3.50	
0.12	0.41	20.50	LE		OLS								
20	A&W86	Ng-r	US-h-si	80&82		CT	-0.63	-10.50		-1.09	0.07	3.50	
0.12	0.42	21.00	LE		OLS								
						Avg	-0.76		-1.60	-1.29	0.07		0.13
0.12	0.42												
						Std	-0.76		-1.60	-1.29	0.07		0.13
0.12	0.42												
						Min	-0.88		-1.80	-1.49	0.07		0.10
0.12	0.41												
						Max	-0.63		-1.25	-1.09	0.07		0.18
0.12	0.42												
						#	2		8	2	2		8
2	2												

Studies looking at elasticities by appliance choice, A&W86, B&G82, H&W81 are shown in Table 15. I only include the significant elasticities for the intermediate run for comparison purposes with all equations summarized in Table A3. There is a fair amount of variation across the studies and data types. One study finds a high elasticity for gas use for central air conditioning on household data (h). Having never seen a natural gas air conditioner, I am a bit dubious about this result. All other estimates on household data are in the inelastic range with the highest elasticity found for heating and no elasticity found for clothes drying, whereas income elasticities are largest for water heating, small for heating, and negative for cooking. When household data is divided between the interstate (h-si) and intrastate (h-sa) market with no price of substitutes included, the price and income elasticities are similar to the household data for heating, but are very high for price elasticities for cooking. The weighted average from the household data finds a price elasticity of -0.75 and an income elasticity of 0.15, which is nearer the estimates on aggregate data for price but nearer the estimates for disaggregate data for income.

The estimates on state data do not support the estimates for disaggregate data with price elasticities varying substantially, income elasticities always zero or negative, and estimates from a regression on state data for total elasticities find both price and income insignificant.

Table 15: Demand Elasticities for Natural Gas by Appliance Choice

C	Product	h	h-sa	h-si	s
	Intermediate Price Elasticities				
21	central air (-cac)	-1.74			
21	clothes drying (-cd)	0.00			-3.90
21	cooking (-ck)	-0.62	-1.98	-1.48	-0.15
21	heating (-ht)	-0.88	-0.75	-0.63	0.00
21	water heat (-wh)	-0.58			-1.36
21	gas not for heating (-ngh)		-1.79	-1.42	
21	*Total (r)	-0.75	-1.21	-1.59	0.00
	Intermediate Income Elasticities				
21	central air (-cac)	0.00			
21	clothes drying (-cd)	0.00			-8.53
21	cooking (-ck)	-0.27	0.00	0.00	-2.54
21	heating (-ht)	0.10	0.11	0.17	-0.17
21	water heat (-wh)	0.51			0.00
21	gas not for heating (-ngh)		0.51	0.00	
21	*Total (r)	0.15	0.06	0.11	0.00

Studies are summarized in Table A3. *Study based on household data is a weighted average of the elasticities by appliance stock, the other three are based on aggregate regressions.

Studies on commercial and industrial natural gas demand are summarized in Table 16. For commercial demand (C21), the patterns are rather similar to those for commercial electricity demand. Average price elasticities are fairly well behaved (-0.26, -0.88, -0.99) but average income elasticities are negative. Within categories we see wide variation. Liu83 finds wide variations in price elasticities across regions using two variants of a DL model as was the case in the residential sector. For the commercial sector, he did not see much variation across price elasticities when the price of substitutes was omitted, but income elasticity changed from being negative to positive. Since he does not report income elasticities across regions we do not know if income elasticities vary as much as those for price. No summary elasticities are readily apparent in the commercial sector.

Table 16: New Demand for Commercial and Industrial Natural Gas Studies

C	Ref	Product	Sample	y1	y2	Type	Psr	t(p)	Pir	Plr	Ysr	t(Y)	Yir	Ylr	Q(-1)	t(Q-1)	Model	ET
21	BDM81	Ng-c	US-9st	67	77	CT	-0.16	-1.14		-1.06	-0.33	-0.96		-2.19	0.85	33.93	LE	OLS
21	BDM81	Ng-c	US-9st	67	77	CT	-0.28	-4.52		-1.86	-0.04	-0.20		-0.24	0.85	74.73	LE	EC
21	BDM81	Ng-c	US-9st	67	77	CT	-0.37	-5.79		-2.27	0.03	0.21		0.21	0.84	76.93	LE	EC-SUR
21	C&M84	Ng-c	US-s14	64	77	CT			-0.78								LgElNgOsGISUR	
21	C&M84	Ng-c	US-s14	64	77	CT	-0.22			-1.15					0.81	40.30	LgElNgOsGISUR	
21	LCC87	Ng-c	US	60	83	T	-0.28			-1.43	0.30			1.95	0.85		LE	EC-SUR
21	Liu83	Ng-c	US-s	67	78	CT		-2.15	-0.42								Stat	OLS
21	Liu83	Ng-c	US-s	67	78	CT		-6.63	-0.52								Stat	OLS
21	Liu83	Ng-c	US-s	67	78	CT		-1.15	-0.34			-4.57	-0.87				Stat	OLS
21	Liu83	Ng-c	US-s	67	78	CT		-4.89	-0.32			5.34	0.46				Stat	OLS
21	Liu83	Ng-c	US-s-r1	67	78	CT				-0.44							DL	OLS
21	Liu83	Ng-c	US-s-r2	67	78	CT				0.06							DL	OLS
21	Liu83	Ng-c	US-s-r3	67	78	CT				-0.86							DL	OLS
21	Liu83	Ng-c	US-s-r4	67	78	CT				-0.69							DL	OLS
21	Liu83	Ng-c	US-s-r5	67	78	CT				-0.78							DL	OLS
21	Liu83	Ng-c	US-s-r6	67	78	CT				-0.85							DL	OLS
21	Liu83	Ng-c	US-s-r7	67	78	CT				-0.25							DL	OLS
21	Liu83	Ng-c	US-s-r8	67	78	CT				-1.06							DL	OLS
21	Liu83	Ng-c	US-s-r9	67	78	CT				-0.28							DL	OLS
21	Liu83	Ng-c	US-s-r10	67	78	CT				-1.91							DL	OLS
21	Liu83	Ng-c	US-s-r1	67	78	CT			1.92								DL	2S
21	Liu83	Ng-c	US-s-r2	67	78	CT			-0.89								DL	2S
21	Liu83	Ng-c	US-s-r3	67	78	CT			-1.17								DL	2S
21	Liu83	Ng-c	US-s-r4	67	78	CT			-1.82								DL	2S
21	Liu83	Ng-c	US-s-r5	67	78	CT			-1.04								DL	2S
21	Liu83	Ng-c	US-s-r6	67	78	CT			-1.00								DL	2S
21	Liu83	Ng-c	US-s-r7	67	78	CT			-0.88								DL	2S

21	Liu83	Ng-c	US-s-r8	67	78	CT			-1.21								DL	2S
21	Liu83	Ng-c	US-s-r9	67	78	CT			-2.04								DL	2S
21	Liu83	Ng-c	US-s-r10	67	78	CT			-2.68								DL	2S
						Avg	-0.26		-0.88	-0.99	-0.01		-0.21	-0.07	0.84			
						Std	0.07		0.98	0.64	0.22		0.67	1.47	0.02			
						Min	-0.37		-2.68	-2.27	-0.33		-0.87	-2.19	0.81			
						Max	-0.16		1.92	0.06	0.30		0.46	1.95	0.85			
						#	5		15	15	4		2	4	5			
22	B&C90	Ng-e	US	77	87:	Tm			-0.14								TlCONg	ISUR
22	B&C90	Ng-e	US-rSW	77	87:	Tm			-0.25								TlCONg	ISUR
22	B&C90	Ng-e	US-rW	77	87:	Tm			-0.40								TlCONg	ISUR
22	Ko93	Ng-e	US	49	91	T			-0.13								TlCONg	SUR?
22	Ko93	Ng-e	US	49	91	T			-0.10								TlCONg	SUR?
22	Hai81	Ng-e	US-plnt	70	75	CT		-4.44	-0.84								TlCONg	ISUR

Table 16 (continued): New Demand for Commercial and Industrial Natural Gas Studies

C	Ref	Product	Sample	y1	y2	Type	Psr	t(p)	Pir	Plr	Ysr	t(Y)	Yir	Ylr	Q(-1)	t(Q-1)	Model	ET
22	Hai81	Ng-e	US-plnt	70	73	CT		-6.64	-1.28								TlCNg	ISUR
22	Hai81	Ng-e	US-plnt	74	75	CT		-4.87	-1.89								TlCNg	ISUR
22	Hai81	Ng-e	US-plnt	70	73	CT		-1.78	-0.19								TlONg	ISUR
22	Hai81	Ng-e	US-plnt	74	75	CT		-9.94	-0.89								TlONg	ISUR
22	Mcd91	Ng-e	US-ut82	87	87	C			-1.84								TlCONgNHyElws	ISUR
						Avg			-0.72									
						Std			0.65									
						Min			-1.89									
						Max			-0.10									
						#			11									
23	BDM81	Ng-i	US-s9	67	77	CT	-0.61	-7.76		-2.40	0.78	5.08		3.08	0.75	31.28	LE	OLS
23	BDM81	Ng-i	US-s9	67	77	CT	-0.63	-12.19		-2.51	0.75	6.64		2.95	0.75	41.28	LE	EC
23	BDM81	Ng-i	US-s9	67	77	CT	-0.62	-12.21		-2.54	0.70	6.56		2.86	0.76	44.76	LE	EC-SUR
23	Con89b	Ng-i	US	70	85	T			-0.58								TlCONgEl	FIML
23	Con89b	Ng-i	US	70	85	T			-0.57								LgCONgEl	FIML

23	Con89b	Ng-i	US	70	85	T			-0.52								TlCOsNgEl	FIML
23	Con89b	Ng-i	US	70	85	T			-0.47								LgCOsNgEl	FIML
23	Con89b	Ng-i	US	70	85	T			-0.57								TlCOsNgEl	FIML
23	Con89b	Ng-i	US	70	85	T			-0.57								LgCOsNgEl	FIML
23	Hal86b	Ng-i	US	60	79	T		-5.32	-0.53								TlCOElNg	ISUR
23	Hal86b	Ng-i	US	60	79	T		-2.88	-0.34								TlCOElNg	ISUR
23	KBP86	Ng-i	US	60	82	CT			-0.42								TlCOElNg	ISUR
23	Kol86	Ng-i	US	60	82	CT	-0.42										Tl2COElNg	ISUR
23	Kol87	Ng-i	US	60	82	CT				-1.34							Tl2COElNg	ISUR
23	LCC87	Ng-i	US	60	83	T	-0.26			-1.80	0.13			1.34	0.91		LE	EC-SUR
23	Liu83	Ng-i	US-s	67	78	CT		0.51	-0.08								Stat	OLS
23	Liu83	Ng-i	US-s	67	78	CT		-7.02	-0.45			3.69	0.68				Stat	OLS
23	Liu83	Ng-i	US-s	67	78	CT		-0.81	-0.24			5.34	0.46				Stat	OLS
23	Liu83	Ng-i	US-s	67	78	CT		-4.89	-0.32								Stat	OLS
23	Liu83	Ng-i	US-s-r1	67	78	CT				-0.24							DL	OLS
23	Liu83	Ng-i	US-s-r2	67	78	CT				0.02							DL	OLS
23	Liu83	Ng-i	US-s-r3	67	78	CT				-0.38							DL	OLS
23	Liu83	Ng-i	US-s-r4	67	78	CT				-0.63							DL	OLS
23	Liu83	Ng-i	US-s-r5	67	78	CT				-0.04							DL	OLS2
23	Liu83	Ng-i	US-s-r6	67	78	CT				-0.24							DL	OLS
23	Liu83	Ng-i	US-s-r7	67	78	CT				-1.13							DL	OLS
23	Liu83	Ng-i	US-s-r8	67	78	CT				0.15							DL	OLS
23	Liu83	Ng-i	US-s-r9	67	78	CT				-0.12							DL	OLS
23	Liu83	Ng-i	US-s-r10	67	78	CT				-0.11							DL	OLS
23	Liu83	Ng-i	US-s-r1	67	78	CT			-1.32								DL	2S
23	Liu83	Ng-i	US-s-r2	67	78	CT			-0.10								DL	2S

Table 16 (continued): New Demand for Commercial and Industrial Natural Gas Studies

C	Ref	Product	Sample	y1	y2	Type	Psr	t(p)	Pir	Plr	Ysr	t(Y)	Yir	Ylr	Q(-1)	t(Q-1)	Model	ET
23	Liu83	Ng-i	US-s-r3	67	78	CT			-3.03								DL	2S
23	Liu83	Ng-i	US-s-r4	67	78	CT			-3.36								DL	2S

23	Liu83	Ng-i	US-s-r5	67	78	CT			-0.78								DL	2S
23	Liu83	Ng-i	US-s-r6	67	78	CT			-5.28								DL	2S
23	Liu83	Ng-i	US-s-r7	67	78	CT			-2.04								DL	2S
23	Liu83	Ng-i	US-s-r8	67	78	CT			0.71								DL	2S
23	Liu83	Ng-i	US-s-r9	67	78	CT			-0.89								DL	2S
23	Liu83	Ng-i	US-s-r10	67	78	CT			-0.73								DL	2S
						Avg	-0.51		-0.98	-0.89	0.59		0.57	2.56	0.79			
						Std	0.15		1.28	0.96	0.27		0.11	0.71	0.07			
						Min	-0.63		-5.28	-2.54	0.13		0.46	1.34	0.75			
						Max	-0.26		0.71	0.15	0.78		0.68	3.08	0.91			
						#	5		23	15	4		2	4	4			
24	Uri88b	Ng-ag	US-s	78	80	C	-1.63	-3.02		-10.00	0.21	2.06		1.28	0.84	9.78	LE	EC
24	Uri88a	Ng-ag	US-s	78	80	CT			-0.42								TlGDLpFoNSUR	
24	U&G92	Ng-ag	US	71	89	T-m	-0.17	-0.33		-0.59					0.71	2.31	LE	GLS-s
24	Uri88b	Ng-ag	US-s	78	80	C	-0.91	0.32		-5.30	0.14	4.08		0.81	0.83	2.58	LE	EC
24	Gow83	Ng-ch	US-sNY	60	78	T	-0.12	-1.69		-0.16	1.41	10.30		1.83	0.23	2.48	LE	3S
24	Gow83	Ng-ch	US-sNY	60	78	T	-0.08	-0.61		-0.12	1.43	5.18		2.17	0.34	1.64	LE	OLS
24	Gow83	Ng-fd	US-sNY	60	78	T	-0.28	-2.88		-0.72	1.74	7.97		4.46	0.61	8.39	LE	3S
24	Gow83	Ng-fd	US-sNY	60	78	T	-0.37			-0.73	1.12	3.45		2.20	0.49	3.71	LE	OLS
24	L&L84	Ng-fd	US	54	76	CT			-0.12								TlONgCEl	ML
24	L&L84	Ng-fd	US	54	76	CT			-0.22				1.35				LgONgCEl	ML
24	Gow83	Ng-me	US-sNY	60	78	T	-0.63	-5.92		-0.96	0.30	2.85		0.56	0.46	6.51	LE	3S
24	Gow83	Ng-me	US-sNY	60	78	T	-0.52	-3.01		-0.73	0.34	2.06		0.67	0.49	4.51	LE	OLS
24	D&C84	Ng-mt	US-s	74	77	CT			-1.48								Sh-2Eq	SUR
24	D&C84	Ng-mt	US-s	75	77	CT	-0.75			-2.87							Sh-LE	SUR
24	D&C84	Ng-mt	US-s	67&71		CT			-1.20								Sh-2Eq	SUR
24	Gow83	Ng-mt	US-sNY	60	78	T	-0.28	-2.12		-2.98	0.16	0.96		0.32	0.50	3.06	LE	OLS
24	Gow83	Ng-mt	US-sNY	60	78	T	-0.37	-4.43		-0.49	0.28	2.96		0.49	0.43	4.71	LE	3S
24	Gow83	Ng-pp	US-sNY	60	78	T	-1.25	-4.37		-2.27	0.54	0.93		0.98	0.45	4.07	LE	3S

24	Gow83	Ng-pp	US-sNY	60	78	T	−1.25	−3.68		−2.31	0.72	1.01		1.33	0.46	3.47	LE	OLS
24	Gow83	Ng-rb	US-sNY	60	78	T	−1.12	−4.49		−2.95	0.41	1.73		1.08	0.62	10.14	LE	OLS
24	Gow83	Ng-rb	US-sNY	60	78	T	−1.49	−8.91		−2.87	0.29	1.69		0.74	0.61	14.02	LE	3S
						Avg	−0.70		−0.69	−2.25	0.65		1.35	1.35	0.54			
						Std	0.50		0.55	2.43	0.52		0.00	1.04	0.16			
						Min	−1.63		−1.48	−10.00	0.14		1.35	0.32	0.23			
						Max	−0.08		−0.12	−0.12	1.74		1.35	4.46	0.84			
						#	16		5	16	14		1	14	15			

C22 contains the new studies of the demand for natural gas for electricity generation. All time series estimates find elasticities less than -0.4 in absolute value. Cross sections tend to be more elastic but vary across time, plant type, and data type. Hai81 finds a more elastic response for 1974-75 than for 1970-73 and a more elastic response when coal and gas are used together than when oil and gas are used together. Mcd91 finds a very elastic price response for a cross section of utilities (-1.84) for 1987 when he uses a translog on coal, oil, natural gas, nuclear, hydro power, and purchased wholesale electricity. Again no obvious price elasticities present themselves, while no income elasticities have been estimated.

C23 in Table 16 contains eight studies on industrial demand on aggregate data. Again we see wide variation across model types. Static and translog models find an inelastic price and inelastic income response where estimated. When a second generation translog is used the long run elasticity is slightly elastic. Price and income elasticities fall when the price of substitutes are included by Liu (1983) on US data.

LE models find elastic price and income response, whereas on the DL model by Liu83 the estimates vary considerably across region and depend upon what lags are included. When the lag is on both the own price and the price of oil products, the long run elasticities tend to be smaller than the intermediate run elasticities where the lag is only on oil products. One suspects that collinearity between variables is the culprit. Although the averages suggest industrial demand is price inelastic, there is rather too much variation to come to a conclusion. Income elasticities are even more mixed and confusing.

Section C25 in Table 16 contains demand elasticities by separate industry. The averages suggest an elastic long run price and income response. We see substantial variation across industries. The three studies by Uri find widely varying price elasticities in the agricultural sector. Otherwise, results within sectors are more consistent with an inelastic price response in the chemical and food industry, a close to elastic response in electric machinery, and an elastic response in the metals, pulp and paper, and rubber products industries.

The overall results for the natural gas market are somewhat similar to the earlier studies. For the residential sector, models on aggregate data tend to find a more elastic price response than for disaggregate data. The exception, on a simple model for disaggregate data with no price of substitute fuels, suggests that more study of the effect of model and included variables should be done on consistent data sets. Static logit and translog models tend to find consistent results on the same data set with price in the inelastic region.

Income effects tend to be consistently small for the residential sector whether the model is estimated on aggregate or disaggregate data. Income effects are erratic in the few studies on the commercial sector. Where estimated, they are most often above 1 in the industrial sector but from lagged endogenous models that we have come to not trust. I come to the same conclusion as earlier that it is difficult to know the effect of economic activity on the commercial and industrial sector. Price response is hard to measure in these two sectors as well. Static models suggest that demand is price inelastic while dynamic models more often suggest it is elastic.

V. Demand for Coal

V.1 Previous Surveys. Coal demand has relatively few studies compared to some of the other fossil fuels with a number of special issues relating to the coal market. There is lack of homogeneity in coal including separate markets for coking coal and steam coal. Pollution regulations have impinged heavily on the market beginning with the Clean Air Act of 1967, amended in 1977 and more recently in 1990. There have been under the boiler fuel use restrictions on oil and gas as well as mood swings about nuclear energy that have affected this market. Measuring price can also be an issue. Since much coal is sold on long term contracts, reported spot prices may not precisely measure, the true cost of coal at any point in time.

In surveying coal demand, almost no coal is used in the residential sector in the US, so demand studies are restricted to the industrial and to the electricity generation sector, which takes the major share of US coal. In earley surveys, Taylor (1977) looks at 3 studies of coal demand, while Bohi (1981) looks at 8 studies. With one overlapping study, they consider 10 studies altogether, which are combined and summarized in Table 17.

The studies in Taylor all use reduced form static or lagged endogenous models on aggregate data. All show total coal, steam coal and coking coal to be price and income inelastic with long run elasticity variations for price and income to be (−0.55/−0.91, 0.27/1). Industrial coal may be more price and less income elastic than other coal demand. Taylor concludes in favor of a short run elasticity of −0.4 and a long run elasticity of coal between −0.7 and −0.9.

Table 17: Demand for Coal Surveyed by Taylor (1977) and Bohi (1981)*.

S	Product		Psr	Pir	Plr	Ysr	Yir	Ylr
56	C	Avg	−0.39		−0.91	0.53		0.60
		#	1		1	1		1
57	C−e	Avg	−0.28		−0.91			
		Std	0.18		0.24			
		Min	−0.46		−1.15			
		Max	−0.09		−0.67			
		#	2		2			
58	C−i	Avg	−0.30	−0.82	−1.61	−0.05	0.31	−0.22
		Std	0.20	0.00	0.46	0.00	0.00	0.00
		Min	−0.49	−0.82	−2.07	−0.05	0.31	−0.22
		Max	−0.10	−0.82	−1.14	−0.05	0.31	−0.22
		#	2	1	2	1	1	1
59	C−i−ck	Avg	−0.25	−0.48	−0.56	0.43	0.00	0.94
		Std	0.00	0.00	0.47	0.00	0.00	0.00
		Min	−0.25	−0.48	−1.14	0.43	0.00	0.94
		Max	−0.25	−0.48	0.00	0.43	0.00	0.94
		#	1	1	3	1	1	1
60	C−i−st	Avg	−0.42	−0.17	−0.79	0.81	0.90	0.85
		Std	0.08	0.00	0.68	0.19	0.00	0.16
		Min	−0.49	−0.17	−2.06	0.62	0.90	0.69
		Max	−0.28	−0.17	0.00	1.00	0.90	1.00
		#	4	1	5	2	1	2
61	C−ii	Avg			−1.48			
		Std			0.75			
		Min			−2.22			
		Max			0.00			
		#			6			

Adding the Bohi studies, we find somewhat more variation across and within categories. Studies on aggregate coal and total demand for electricity generation still tend to be inelastic. There is some evidence that total industrial demand is price elastic and has a negative income elasticity. The elastic price response is supported by the new studies on demand by industry (C−ii) but not by industrial demand broken down into coking (C−i−ck) and steam coal (C−i−st) both of which appear to find inelastic price and positive but inelastic income demand.

Bohi concludes that little is known about coal demand, but suggests that demand is price elastic from studies on industry data. However, he feels that there have been too many shifts in supply and demand that have not been captured in the studies to expect them to be tracing out a demand equation. Putting the two surveys together, I find the evidence mixed but might be slightly more inclined to favor an inelastic price and income response.

V.2 New Studies on the Demand for Coal. There are 11 new studies on coal demand included in Table 18. The four on demands for electricity generation in C26, are all in the inelastic region averaging −0.4. All are on static models and are partial elasticities, since they look at the change in share but do not include output effects. The estimates on T data tend to have elasticities near −0.3, while those on C and CT data tend to be more elastic. Hai81 finds higher elasticities on his CT for 1970−73 than for 1974−1975. These studies suggest a lower price elasticity for coal than the earlier studies.

Table 18: New Demand for Coal Studies

C	Ref	Product	Sample	y1	y2	Type	Psr	t(p)	Pir	Plr	Model	ET
26	Mcd91	C−e	U−ut82	87	87	C			−0.47		TlCONgNHyElws	ISUR
26	Hai81	C−e	US−plnt	70	75	CT		−4.06	−0.49		TlCONg	ISUR
26	Hai81	C−e	US−plnt	70	73	CT		−10.86	−0.68		TlCO	ISUR
26	Hai81	C−e	US−plnt	74	75	CT		−2.65	−0.37		TlCO	ISUR
26	Hai81	C−e	US−plnt	70	73	CT		−9.92	−0.90		TlONg	ISUR
26	Hai81	C−e	US−plnt	74	75	CT		−3.23	−0.28		TlONg	ISUR
26	Ko93	C−e	US	49	91	T			−0.26		TlCONg	SUR
26	Ko93	C−e	US	49	91	T			−0.26		TlCONg	SUR
26	B&C90	C−e	US	77	87:	Tm			−0.26		TlCONg	ISUR
26	B&C90	C−e	US−rNC	77	87:	Tm			−0.12		TlCONg	ISUR
26	B&C90	C−e	US−rSE	77	87:	Tm			−0.23		TlCONg	ISUR
26	B&C90	C−e	US−rNE	77	87:	Tm			−0.38		TlCONg	ISUR
26	B&C90	C−e	US−rSW	77	87:	Tm			−0.52		TlCONg	ISUR
						Avg			−0.40			
						Std			0.20			
						Min			−0.90			
						Max			−0.12			
						#			13			
27	Con89b	C−i	US	70	85	T			0.01		TlCO+tNgEl	FIML
27	Con89b	C−i	US	70	85	T			0.08		LgCO+tNgEl	FIML
27	Con89b	C−i	US	70	85	T			−1.11		TlCOsNgEl	FIML
27	Con89b	C−i	US	70	85	T			−1.01		LgCOsNgEl	FIML
27	Con89b	C−i	US	70	85	T			−1.12		TlCOsNgEl	FIML
27	Con89b	C−i	US	70	85	T			−0.71		LgCOsNgEl	FIML
27	Hal86b	C−i	US	60	79	T		−3.12	−0.38		TlCOElNg	ISUR
27	Hal86b	C−i	US	60	79	T		−11.00	−0.70		TlCOElNg	ISUR
27	KBP86	C−i	US	60	82	CT	−0.02				Tl2COElNg	ISUR
27	Kol86	C−i	US	60	82	CT	−1.62				Tl2COElNg	ISUR
27	Kol87	C−i	US	60	82	CT				0.35	Tl2COElNg	ISUR
						Avg	−0.82		−0.62	0.35		
						Std	0.80		0.45	0.00		
						Min	−1.62		−1.12	0.35		
						Max	−0.02		0.08	0.35		
						#	2		8	1		
28	D&C84	C−mt	US−s	67&71		CT			−0.91		Sh−2Eq	SUR
28	D&C84	C−mt	US−s	74	77	CT			−0.78		Sh−2Eq	SUR
28	D&C84	C−mt	US−s	75	77	CT	−0.84			−2.52	Sh−LE	SUR
28	L&L84	C−fd	US	54	76	T			−0.60		TlONgCEl	SML
28	L&L84	C−fd	US	54	76	T			−0.28		LgONgCEl	SML
						Avg	−0.84		−0.64	−2.52		
						Std	0.00		0.00	0.00		

Min	−0.84		−0.91	−2.52
Max	1.00		−0.28	−2.52
#	6		4	1

All industry coal demand equations on aggregate data are estimated with share type equations and none estimate an income or economic activity elasticity in Table 18, C27. Con89b finds a positive price response using translog and logit models with coal, oil, natural gas, and electricity when oil includes transportation fuels (O+t) but negative and often elastic estimates when only oil (O) for stationary uses are included. His elasticities tend to be smaller in absolute value when using a translog than a logit model. The three estimates using translog models on cross sections of OECD countries are more erratic and unbelievable. Kol86 using a translog model that allows for quasi fixed capital finds a short run elasticity of −1.62, whereas KBP86 find an elasticity of only −0.02 and Kol87 finds long run elasticity of 0.35, all on a similar model and data set.

There are five estimates for coal demand by product group in Table 18, C28, three for the metal industry and two for food processing. All intermediate and short run price responses are inelastic with food processing having the lower elasticity. D&C84 find a long run elasticity on a lagged endogenous share model that is about three times as elastic as on a static model. They find a lower elasticity on post 1973 data than on pre 1973 data. L&L84 find a less elastic response using logit than using a translog model as in Con89b.

One would be hard pressed to come to any conclusions about the industrial sector from the new studies. I still might favor an inelastic price response and would suggest that elasticities have fallen from the earlier studies. Studies on electricity generation are more consistent, they suggest a price elasticity near −0.5 with elasticity falling after 1973 and lower than for earlier studies.

VI. Demand for Oil, Oil by Sector, and Oil Products VI.1 Previous Surveys of Nontransport Oil Demand. Special issues in the oil market include product aggregation, where the elasticity is measured, and reversibility. Studies have aggregated oil demand in different ways. A few studies have looked at the demand for oil (O) others at demand for total oil products (Op). However, except as an input at refineries, oil is not typically demanded directly, but rather oil demand is derived from the demand for products. Some studies have aggregated oil product demand by sector (e.g. electricity generation (O−e), industry excluding transport fuels (O−i), industry including transportation fuels (O+t−i) residential (O−r), transportation (O−t), and nontransportation uses (O−ntr)); others by product (e.g. LPG, Gasoline (G), Jet Fuel (J), Diesel (D), Light fuel oil (Fo−lt), Heavy fuel oil (Fo−hv)); and yet others by product by sector (e.g. heavy fuel oil in the industrial sector (Fo−Hv−i).

Another issue is where the elasticity is generated. Let the elasticity be $\varepsilon = (\partial Q/\partial P)(P/Q)$. If Q is the demand for products and if demand is to be related to the retail price (P), P needs to be some weighted average of the retail prices of all products and we have the usual problems of aggregation across products.

If we want to relate the demand for products to the price of crude oil which I refer to as the wholesale price (P_w). The retail price $P = P_w + t$, where t represents tax, refinery margin, and transportation. If t is a constant equal to t_c then $P = P_w + t_c$, if t is a constant percent of the wholesale price $t_\%$ then $P = (1+t_\%)P_w$. To convert the retail price elasticity to a wholesale price elasticity, we need to relate a percentage change in wholesale price to a percentage change in retail price. If t is a constant t_c and does not change when the wholesale price changes, then we can multiply the retail price elasticity $(\partial Q/\partial P)(P/Q)*(P_w/P)$ to give us the wholesale price elasticity $(\partial Q/\partial P)(P_w/Q)$. If t is a constant percent that does not change as the wholesale price changes, then a wholesale price increase of x% will increase retail prices by the same percent and the wholesale and retail prices elasticities are equal.

Since at least portions of our t can be expected to be unrelated to the wholesale price, we can expect the wholesale price elasticity to be smaller than the retail price elasticity. Moreover, since t is not likely to have remained either a constant percent or a constant over time, the relationship between the wholesale and retail elasticity is not so clear cut and estimates using oil prices will suffer the usual aggregation problems and the additional bias for the true wholesale elasticity, which changes every time the relationship between wholesale and retail price changes. For this reason, if one needs to find a wholesale elasticity at this or any other level aggregation, it is probably better to estimate the equation at the retail level and then convert it to a wholesale elasticity.

A third approach considers demand for crude oil directly along with the price of crude oil rather than products. This approach clouds the issue even further unless no products are imported or exported or they are a constant or a constant percent. An additional problem with studies on aggregate oil demand is that they are not always clear about which of the above approaches they have taken. We will see a variety of these approaches taken below in the new studies.

Taylor (1977), Bohi (1981), and Bohi and Zimmerman (1984) each survey a few studies of nontransport oil demands. These 17 studies are summarized in Table 19. In some cases heavy and light fuel oil as well as fuel oil for heating have been estimated separately. Since no systematic difference was found between these demands they have been combined for each sector.

Averages from these early studies (S62) suggest that long run price and income elasticities for fuel oils in the residential sector are inelastic (-0.75/0.44) and commercial elasticities (S63) are somewhat similar with perhaps a bit less price elasticity and a bit more income elasticity (−0.64/0.73). There is, however, a fair amount of variation within categories and when these two sectors are combined (S65) demand becomes price and income elastic in the long run (−1.05/1.52). These elasticities are not in the range of the other elasticities and suggest that estimates may be sensitive to aggregation.

Moving on to the electricity generation (S66), a long run elasticity of −1.50 is obtained on a cross section of plant data. However, Bohi concludes that the long run elasticity is uncertain because the gas demand estimates from plants burning only oil and gas consistently overstated consumption in forecasting experiments, which is likely the result of supply constraints.

Aggregate fuel oil demand in the industrial sector (S67) suggests a slightly elastic price response −1.07, data by individual industry (S68) suggest an even more elastic response −1.87, whereas industry studies that break demand into heavy and light demand for industrial use find an inelastic response (S69) −0.76, that is close to that for the residential sector. Again the results seem sensitive to aggregation and studies on consistent data would be useful to determine whether these differences are differences across aggregation or other parameters. The study on aggregate light fuel oil (S71) finds elasticities between those for the separate sectors, suggesting less aggregation bias across sectors than across products.

The only reported income elasticities on the industrial sector are all from the same study and are all identically 1 in the short and long run, which leads me to suspect they were constrained to be one in the estimation procedure.

In the above surveys, none of the authors come to any conclusions about the elasticities in the fuel oil markets and all authors point to problem of poor data quality. I would further suggest that elasticities appear to be sensitive to the level of product aggregation.

Table 19: Nontransport Oil Demands Surveyed by Taylor(1977), Bohi(1981), and Bohi and Zimmerman(1984).

S	Product		Psr	Pir	Plr	Ysr	Yir	Ylr
62	FO−r	Avg	−0.27		−0.75	0.14		0.44

	FO-r-lt	Std	0.21	0.41	0.09	0.24
	FO-r-ht	Min	-0.70	-1.50	0.00	0.00
		Max	0.00	0.00	0.30	0.79
		#	7	7	6	6
63	FO-c	Avg	-0.49	-0.64	0.73	0.73
	FO-c-hv	Std	0.13	0.06	0.00	0.00
	FO-c-lt	Min	-0.61	-0.70	0.73	0.73
		Max	-0.30	-0.55	0.73	0.73
		#	3	4	2	2
64	K-r	Avg	-0.17	-1.08	0.30	1.94
		#	1	1	1	1
65	FO-r&c	Avg	-0.17	-1.05	0.88	1.52
	FO-r&c-lt	Std	0.03	0.59	0.38	0.18
		Min	-0.19	-1.76	0.50	1.33
		Max	-0.13	-0.27	1.26	1.70
		#	3	5	2	2
66	FO-e	Avg	-0.10	-1.50		
		Std	0.00	0.00		
		Min	-0.10	-1.50		
		Max	-0.10	-1.50		
		#	1	1		
67	FO-i	Avg	-0.11	-1.07		
		Std	0.00	0.40		
		Max	-0.11	-1.57		
		Min	-0.11	-0.50		
		#	1	5		
68	FO-ii	Avg		-1.87		
		Std		0.75		
		Max		-2.82		
		Min		-0.77		
		#		4		
69	FO-i-lt	Avg	-0.24	-0.76	1.00	1.00
	FO-i-hv	Std	0.08	0.17	0.00	0.00
		Min	-0.34	-1.01	1.00	1.00
		Max	-0.13	-0.54	1.00	1.00
		#	4	4	2	2
70	K-i	Avg	-0.26	-0.75	1.00	1.00
		#	1	1	1	1
71	FO-lt	Avg	-0.12	-0.61	0.12	0.61
		#	1	1	1	1

VI.2 New Studies of Nontransport Oil Demand. All the new studies on nontransportation demand for oil are in Table 20. For total oil demand in C29, which none of the earlier surveys included, all studies are on time series data, all are dynamic for price but static for income, all but one use the price of oil. Long run price elasticity averages -0.5, intermediate income elasticity is 0.8. B&P89 and G&R88 do not find evidence of an asymmetric response to price.

Table 20: New Studies of Nontransport Demand for Oil.

C	Ref	Product	Samp	y1	y2	Type	Psr	t(p)	Pir	Plr	Ysr	t(Y)	Yir	Ylr
Price		Model	ET											
29	B&P89	O	US	72	88	Tq	-0.08	-5.64		-0.56		11.81	1.13	
Po		PDL	OLS?											
29	Gat86	O	US	50	82	T	-0.05	-2.45		-0.37		10.88	0.88	
Po		Stat	GLS-s2											
29	G&R88	O	US	50	85	T	-0.07	-2.79		-0.38			0.60	
Po		DL	GLS-h											
29	G&R88	O	US	50	85	T	-0.07	-3.25		-0.36			0.70	
Po		PDL	GLS-h											
29	G&R88	O	US	50	85	T	-0.08	-2.79		-0.34			0.60	
Po		DL-Asym	GLS-h											
29	G&R88	O	US	50	85	T	-0.04	-1.67		-0.33			0.89	
Po		PDL	GLS-s											
29	G&R88	O	US	50	85	T	-0.19	-4.35		-0.72			0.88	
Po		DL	GLS-s											
29	L&R86	O	US	70	82	T	-0.25			-0.94			0.70	
Pop		DL	FIML											
						Avg	-0.10			-0.50			0.80	
						Std	0.07			0.21			0.17	
						Min	-0.25			-0.94			0.60	
						Max	-0.04			-0.33			1.13	
						#	8			8			8	
30	U&B88	Op	US	73	87	Tm		-8.27	-0.83			2.19	0.90	
Po		Stat	FIML											
30	Bro83	Op	US	71	79	Tq	-0.04	-5.25		-0.25		10.61	1.09	
Pop		OL	OLS?											
30	Bop84	Op	US	78	92	Tm			-0.20				0.31	
Pop		Stat	OLS											
30	Bop84	Op	US	66	73	Tm			-0.15				0.71	
Pop		Stat	OLS											
						Avg	-0.04		-0.39	-0.25			0.75	
						Std	0.00		0.31	0.00			0.29	
						Min	-0.04		-0.83	-0.25			0.31	
						Max	-0.04		-0.15	-0.25			1.09	
						#	1		3	1			4	

C	Ref	Product	Samp	y1	y2	Type	Psr	t(p)	Pir	Plr	Ysr	t(Y)	Yir	Ylr
Q(-1)	t(-1)	Model	ET											
31	D&S88	O-r	US-s	71	74	CT	-0.10	-2.77		-2.77				
0.96	74.16	LE	EC											
31	D&S88	O-r	US-s	78	82	CT	-0.59	-3.21		-1.85				
0.68	15.27	LE	EC											
31	LCC87	O-r-ht	US	60	83	T	-0.21			-3.50	0.21			2.28
0.91		LE	EC-SUR											
31	Uri83b	O-r	US-rNE	47	78	T			-1.18					
		TlNgOElSUR-s												
31	Uri83b	O-r	US-rMAt	47	78	T			-0.90					
		TlNgOElSUR-s												
31	Uri83b	O-r	US-rENC	47	78	T			-0.77					
		TlNgOElSUR-s												
31	Uri83b	O-r	US-rWNC	47	78	T			-0.83					
		TlNgOElSUR-s												
31	Uri83b	O-r	US-rSAt	47	78	T			-1.22					
		TlNgOElSUR-s												

31	Uri83b	O-r	US-rESC	47	78	T			-0.99								TlNgOElSUR-s	
31	Uri83b	O-r	US-rWSC	47	78	T			-0.92								TlNgOElSUR-s	
31	Uri83b	O-r	US-rMt	47	78	T			-1.00								TlNgOElSUR-s	
31	Uri83b	O-r	US-rPc	47	78	T			-0.80								TlNgOElSUR-s	
31	Uri83b	O-r	US	47	78	Avg			-0.92								TlNgOElcomputed	
						Avg	-0.30		-0.95	-2.71	0.21			2.28	0.85			
						Std	0.21		0.14	0.68	0.00			0.00	0.12			
						Min	-0.59		-1.22	-3.50	0.21			2.28	0.68			
						Max	-0.10		-0.77	-1.85	0.21			2.28	0.96			
						#	3		10	3	1			1	3			

Table 20 (continued): New Studies Nontransport Demand for Oil.

C	Ref	Product	Samp	y1	y2	Type	Psr	t(p)	Pir	Plr	Ysr	t(Y)	Yir	Ylr	Q(-1)	t(-1)	Model	ET
32	Gar83a	LPG-r	US-h	80	81	CTm		-6.15	-1.30			1.69	0.21				StatSk	OLS?
32	BTR83	FO-r	US-s48	60	75	CT	-0.19	-2.99		-0.67	-0.08	-0.80		-0.28	0.72	28.50	LE	EC
32	BTR83	FO-r	US-s48	60	75	CT	-0.18	-2.81		-0.62	0.11	1.96		0.40	0.72	28.02	LE	EC
32	BTR83	FO-r	US-s48	60	75	CT	-0.18	-2.80		-0.62	0.11	1.90		0.40	0.72	28.04	LE	EC
32	BTR83	FO-r	US-s48	60	75	CT	-0.18	-2.80		-0.62	0.11	1.97		0.38	0.72	28.19	LE	EC
32	Gar83a	FO-r	US-h	79	80	CTm		-2.45	-1.30			4.50	0.23				StatSk	2S
32	Gar85	FO-r	US-h	79	80	CTm		3.14	-1.56			4.50	0.23				StatSk	OLS
32	G&H84	FO-r	US-h	72	73	CTq		-3.77	-1.34			5.44	0.20				StatSk	OLS
32	G&H84	FO-r-ht	US-h	72	73	CTq		-2.19	-1.09			3.81	0.18				StatSk	OLS
32	G&H84*	FO-r-wh	US-h	72	73	CTq		-1.27	-3.07			1.32	0.31				StatSk	OLS
						Avg	-0.18		-1.32	-0.63	0.06		0.21	0.22	0.72			
						Std	0.01		0.15	0.02	0.08		0.02	0.29	0.00			
						Min	-0.19		-1.56	-0.67	-0.08		0.18	-0.28	0.72			
						Max	-0.18		-1.09	-0.62	0.11		0.23	0.40	0.72			
						#	4		5	4	4		5	4	4			
33	C&M84	O-c	US-s14	64	77	CT			-0.30								LgElNgOISUR	
33	C&M84	O-c	US-s14	64	77	CT	-0.07			-0.40					0.81	40.30	LgElNgOISUR	
33	LCC87	O-c-ht	US	60	83	T	-0.19			-3.50	0.20			4.39	0.95		LE	EC-SUR

						Avg	-0.13		-0.30	-1.95	0.20			4.39	0.88			
						Std	0.06		0.00	1.55	0.00			0.00	0.07			
						Min	-0.19		-0.30	-3.50	0.20			4.39	0.81			
						Max	-0.07		-0.30	-0.40	0.20			4.39	0.95			
						#	2		1	2	1			1	2			
34	Hai81	O-e	US-plnt	70	75	CT		-6.91	-1.31								TlCONg	ISUR
34	Hai81	O-e	US-plnt	70	73	CT		-13.69	-3.07								TlCO	ISUR
34	Hai81	O-e	US-plnt	74	75	CT		-5.96	-3.11								TlCO	ISUR
34	Hai81	O-e	US-plnt	70	73	CT		-6.57	-0.58								TlONg	ISUR
34	Hai81	O-e	US-plnt	74	75	CT		-0.43	-0.08								TlONg	ISUR
34	Mcd91	O-e	US-ut82	87	87	C			-2.25								TlCONgNHyElws	ISUR
34	Ko93	O-e	US	49	91	T			-0.28								TlCONg	SUR
34	Ko93	O-e	US	49	91	T			-0.29								TlCONg	SUR
34	B&C90	O-e	US	77	87	Tm			-0.59								TlCONg	ISUR
34	B&C90	O-e	US-rNE	77	87	Tm			-0.39								TlCONg	ISUR
34	B&C90	O-e	US-rNC	77	87	Tm			-1.29								TlCONg	ISUR
34	B&C90	O-e	US-rSE	77	87	Tm			-0.67								TlCONg	ISUR

Table 20 (continued): New Studies Nontransportat Demand for Oil.

C	Ref	Product	Samp	y1	y2	Type	Psr	t(p)	Pir	Plr	Ysr	t(Y)	Yir	Ylr	Q(-1)	t(-1)	Model	ET
34	B&C90	O-e	US-rW	77	87	Tm			-0.71								TlCONg	ISUR
						Avg			-1.13									
						Std			1.00									
						Min			-3.11									
						Max			-0.08									
						#			13									
35	Con89b	O-i	US	70	85	T			-0.44								TlCONgEl	FIML
35	Con89b	O-i	US	70	85	T			-0.33								LgCONgEl	FIML
35	Con89b	O+t-i	US	70	85	T			-0.13								TlCO+tNgEl	FIML
35	Con89b	O+t-i	US	70	85	T			-0.08								LgCO+tNgEl	FIML

35	Con89b	O-i	US	70 85	T			-0.12					
		TlCONgEl		FIML									
35	Con89b	O-i	US	70 85	T			-0.09					
		LgCONgEl		FIML									
35	Hal86b	O-i	US	60 79	T		s	+					
		TlCOElNg		ISUR									
35	Hal86b	O-i	US	60 79	T		s	+					
		TlCOElNg		ISUR									
35	KBP86	O-i	US	60 82	CT	-0.13							
		Tl2COElNg		ISUR									
35	Kol86	O-i	US	60 82	CT	-0.21							
		Tl2COElNg		ISUR									
35	Kol87	O-i	US	60 82	CT				-0.80				
		Tl2COElNg		ISUR									
35	LCC87*	O-i-ht	US	60 83	T	-0.20			-3.40	0.21			4.37
0.95		LE		EC-SUR									
					Avg	-0.18		-0.20	-0.80				
					Std	0.03		0.14					
					Min	-0.21		-0.44					
					Max	-0.13		-0.08					
					#	3		6	1				
36	L&L84	O-fd	US	54 76	T			-0.57					
		TlONgCElStEqLM		ML									
36	L&L84	O-fd	US	54 76	T			-0.57					
		LgONgCElStEqLM		ML									
					Avg			-0.57					
					Std			0.00					
					Min			-0.57					
					Max			-0.57					
					#			2					
37	Uri88a	FO-ag	US-s	78 80	CT			-1.59					
		TlGDLpFoNgEl		SUR									
37	D&C84	FO-mt	US-s	74 77	CT			-1.52					
		Sh-2Eq		SUR									

Table 20 (continued): New Studies Nontransport Demand for Oil.

C	Ref	Product	Samp	y1 y2	Type	Psr	t(p)	Pir	Plr	Ysr	t(Y)	Yir	Ylr
Q(-1)	t(-1)	Model		ET									
37	D&C84	FO-mt	US-s	67&71	CT			-0.36					
		Sh-2Eq		SUR									
37	D&C84	FO-mt	US-s	75 77	CT	-0.58			-1.65				
		ShLE		SUR									
					Avg	-0.58		-1.16	-1.65				
					Std	0.00		0.56	0.00				
					Min	-0.58		-1.59	-1.65				
					Max	-0.58		-0.36	-1.65				
					#	1		3	1				
38	U&G92	LPG-ag	US	71 89	Tm	-0.28	-0.13		-1.32				
0.79	4.20	LE		GLS-s									
38	Uri88a	LPG-ag	US-s	78 80	CT			-4.05					
		TlGDLpFoNgEl		SUR									

```
                                      Avg  -0.28        -4.05 -1.32
0.79
                                      #        1            1     1
39 Uri89  D-ag    US-s42 80 80 C    -0.42  -2.11        -1.50  0.08  2.04         0.29
 0.72  5.36 LE           IV
39 Uri88a D-ag    US-s   78 80 CT                 -0.75
            TlGDLpFoNgEl SUR
39 Uri89  D-ag    US-s   80 80 C    -0.39  -2.56        -1.37  0.07  3.03         0.25
 0.72  5.36 LE           IV
                                      Avg  -0.40        -0.75 -1.43  0.08         0.27
 0.72
                                      Std   0.02         0.00  0.07  0.00         0.02
 0.00
                                      Min  -0.42        -0.75 -1.50  0.07         0.25
 0.72
                                      Max  -0.39        -0.75 -1.37  0.08         0.29
 0.72
                                      #        2            1     2     2            2
    2

40 Gre88  FO      US     68 82 Tq   -0.10  -2.32        -0.24  0.73  3.97         1.73
 0.58  8.46 LE           FIML
40 Bop83  K       US     67 76 Tm    0.67   8.80         0.26 -1.50 -2.50        -1.60
 0.06  0.62 LE           OLS

41 Gat92b O-ntr   US     49 90 T    -0.09    s          -2.35  0.03  1.00         0.82
 0.96 s     LE           OLS
41 Gat92b O-ntr   US     49 90 T    -0.19    s          -0.68  0.38 s             1.36
 0.72 s     LE-Pmax      OLS
41 Gat92b O-ntr   US     49 90 T     0.03   0.90         0.10
 0.72 s     LE-Pcut      OLS
41 Gat92b O-ntr   US     49 90 T     0.02   0.50         0.06
 0.72 s     LE-Prec      OLS
41 Gat92b O-ntr   US     49 90 T    -0.12    s          -0.77  0.22 s             1.47
 0.85 s     LE-Pmax      OLS
41 Gat92b O-ntr   US     49 90 T    -0.03  -0.70        -0.23
 0.85 s     LE-Pcut      OLS
                                      Avg  -0.07              -0.65  0.21         1.22
 0.80
                                      Std   0.08               0.83  0.14         0.28
 0.09
                                      Min  -0.19              -2.35  0.03         0.82
 0.72
                                      Max   0.03               0.10  0.38         1.47
 0.96
                                      #        6                  6     3            3
    6
```

*Elasticities not included in the averages.

The only study that uses the price of oil products L&R86 measures a more elastic price response, as would be expected, since retail price changes should have changed a smaller percent than crude prices.

Gately (1992a), not shown here because it is estimated on data for the OECD with no separate estimate for the US, concludes that price elasticities are not reversible and the price elasticity for the price decreases after 1986 may be 20% those of the earlier price rises. Since he appeared to use the price of crude oil, as do most of the studies in C29, one should check how oil prices and retail prices were related over the sample, and whether that relationship changed.

Elasticities for oil product demand all on quarterly and monthly data in C30 tend to have a somewhat lower price elasticity but a similar income elasticity to oil demand. The only study that uses the price of oil finds a more elastic price response. Bop84 finds less than half the income response on data from 1978 to 1992 than on data from 1966 to 1973.

From these two categories the only ones that, I think, make economic sense are those that look at the demand for oil products and use the price of products in C30. These suggest a fairly inelastic price response and inelastic income response that is inelastic and has fallen in recent years. However, since all data was either monthly or quarterly, one would not expect that these studies capture long run adjustment. Further, the sensitivity to product aggregation noted above would cause us to further suspect these estimates.

Demand studies for fuels by sector came to be particularly popular with the use of translog models or other fuel share models that explicitly measure interfuel substitution. In these types of studies, the three sectors most often considered are electricity generation, industrial demand, and residential demand. Energy products are assumed to be separable from other goods or inputs in utility or production functions with oil products, except transportation oils, aggregated into one oil product. We will see examples of these in the sectoral studies shown below.

All studies for residential demand are on aggregate data in C31. Those using LE models find large price elasticities, whether on total oil consumption or heating oil consumption, but variation across studies is large. Income elasticities for these same studies are even more mixed. D&S88 finds income insignificant and omits it, LCC87 finds long run income elasticities to be 2.28.

Uri83b uses a translog function and finds intermediate run elasticities that are slightly inelastic on average with variation across regions from -0.77 to -1.21. From this category I might conclude that long run demand could be price elastic, but that there is no information on income elasticity.

C32 has demands by product in the residential sector. All the estimates on household data are static stock models with stocks of appliances represented by dummy variables. Except for fuel oil for water heating with its very elastic price response (-3.07), price elasticities average -1.32 and income elasticities average 0.21 for both LPG and fuel oil. The LE models obtain a lower average long run price elasticities of -0.63 and a long run income elasticity of 0.22.

Both types of models in this category support a small inelastic income response, whereas the relationships between price elasticities are the reverse that of C31. If we find more credibility in the studies on household data, we would again conclude that price response might be price elastic.

There are three estimates for the commercial sector in C33. The results on the LE model are typically perverse. The static and dynamic logit model obtain price elasticities of -0.3 and -0.4, suggesting an inelastic price response.

The estimates on demand for oil for electricity generation in C34 are all on translog models and are quite mixed. Hai81 finds a much higher price elasticity (-3.09) in oil-coal electric plants than in coal-oil-gas electric plants (-1.31), or oil-gas plants (less elastic than -0.6). We see little shift in the price elasticity in the coal-oil plants from 1970-73 to 1974-75, but his elasticity fell to insignificance in the oil-gas plants on data for 1974-1975. This inelastic response between oil and gas for 1974-75 might reflect gas shortages, which were particularly severe from 1974-1977. Mcd81 finds a relatively high elasticity (-2.25) on his translog that includes coal, oil, natural gas, hydropower, nuclear, and wholesale power purchases. Ko93 finds low price elasticities on a long annual time series -0.28, but B&C90 find a higher elasticity averaging -0.78 but with significant variation across regions. Overall the results suggest, there is probably an elastic response to price in fuel oil use in electricity generation, but with substantial variation across regional and plant type.

Demand for oil in industry on aggregate data are reported in C35. There are three studies with separate estimates for the US that use CT data on OECD countries and have the theoretical appeal of specifically considering fixed capital in the short run. KBP86 and Kol86 report a short run response in one paper of -0.13 and -0.21 and Kol87 reports a slightly inelastic long run response -0.80 in another.

There are three studies on US time series. LCC87 finds a short run elasticity of -0.2 on a lagged endogenous model, which is very near the one estimated by Kol86. The long run elasticity for both price and income, however, are very high as a result of the large coefficient on the lagged endogenous variable leading me to leave LCC87's elasticities out of the averages. Hal86b finds positive and significant estimates but does not report their actual values. Con89b uses translog and logit specifications on a short time series with his static price elasticity averages of -0.20 very near the short run estimate. He finds lower elasticities when transportation fuels are included (O+t) than when they are not, he finds a more elastic response using a translog model than a logit model, and lower elasticities when emission and supply constraints are included.

Overall, the estimates suggest a short run elasticity of demand of -0.2 or less. One might cautiously conclude a long run price elasticity of -0 .8, but should remember the usual caveat about aggregation and locational bias. There is little one can say about income elasticities.

C36-C39 contain estimates for demands by industry. L&L84 find identical inelastic responses for total oil demand on a logit and a translog model for the food industry of -0.57. D&C84 find an elastic price response for fuel oil demand on a static and a dynamic fuel share model on post 73 data for the metal industry, but not on an estimate on earlier data. Uri88a and U&G92 find conflicting estimates for LPG demand by agriculture. The cross section time series estimate on a translog model is -4.05 while a lagged endogenous on monthly data finds a long run estimate of -1.32. The translog result on LPG is probably because it is small share of the total.

It is difficult to come to an overall conclusion for the industrial sector. There is little information on income elasticities. Estimates on aggregate data more often put the elasticity for price in the inelastic range, while estimates on data by industry more often put it in the elastic range. Elasticities appear to be lower than in the earlier studies, but it will take more studies by industry to determine whether the aggregate studies are suffering from aggregation bias or the industry studies are not on representative industries.

The two estimates that aggregate for fuel across sectors are in C40. Both use LE models. Gre88 finds fuel oil to be rather price inelastic and rather income elastic. Bop83 finds a positive price and negative income elasticity for kerosene demand. His explanation that kerosene is a Giffen good is rather hard to swallow. One might rather expect that the LE model and collinearity might be to blame.

C41 contains estimates by Gat92b on nontransportation demand for oil. On a symmetric LE model, he finds a familiar pattern. High price elasticities and insignificant income elasticities. On both his asymmetric models he finds the price response to an increase in price above the maximum to be near −0.7, but the response to a price decrease or a price recovery to be insignificant. Income elasticities on these asymmetric models are elastic averaging 1.42.

VI.3 Previous Surveys of Demand for Oil for Transportation. Gasoline has been one of the most heavily studied products and demand for gasoline has the most frequent and the most recent surveys. (Taylor (1977), Bohi (1981), Kouris (1983), Bohi and Zimmerman (1984), Dahl (1986), Dahl and Sterner (1990,1991a,1991b), and Goodwin (1992)). Most of the estimates for transportation fuels are for gasoline, most surveys consider demands for all available countries not just the US, and there are only a few estimates of other transportation fuels that are also included.

Taylor (1977) considers 8 studies on the demand for gasoline, which are summarized in Table 21. All the models are on aggregate data but there is a fair range of modelling types including lagged endogenous model, a Houthakker and Taylor specification, a linear expenditure system, one market simultaneous system, and one structural model. The studies are divided up into studies for residential (S72), commercial (S73), and total demand (S74).

Taylor concludes that although the evidence is mixed, the short run elasticity is −0.1 to −0.5 and the long run is between −0.25 and −1. One might also note the high demand price elasticity on the commercial sector and that the studies suggest that demand is income elastic.

Little work has been done on other transport fuels. Taylor (1977) sites three estimates by Federal Energy Administration (1976) on truck fuel, bus fuel, and rail diesel (S75−S77). Price elasticities vary little across the three types of transport −0.37/−0.54, but income elasticities vary substantially from lows of 0.14 and 0.28 for rail diesel and bus fuel demand, respectively, to a high of 1.46 for truck fuel demand.

Bohi (1981) considers 11 studies, which represent an even wider array of model and data types including disaggregate data, but few include post 1974 data (S78−S81). These studies show an uncommon amount of price elasticity consistency. Short run price elasticities vary from −0.11/−0.41 and long run elasticities vary from −0.32/−0.77 leading Bohi to conclude in favor of a short run elasticity of −0.2 and a long run price elasticity of −0.7. Bohi claims that income elasticity is significant and found to be near 1. This statement is perhaps a bit too strong for although three of the estimates are near 1, the other 5 are either distinctly below or above 1 and the range for the income elasticities is wider than for the price elasticities 0.4/1.74. Bohi categorizes his studies as he did earlier and we find some familiar patterns: studies on disaggregate data find low income elasticities while structural models may find lower income and price elasticities.

Kouris (1983) considers 12 studies that are summarized below in S82−S85. The four estimates on international CT data (S82) have both price and income elasticities in the elastic region. His 14 estimates on country T data using dynamic models finds a slightly inelastic long run price elasticity (S83). But as we have seen earlier in dynamic models, particularly those that use a lagged endogenous formulation, there is wide variation across the estimates. The income elasticity he reports is not designated as long run or short run, but its size and the text suggest it is a short run elasticity.

The seven estimates on static time series (S84) are referred to as short run elasticities since auto efficiency is included in the model. They are very close to the average short run elasticities from the dynamic models at −0.19.

The income effect, which is reported as the elasticity of the car park (which I take to mean the stock of cars), is much larger than in the dynamic model. However, given that the models appear to be quite different, this inconsistency is not unexpected.

His survey of 7 estimates for the US (S85) leads him to conclude that the short run price elasticity is −0.2 to −0.4 and the long run elasticity is −0.7 as did Bohi in his earlier survey.

Bohi and Zimmerman (1984) consider an additional 10 studies on the demand for gasoline that include more post 1973 data. They stratify across model types in the same way as before in (S86−S91) and find more inconsistency across results from these studies than earlier. Short run elasticities now vary from insignificance to −0.77, long run price elasticities vary from insignificance to −1.59, short run income elasticities vary from −0.18 to 1.20, while long elasticities vary from −0.34 to 1.35.

Table 21: Transport Oil Demand Elasticities Surveyed in Taylor (1977), Bohi (1981), Bohi and Zimmerman (1984), and Dahl (1986).

S	Taylor (1977)		Psr	Pir	Plr	Ysr	Yir	Ylr
72	G−r	Avg	−0.18	−0.77	−0.72	0.45	1.34	1.44
		Std	0.12		0.22	0.03		0.33
		Min	−0.37		−1.03	0.41		0.98
		Max	−0.07		−0.48	0.48		1.69
		#	4	1	5	2	1	3
73	G−c	Avg		−3.80				
		#		1				
74	G	Avg	−0.64		−0.53	0.52		1.17
		Std	0.17		0.28	0.22		0.17
		Min	−0.80		−0.80	0.30		1.00
		Max	−0.47		−0.25	0.74		1.33
		#	2		2	2		2
75	F−Tk	Avg			−0.54			1.74
		#			1			1
76	F−Bs	Avg			−0.48			0.28
		#			1			1
77	D−rr	Avg			−0.37			0.14
		#			1			1
Bohi (1981)								
78	G Stat Agg	Avg	−0.19		−0.59	0.24		1.03
		Std			0.18	0.00		0.31
		Min			−0.77	0.24		0.72
		Max			−0.40	0.24		1.34
		#	1		2	1		2
79	G Stat Disag	Avg			−0.60			0.40
		#			1			1
80	G Dyn Agg	Avg	−0.18		−0.61	0.49		1.33
		Std	0.05		0.17	0.08		0.32
		Min	−0.23		−0.77	0.38		1.02

	Max	−0.11	−0.32	0.58	1.74
	#	5	5	4	4
81 G Struct	Avg	−0.33	−0.48	0.16	0.93
	Std	0.08	0.12	0.00	0.00
	Min	−0.41	−0.60	0.16	0.93
	Max	−0.24	−0.36	0.16	0.93
	#	2	2	1	1

Table 21 (continued): Transport Oil Demand Elasticities Surveyed in Taylor (1977), Bohi (1981), Bohi and Zimmerman (1984), and Dahl (1986).

S Kouris (1983)		Psr	Pir	Plr	Ysr	Yir	Ylr
82 G Stat	Avg			-1.09			1.23
Int CT	Std			0.23			0.37
	Min			-1.31			0.84
	Max			-0.75			1.73
	#			4			3
83 G Dyn, Agg	Avg	-0.19		-0.94	0.20		
T Country	Std	0.27		0.51	0.20		
	Min	-1.14		-1.77	0.00		
	Max	0.00		0.00	0.58		
	#	14		14	14		
84 Stat, T	Avg	-0.19			0.85		
Countries	Std	0.04			0.05		
	Min	-0.26			0.80		
	Max	-0.12			0.95		
	#	7			7		
85 G US	Avg	-0.30		-0.68		not reported	
	Std	0.12		0.19			
	Min	-0.46		-1.02			
	Max	-0.11		-0.36			
	#	7		7			
Bohi and Zimmerman (1984)							
86 G Stat	Avg	-0.26			0.36		
Agg	Std	0.09			0.00		
	Min	-0.34			0.36		
	Max	-0.17			0.36		
	#	2			2		
87 G Dyn	Avg	-0.07		-0.48	0.09		0.27
Agg	Std	0.06		0.78	0.25		0.46
	Min	-0.15		-1.59	-0.18		-0.34
	Max	0.00		0.14	0.42		0.76
	#	3		3	3		3
88 G Dyn	Avg	-0.17		-0.88	0.08		0.43
Internat	Std	0.04		0.12	0.02		0.08
	Min	-0.20		-1.00	0.06		0.35
	Max	-0.13		-0.76	0.10		0.50
	#	2		2	2		2
89 G Stat	Avg	-0.21	-0.44	-0.54	0.60		1.35
DynSk	#	1	1	1	1		1

Table 21 (continued): Transport Oil Demand Elasticities Surveyed in Taylor (1977), Bohi (1981), and Bohi and Zimmerman (1984), and Dahl (1986).

S		Psr	Pir	Plr	Ysr	Yir	Ylr
90 G StatSk	Avg	-0.46			0.43		
Disag	Std	0.20			0.13		
	Min	-0.77			0.29		
	Max	-0.22			0.56		
	#	4			4		
91 G DynSk	Avg	-0.13			0.89		
Agg	Std	0.04			0.26		
	Min	-0.17			0.56		
	Max	-0.07			1.20		
	#	3			3		

Dahl (1986):p73)		Psr	Pir	Plr	Ysr	Ylr
92	m,q	-0.12			0.31	
	a	-0.29		-1.02(CS) -0.60(LE,DL)	0.47	1.38

Dynamic models particularly on monthly or quarterly data show the most unstable results. Discounting those studies, they conclude that the short run elasticity is -0.2, as before, and the long run elasticity is still less than 1 in absolute value. They do not come to any conclusion on income elasticity, but discounting the dynamic models we might conclude that the short run income elasticity is near 0.4 and the long run elasticity is in the elastic region.

Dahl(1986) surveys 69 studies of gasoline demand and found a great deal of variation in elasticities until they were stratified by data and model type. These stratified elasticities showed a surprising amount of consistency and allowed development of the following summary elasticities for gasoline demand, shown in Table 21, S92. The monthly to quarterly price elasticity is -0.12, the annual elasticity is -0.29, and the long run price elasticity is -1.02. The monthly income elasticity is 0.31, the annual income elasticity is 0.47, while the long run income elasticity is 1.38.

Gasoline demand LE models do not seem to pick up long run price elasticities. When estimated on monthly and quarterly data they will pick up shorter run adjustments at most, unless annual lags are used. In CT data, as cross sections get larger with more data variation and time series get shorter, more long run adjustment is captured. LE-Sk models tend to capture at most short run adjustment. Lags on income may be shorter and more consistent with the lag implied by a LE model than those on price.

The market appears to handle short term disruption fairly well. The log form tends to dominate the linear form for gasoline demand. Highway gasoline consumption is more elastic than either agricultural gasoline consumption or total highway fuel consumption. There is some evidence that single equation techniques give a less elastic price response on US data and that random coefficients give atypical results, particularly on LE models.

More recently this survey has been updated by Dahl and Sterner (1990, 1991a, 1991b). Since these studies are fairly recent and the most complete available, I draw heavily from them with their studies summarized in Table 22. They found that the many studies on gasoline demand arrive at apparently conflicting results, which is quite natural with studies based on different models, types of data, countries, time periods, different functional forms, and econometric techniques. However, they also found that if properly stratified, compared, and interpreted, different models and data types tended to produce a reasonable degree of consistency.

Their ten basic model types (M) used for stratification with notation changed to be consistent with this document are:

Stat (M1) $G = f_1(P,Y))$

LE (M2) $G = f_2(P,Y,G_{t-1})$

StatSk (M3) $G = f_3(P,Y,Sk)$

SkChar (M4) $G = f_4(P,Y,V,CHAR)$, where Char is some characteristic of the vehicle stock such as miles per gallon.

DL (M5) $G = f_5(\Sigma P_{t-i},\Sigma Y_{t-i}))$

LE-DL (M6) $G = f_6(\Sigma_i P_{t-i},\Sigma_i Y_{t-i},\Sigma_i G_{t-1})$

Sk-DL (M7) $G = f_7(P_{t-i},\Sigma_i Y_{t-i},Sk)$

Sk-LE (M8) $G = f_8(P,Y,Sk,G_{t-1})$.

G/Sk (M9) $G/V = f_9(P,Y,V,G/V_{t-1}))$

Drollas (M10) $G = f_{10}(P,Ptr,Y,Pa,P_{t-1},Y_{t-1}, G_{t-1})$

Models are also stratified by periodicity of data which is monthly (m) quarterly (q), and yearly (y). Data types include disaggregate data on individual households as well as aggregated data by region and country on (T), (C), and (CT). Lagged endogenous models are further stratified by the length of the lag - one month (1m), twelve months (12m), one quarter (1q) or four quarters (4q).

Their summary statistics for the 18 resulting categories for these stratifications are in Table 22 (S93-S110). Where analysis of variance found no significance difference between data sets TS and CSTS, they are combined.

Beginning with the static models, they found the estimates on monthly and quarterly data (S94) to be roughly half of those on annual data (S93). Comparing the annual static elasticities to the annual lagged endogenous model (S95), they find the static price elasticity -0.53 seems to be an intermediate elasticity between the short and long elasticity for the lagged endogenous model, but the static income elasticity at 1.16 appears to measure long run elasticity. Such evidence could suggest that consumers with a clearer idea of their future income than of future gasoline price are able to adjust to income changes faster. An equally appealing argument is that income is more correlated over time than price and, hence, omitting variables for income causes less bias in the estimates than the omission of price variables. Whatever the reason, the implication for forecasting and policy analysis is that static models tend to underestimate long run adjustment to price changes but not to income changes relative to the annual lagged endogenous model.

S96-S99 summarize studies using the lagged endogenous model with periodicities shorter than one year. These four categories show the difficulties that seasonal variation can make to interpreting results. Whether the lag on this seasonal data is one period or one year, the short run average price elasticities vary only minimally between -0.13 and -0.20. However, estimates with a quarterly or monthly lag seem to pick up smaller long run price elasticities, while those on annual lags appear to pick up smaller income effects. Such a pattern can be explained by the seasonal patterns with current gasoline consumption more highly correlated with consumption the same season last year than last season. These inconsistencies on seasonal data suggest that researchers should pay close attention to seasonal effects before using seasonal estimates for overall long run forecasting or policy analysis.

Table 22: Transport Oil Demand Elasticities Surveyed in Dahl and Sterner (1990,1991a,1991b) and Goodwin (1992)

Dahl and Sterner (1990, 1991a, 1991b)

S	Model Type	Data Type	Data Period		Price Elasticity SR	Price Elasticity IR	Price Elasticity LR	Income Elasticity SR	Income Elasticity IR	Income Elasticity LR	Vehicle Elasticity	Q(t-1)	# of Estimates
93	M1(Stat)	T	y	Avg		-0.53			1.16				22
				Std		0.33			0.41				
				Min		-1.36			0.37				
				Max		0.28			1.90				
94	M1(Stat)	T	m,q	Avg		-0.29			0.52				81
				Std		0.21			0.34				
				Min		-1.28			-0.15				
				Max		0.59			1.71				
95	M2(LE)	CT/T	y	Avg	-0.24		-0.80	0.45		1.31		0.65	38
				Std	0.12		0.48	0.22		0.47		0.16	
				Min	-0.50		-2.00	0.09		0.40		0.28	
				Max	-0.03		-0.10	1.02		2.51		0.88	
96	M2(LE1q)		q	Avg	-0.13		-0.28	0.44		1.02		0.56	17
	CT/T			Std	0.10		0.21	0.19		0.26		0.17	
				Min	-0.38		-0.77	0.15		0.50		0.15	
				Max	-0.02		-0.05	0.87		1.52		0.77	
97	M2(LE4q)	T	q	Avg	-0.14		-0.59	0.20		0.75		0.75	10
				Std	0.04		0.21	0.05		0.11		0.06	
				Min	-0.21		-1.03	0.09		0.54		0.63	
				Max	-0.09		-0.38	0.27		0.98		0.84	
98	M2(LE1m)	T	m	Avg	-0.20		-0.23	0.58		0.85		0.33	4
				Std	0.21		0.20	0.31		0.36		0.20	
				Min	-0.55		-0.55	0.16		0.27		-0.01	
				Max	-0.02		-0.04	0.99		1.24		0.51	

Table 22 (continued): Transport Oil Demand Elasticities Surveyed in Dahl and Sterner (1990, 1991a, 1991b), and Goodwin (1992).

S	Model Type	Data Type	Data Period		Price Elasticity SR	Price Elasticity IR	Price Elasticity LR	Income Elasticity SR	Income Elasticity IR	Income Elasticity LR	Vehicle Elasticity	Q(t-1)	# of Estimates
99	M2(LE12m)T		m	Avg	-0.19		-0.88	0.22		0.64		0.63	5
				Std	0.14		0.79	0.29		0.92		0.21	
				Min	-0.46		-2.42	-0.16		-0.84		0.34	
				Max	-0.09		-0.21	0.70		1.56		0.82	
100	M3(StatSk)CT/T		y	Avg		-0.31			0.52		0.52		50
				Std		0.26			0.35		0.41		
				Min		-1.05			-0.71		-0.02		
				Max		0.15			1.43		2.61		
101	M3(StatSk)T		m,q	Avg		-0.42			0.18		0.50		5
				Std		0.13			0.04		0.73		
				Min		-0.58			0.14		-0.73		
				Max		-0.24			0.22		1.07		
102	M4(SkChar) CT/T		y	Avg		-0.16			0.29		0.48		6
				Std		0.11			0.14		0.18		
				Min		-0.32			0.07		0.29		
				Max		-0.08			0.00		0.66		
103	M4(SkChar) CT/T		m,q	Avg		-0.32			0.17		0.45		8
				Std		0.15			0.29		0.28		
				Min		-0.69			-0.22		0.11		
				Max		-0.11			0.71		1.00		
104	M4(SkChar) Household		q,y	Avg		-0.52			0.41				5
				Std		0.21			0.12				
				Min		-0.77			0.29				
				Max		-0.22			0.56				

Table 22 (continued): Transport Oil Demand Elasticities Surveyed in Dahl and Sterner (1990, 1991a 1991b), and Goodwin (1992)

C	Model Type	Data Type	Data Period		Price Elasticity SR	Price Elasticity IR	Price Elasticity LR	Income Elasticity SR	Income Elasticity IR	Income Elasticity LR	Vehicle Elasticity	Q(t-1)	# of Estimates
105	M4&M1	C	y	Avg		−1.01			0.61		0.40		6
	Stat, SkChar			Std		0.25			0.33		0.27		
				Min		−1.33			0.32		0.05		
				Max		− 0.70			1.22		0.86		
106	M8(SkLE)		y	Avg	−0.12		−0.29	0.38		0.60	0.19 0.32	0.40	8
	CT/T			Std	0.08		0.28	0.30		0.31	0.09 0.16	0.25	
				Min	−0.30		−0.98	0.04		0.05	0.00 0.00	0.20	
				Max	−0.05		−0.12	0.80		0.88	0.26 0.57	0.80	
107	M9(G/Sk)		y	Avg	−0.17		−1.05	0.14		0.87	−0.18	0.84	4
	CT			Std	0.07		0.14	0.06		0.06	0.12	0.06	
				Min	−0.24		−1.26	0.07		0.79	−0.34	0.76	
				Max	−0.08		−0.91	0.23		0.94	−0.04	0.93	
108	M7(SkDL)		y	Avg	−0.08		−0.97		0.57		0.28		4
	CT/T			Std	0.06		0.15		0.20		0.13		
				Min	−0.16		−1.26		0.33		0.10		
				Max	−0.01		−0.90		0.89		0.41		
109	M6(LE−DL)	T	y	Avg	−0.22		−0.94	0.39		1.09			11
				Std	0.14		0.45	0.21		0.45			
				Min	−0.50		−1.81	0.01		0.07			
				Max	−0.01		−0.37	0.65		1.54			
110	M10(Drol)	T	y	Avg	−0.41		−0.77	0.42		1.11			9
				Std	0.11		0.19	0.23		0.18			
				Min	−0.57		−1.20	0.06		0.89			
				Max	−0.24		−0.55	0.75		1.39			

Table 22 (continued): Transport Oil Demand Elasticities Surveyed in Dahl and Sterner (1990, 1991a, 1991b), and Goodwin (1992)

Conclusions from Dahl and Sterner Gasoline Demand Surveys.

	Price		Income		#	Most
S	SR	LR	SR	LR	Studies	Recent
111 Dahl&Sterner	-0.24(S95)	-0.80(S95)	0.45(S95)	1.16(S93)	97	1988
	-0.31(S100)	-1.01(S105)	0.52(S100)	1.31(S95)		
	-0.22(S106-S110)	-0.92(S107-S110)	0.44(S107-S110)	1.10(S109-S110)		
Average	-0.26	-0.86	0.48	1.21		

S Goodwin (1992)		Psr	Pir	Plr
112 TS	Avg	-0.27	-0.53	-0.71
	Std	0.18	0.47	0.41
	#	51	8	45
113 CS	Avg	-0.28	-0.18	-0.84
	Std	0.13	0.10	0.18
	#	6	6	5

Moving on, a common model that captures short run adjustment by inclusion of the vehicle stock is StatSk (S100,S101). Again the bulk of the models are annual models. Since they again found no significant difference between estimates on CT and T data, they pool them into S100. The averages for gasoline price, income and vehicle elasticity are respectively, -0.31, 0.52, and 0.52. If they compare vehicle model results with the simpler static model (S93), they find that they imply that roughly half of the annual adjustment (-0.31/-0.53 for price and 0.52/1.16 for income) comes through utilization or changes in vehicle characteristics rather than changes in the number of vehicles. Everything else equal, adding 1% to the vehicle stock adds only 0.5% to gasoline consumption implying each additional vehicle is used less intensely.

The average price and income elasticities are also surprisingly close to the short run estimates of price and income elasticities from the annual lagged endogenous model (S95), which supports the interpretation of both of these as short run elasticities. Comparing the vehicle (S100) to the vehicle characteristics models (S102) allows us to further distinguish between changing utilization and changing vehicle characteristics. They suggest that about one third (-0.16/-0.52) of early adjustment to price comes from changes in utilization and a somewhat smaller proportion 0.29/1.16 of early adjustment to income comes from changes in utilization. Across the vehicle and vehicle characteristics model the average vehicle elasticities are rather consistent ranging from 0.45 to 0.52.

Again the monthly/quarterly data (S103) do not provide good insights into adjustment. Price becomes unexpectedly more elastic while income becomes more expectedly less so. Vehicle elasticities are similar. Given that quarterly vehicle elasticity and characteristic data are no doubt extrapolated, some of their seasonal variation might be picked up by the price elasticity. Again the results suggest that periodicities shorter than a year may be unreliable.

The few studies on household data (S104) give more elastic responses to price and income than the other annual vehicle characteristic models (S102) with the difference for price significant at the 1% level. The next category (S105) lets us investigate further the effects of pure cross sectional variation. Although one expects C data should provide long run elasticities, the evidence on CT vs T data suggested no statistical difference between the two data types, once studies are stratified by model type and data periodicity. Household data provides some evidence of a more elastic price response. Unfortunately there are only seven studies on strict CS for aggregate data. Two are static with a lot of demographic variables, 5 are some sort of vehicle or vehicle characteristic model. All models give a more elastic price response averaging -1.01 than averages estimated on annual vehicle models (S100) of -0.31 and the difference is again significant for price.

There are two interpretations of the differences in these price elasticities that bear looking into. If the cross section really does provide more price variation and hence measures more adjustment than that imposed by the lagged endogenous, then the long run price elasticity may be greater than 1 in absolute value. The second interpretation is that cross sections provide much more variation in non income, price, and vehicle variables. If these differences are attributed to price we may simply be overestimating elasticities.

Baltagi & Griffin (1983) is the most systematic study on this issue. They argue strongly that pooling has a number of very important advantages over individual time series estimates. The most important of these is the gain in efficiency due to the far larger number of observations. According to their argument, CT data are always preferable to pure TS or CS data. CT data may, however, be more sensitive to the choice of estimator. They test several generalized least squares estimators and find that results may vary for price elasticity from -0.6 to -0.9 depending on the estimation method used. These low results depend partly on the use of gasoline per vehicle as the dependent variable. The elasticity of the vehicle stock to gasoline prices is implicitly assumed to be zero.

The more complicated sets of dynamic models in S106-S110 include combinations of lags and/or vehicles. Unfortunately as models become more complicated, they also tend to become less comparable within categories. Nevertheless, they still might provide some insights into lag structure and they proceed to look at these categories. S106 and S107 both contain some sort of vehicle and lagged endogenous variable. In S106, there is a vehicle variable and a lagged endogenous variable on the right hand side of the equation as shown in the vehicle lagged endogenous model (M8). When the model is estimated this way, the implied long run elasticities for income and price and vehicles more closely represent short run for other models. Since this formulation implies the same lag structure on income as on vehicle stock, they do not recommend this formulation for estimation purposes.

The better alternative is for the dependent variable to be gasoline per auto as in our vehicle use lagged endogenous model (M9) with estimates shown in S107. Under this formulation, the elasticities for price and income do not include the changes in the number of automobiles only the changes in utilization. Long run price estimates under this second interpretation are rather elastic at -1.05. Since these elasticities do not contain total adjustment, they suggest that price may be more elastic than that implied by the simpler lagged endogenous model. Income elasticities compared to the lagged endogenous model in S95 suggest that a third of the long run elasticity comes from changes in the number of vehicles with the rest from changes in utilization and the characteristics of the vehicle stock.

In (S108) are included the four studies with a lag on price but no lag on income or vehicles. Hence, the models are dynamic in price but static in income and vehicles. Surprisingly, they seem to measure elasticities somewhat similar to their separate counter parts - long and short run price elasticities as in the simpler dynamic models (S95) but a short income elasticity similar to the simpler nondynamic vehicle models (S100).

In S109, they combine DL models with LE-DL and find somewhat similar price and income elasticities compared to the more simple lagged endogenous model. However, within this category are 5 studies that are inverted V lags while the others are not. Averages for the inverted V studies are -1.21 for the long run price elasticity compared to averages for the other studies of -0.60. If they divide the studies in the vehicle other lag category (S108) between those with an inverted V and those with a declining lag, they find this same dichotomy for the price elasticity with averages of -1.20 and -0.65 respectively. If they pool S107 and S109 and stratify by lag type, they find the difference between the price elasticity for the geometric and the inverted V lag to be significant at the 5% level.

S110 contains results from Drollas (1984) that are of particular interest. His model is derived from the most complex of the adjustment processes applied to gasoline demand modelling. His reduced form (M10) includes both current and lagged gasoline price and income as well as a lagged endogenous variable, a price of vehicles and a price of alternative transit. His long run price elasticities are quite similar to the lagged endogenous model but income elasticities when more complex adjustment is considered is somewhat less. Within this category constraining the lag structure to be an inverted v or a geometric lag did not seem to make much systematic difference.

While S108 and S109 implied that an inverted V may capture a more elastic response than a geometric lag, S110 did not. Since an inverted V and a geometric lag both have intuitive appeal, further work in this area would be useful to resolve the issue of which lag appears to best capture adjustment.

Dahl and Sterner come to a number of conclusions in their survey. They found little statistical difference between T and CT data, but some evidence that strict cross section might measure a larger price response. Sorting out whether the larger variation in price causes the larger measured response or larger differences in other nonincluded variables is a challenge they threw out to researchers.

The difference between annual and seasonal data is much more striking. Although in simple static models with only income and gasoline price, they got the expected differences between annual and monthly/quarterly data, for other more complex models - ones that contained vehicle stock, vehicle characteristics, or a lagged endogenous models - the estimates were much less predictable. They suggest that seasonal driving patterns and auto purchases as well as deficiencies in seasonal data might all contribute to the lack of consistency in these estimates and urge caution whenever seasonal data is being used, particularly if estimates of long run adjustment are required.

The simple static models on annual data seem to measure an intermediate price elasticity but an income elasticity closer to other long run estimates. Simple vehicle and vehicle characteristics models measure short run income and price adjustments and suggest that between a quarter and a third of short run adjustment comes from changes in utilization of the vehicle stock.

Vehicle models can be designed that tend to provide estimates close to others that are considered to be long run, however, care should be exercised in choosing the structure of the model. If income is entered in a static way but price is entered dynamically, the model seems to be able to measure long run price but only short run income response. If vehicles are entered in a way that implies a geometrically declining lag on the vehicle stock variable as well as other variables, long run adjustment does not seem to be measured.

Although the lagged endogenous model appears to be quite robust, they do find rather wide variation across the estimates leaving the issue of lag structure unresolved. There is some evidence that an inverted V implies a more elastic price response than a geometric lag. Since both types of lags have economic appeal, more systematic testing of this issue is in order. We might note that the variations in results using dynamic models does not appear as large for gasoline demand as for the other products already surveyed.

Once stratified and interpreted, they find a number of models that provided alternative estimates for representative short and long run elasticities that are shown in S111, Table 22. Although there is wider divergence between long run than short run estimates, testing across these alternative estimates they do not find any statistical difference across any of these categories. Hence, they took an average of the elasticities in all of these studies to come up with overall average representative elasticities.

In comparing elasticities from earlier surveys they find representative elasticities for the short run do not vary greatly. A wide range of model types seem to capture the same short run adjustment and although the numerous additional recent studies may suggest a somewhat more elastic response, they do not change our perception of short run elasticity very greatly.

Long run representative elasticities across surveys vary more widely. But as in the earlier works there is strong evidence that gasoline consumption is responsive to price and income and if anything the addition and stratification of studies suggests that response may be getting larger. Strict cross sections still tend to provide the most elastic price response as in Dahl (1986), but averages for the lagged endogenous and the more complicated lag models seemed to have now converged somewhat towards the cross section estimates. Their conclusions for representatve short and long run price and income elasticie are (-0.26/-0.86 and 0.48/1.21).

Goodwin (1992) surveys 12 gasoline demand studies, most of which have not been surveyed by Dahl and Sterner. He stratifies his studies across estimates on T and CT data. In general, his estimates support the Dahl and Sterner results with short run elasticities averaging near -0.26. His long run cross section studies measure a more responsive price elasticity than do his time series estimates. He finds a long run response between -0.71 and -0.84. Goodwin also quotes a survey by Henscher and Young (1991) on Australian studies that are consistent with the long run elasticities of -0.7 to -0.8 of Goodwin.

In the above surveys, the US is typically not considered separately from other studies on international data or data on other countries. Although the elasticities appear fairly robust, further work could be done to determine whether there are any systematic differences in elasticities for the US than for other countries.

VI.4 New Studies on Demand for Oil for Transport. The 11 new studies of gasoline demand in the US are summarized in Table 23. There are 7 estimates on a static model. The one on monthly data (C42) finds characteristically low price and income elasticities of -0.2 and 0.4, which are lower than the similar estimates from (S94) of -0.29 and

0.52. The new studies on static models with annual data (S43) also seem to find lower income and price elasticities (-0.22/0.72) when compared to S93 (-0.53/1.16). This is particularly true as the 1980s become a larger portion of the data set. These lower income elasticities might reflect lagged adjustments to the price increases of the 1980's, effects of CAFE standards, reversibility with a smaller response to price decreases than to price increases, or demographic changes.

S&F92 are specifically concerned with distortions that might arise from data inaccuracies and problems of aggregating all fuels together. They disaggregate and consider fuels used in automobiles, which in the US is essentially gasoline. They also consider total fuel gasoline consumption for highway use, which would include gasoline use in trucks and buses. When truck use is included the changes are minimal with a slight increase in price elasticity and a slight decrease in income elasticity.

Table 23: New Studies on the Demand for Transportation Oil in the US

C	Ref	Prod	Sample	y1	y2	Type	Psr	t(p)	Pir	Plr	Ysr	t(y)	Yir	Ylr	Q(t-1)	t(-1)	Model	ET
42	L&W89	G	US-WA	84:1	88:12	Tm		-3.13	-0.20			1.52	0.40				Stat	2S
43	D&H85	G/	US	65	70-81	T		-3.66	-0.37			6.60	1.06				Stat	OLS
43	D&H85	G/	US	65	70-81	T		-2.83	-0.29			5.84	1.12				Stat	OLS
43	SFP92	G-hw	US	70	89	T		-3.46	-0.19			1.65	0.32				Stat	GLS-s
43	SFP92	F-au	US	70	89	T		-3.11	-0.17			1.95	0.38				Stat	GLS-s
43	Ste90	G	US	60	85	T		-1.41	-0.08			8.24	0.74				Stat	GLS-s
						Avg			-0.22				0.72					
						Std			0.10				0.33					
						Min			-0.37				0.32					
						Max			-0.08				1.12					
						#			5				5					
44	SFP92	F-au	US	70	89	T	-0.18	-3.15			0.23	0.79					Stat-Sk	GLS-s
44	SFP92	G-hw	US	70	89	T	-0.20	-3.46			0.18	0.63					Stat-Sk	GLS-s
44	Ste90	G	US	60	85	T	-0.13	-1.84			0.55	2.98					Stat-Sk	GLS-s
						Avg	-0.17				0.32							
						Std	0.03				0.16							
						Min	-0.20				0.18							
						Max	-0.13				0.55							
						#	3				3							
45	Uri88a	G-ag	US-st	78	80	CT			-0.38								TlGDLpFoNgEl	lSUR
45	Uri89	G-ag	US-st	80	80	C	-0.31	-2.32		-1.14	0.09	2.70		0.32	0.73	5.94	LE	IV
45	Uri89	G-ag	US-st43	80	80	C	-0.36	-3.11		-1.28	0.10	3.05		0.35	0.72	5.43	LE	IV
						Avg	-0.34		-0.38	-1.21	0.09			0.33	0.72			
						Std	0.03			0.07	0.01			0.01	0.01			

Min	-0.36		-1.28	0.09	0.32	0.72
Max	-0.31		-1.14	0.10	0.35	0.73
#	2	1	2	2	2	2

Table 23 (continued): New Studies on the Demand for Transport Oil in the US

C	Ref	Prod	Region	Y1	Y2	Type	Psr	tstat	Pir	Plr	Ysr	tstat	Yir	Ylr	Q(t-1)	tstat	Model	ET
46	Hsi90	G/	US	60	85	T		-2.82		-0.63		5.05		0.72			LE	BxCx-s
46	Hsi90	G/	US	60	85	T	-0.20	-4.90		-0.33	0.35	3.70		0.58	0.40	3.35	LE	GLS-s
46	KKB91	G	US	51	83	T	-0.17	11.88		-0.23	0.65	5.61		0.87	0.25	3.85	LE	2SLS
46	Ste90	G	US	60	85	T	-0.18	-6.58		-1.00	0.18	2.61		1.00	0.82	12.43	LE	OLS
46	Ste90	G	US	60	85	T	-0.13	-3.57		-0.57	0.19	2.40		0.83	0.77	7.03	INV.V	OLS
46	Ste90	G	US	60	85	T	-0.29	5.63			0.12	0.82			1.01	14.86	LE-OL	OLS
						Avg	-0.19			-0.55	0.30			0.80	0.65			
						Std	0.05			0.27	0.19			0.14	0.28			
						Min	-0.29			-1.00	0.12			0.58	0.25			
						Max	-0.13			-0.23	0.65			1.00	1.01			
						#	5			5	5			5	5			
47	Ste90	G	US	60	85	T	-0.19	-3.50		-1.20	0.16	0.91		1.22			PDL	GLS-s
47	Gat91	G/	US	66	89	T	-0.00	-0.10		-0.46		1.50	0.70				PDL	OLS
47	Gat91	G/	US	66	89	T	-0.03	-2.40		-0.67		2.50	0.63				PDL	OLS
										-0.31	Price cut							
47	Gat91	G/	US	66	89	T	-0.07	-5.70		-0.77		1.58	0.38				PDL	OLS
										-0.24	Price cut							
						Avg	-0.07			-0.61	0.16		0.57	1.22				
						Std	0.07			0.32	0.00		0.14	0.00				
						Min	-0.19			-1.20	0.16		0.38	1.22				
						Max	-0.00			-0.24	0.16		0.70	1.22				
						#	4			6	1		3	1				
48	H&R91	G-r	US	70:I	89:IV	Tq			-0.61				0.47				Ex-l	ML-s
48	H&R91	G-r	US	79:I	85:IV	Tq			-0.63				0.34				Ex-l	ML-s
48	H&R91	G-r	US	74:I	78:IV	Tq			-0.85				0.58				Ex-l	ML-s
48	H&R91	G-r	US	70:I	73:IV	Tq			-0.40				1.10				Ex-l	ML-s
48	H&R91	G-r	US	86:I	89:IV	Tq			-0.47				0.74				Ex-l	ML-s
						Avg			-0.59				0.65					
						Std			0.15				0.26					
						Min			-0.85				0.34					
						Max			-0.40				1.10					
						#			5				5					

Table 23 (continued): New Studies on the Demand for Transportation Oil in the US

C	Ref	Prod	Region	Y1	Y2	Type	Psr	tstat	Pir	Plr	Ysr	tstat	Yir	Ylr	Q(t-1)	tstat	Model	ET
49	Rao93	G	US-Padd1	83:1	90:12	CTm	-0.15			-0.64	0.56		0.63				3eq	OLS
49	Rao93	G	US-Padd2	83:1	90:12	CTm	-0.13			-0.93	0.46		0.53				3eq	OLS
49	Rao93	G	US-Padd3	83:1	90:12	CTm	-0.10			-1.10	0.34		0.43				3eq	OLS
49	Rao93	G	US-Padd4	83:1	90:12	CTm	-0.16			-1.99	0.50		0.55				3eq	OLS
49	Rao93	G	US-Padd5	83:1	90:12	CTm	-0.16			-1.23	0.54		0.61				3eq	OLS
						Avg	-0.14			-1.18	0.48		0.55					
						Std	0.02			0.45	0.08		0.07					
						Min	-0.16			-1.99	0.34		0.43					
						Max	-0.10			-0.64	0.56		0.63					
						#	5			5	5		5					
50	Uri85	J	US	81	83	T-m		-2.66	-0.39			2.08	0.07				Stat3eq	ISUR
50	Gat88	J	US	66	86	T		-4.00	-0.10			11.00	0.68				Stat	OLS
50	Gat88	J	US	66	86	T						4.20	0.30				Stat	GLS-s
50	Gat88	J	US	66	86	T		-4.70	-0.15			9.00	0.40				Stat	GLS-s
						Avg			-0.21				0.36					
						Std			0.13				0.22					
						Min			-0.39				0.07					
						Max			-0.10				0.68					
						#			3				4					
51	Wir91	O-t	US	62	85	T		-3.30		-0.56		6.00		1.02	0.74	8.60	2Eq	NL?-s
51	Wir91	O-t	US	62	85	T		-5.10		-0.72		10.90		1.10			2Eq	NL?-s
51	Gat92b	O-t	US	49	90	T	-0.01	s		-0.18		s	0.63				PDL	GLS-s
51	Gat92b	O-t	US	49	90	T	-0.00	-1.00		-0.07		s	0.70		Pmax		PDL-Asym	GLS-s
51	Gat92b	O-t	US	49	90	T	0.00	0.04		0.00					Pcut		PDL-ASym	GLS-s
51	Gat92b	O-t	US	49	90	T	-0.02	s		-0.57					Prec		PDL-ASym	GLS-s
51	Gat92b	O-t	US	49	90	T	-0.01	s		-0.21		s	0.78		Pmax&Prec		PDL-Asym	GLS-s
51	Gat92b	O-t	US	49	90	T	-0.00	-0.50		-0.04					Pcut		PDL-ASym	GLS-s
51	Hog89	O-t	US	60	84	T	-0.14	-2.91									SgElNelOtrOth	ML
51	Hog89	O-t	US	60	84	T		-5.06		-0.92							SgElNelOtrOth	ML
51	Hog89	O-t	US	60	84	T		-3.29		-0.67							TlElNelOtrOth	ML
						Avg	-0.03			-0.39			0.70	1.06	0.74			
						Std	0.05			0.31			0.06	0.04	0.00			
						Min	-0.14			-0.92			0.63	1.02	0.74			
						Max	0.00			0.00			0.78	1.10	0.74			
						#	7			10			3	2	1			

The three estimates using a StatSk model in C44 get similar price elasticities to the static models (-0.17), but income elasticities are reduced by 25% to 50% averaging 0.32. C43 and C44 suggest that 0.32/0.72 or 44% of the income adjustment reflect changes changes in use and the size of the autos, while the remaining 56% reflects changes in the number of autos. As is the case for static models both income and price elasticities are reduced from the earlier studies in S100, which average -0.31 and 0.52.

Uri88a, using a translog model on CT data from 1978 to 1980, finds the gasoline price elasticity for agriculture to be -0.38, which is very close to the short run estimate of Uri89 on an LE on a cross section for 1980 with the lagged value from 1979 of -0.34. Long run price from the LE is much higher at -1.21, but with long run income elasticity averaging only 0.33.

There are 6 estimates using a LE and other DL models in C46. On average they find lower short/long run price and income elasticities (-0.19/-0.55, 0.30/0.80) than the averages in S95 (-0.24/-0.80, 0.45/1.31) All studies seem to suggest a lower income elasticity, whereas the price elasticities are more mixed. For example, Sterner (1990) finds price and income elasticizes of -1 and 1 using a LE model. These elasticities fall, especially for price, when an inverted V model is used, whereas they can not be computed for a more complicated lagged endogenous model because the coefficient on the lagged endogenous variable is greater than 1. Hsi90 finds lower income and price elasticities than Ste90 using a similar sample with a correction for serial correlation on a double log model and a Box Cox estimation is used. K&K91 estimate a simultaneous system of supply and demand and find a rather small long run price elasticity of -0.23, however, the lags implied by a lagged coefficient of 0.25 seem rather short given the life of the average vehicle. Again we see the variability of the lagged endogenous model with the long run elasticities, particularly for price, heavily dependent on the value of the lagged endogenous variable.

PDL models are summarized in C47. Ste90 finds a very elastic long run price and income response with a PDL on price and income (-1.20/1.22). This model, however, did not fit as well as the other lagged specifications in the section above this, nor is it corroborated by the other study in the category. Gat91 using a PDL on only price on data through 1989 and including a CAFE standard variable finds much lower elasticities. His price elasticity of -0.46 is on a model with perfect reversibility. His higher estimates of -0.67 and -0.7 are the elasticities for price increases based on two models with imperfect reversibility, which are his preferred models. His elasticities for price decreases in these same two models are lower at -0.24 and -0.41. Income elasticities are highest when perfect reversibility is assumed, but were sensitive to the type of reversibility model assumed.

H&R91 use a linear expenditure model on quarterly data and find higher price elasticies but similar income elasticities to static models on annual data (-0.59/0.65). Both are higher than the monthly and quarterly averages from S93 (-0.29/0.52). The interesting result from their study, however, is that there is considerable variation in elasticities over various parts of the sample. Price elasticities are lowest from 1970-1973 and from 1986-1989. They are highest from 1974-1978. Income elasticities are highest from 1970-1973 and lowest from 1979-1985. The averages of the income elasticities are higher when the averages of the periods are taken, than when the model is estimated over the whole sample. It would be interesting to do more work to determine if this same pattern is found for other models and other products and to try to determine whether reversibility, excluded demographic variables, or lags in adjustment might be the cause.

The last model considered is Rao93 (C49), who uses a 3 equation structural model that includes a vehicle miles equation, a car stock equation, and a car stock turnover equation on monthly data. Long run price elasticities show rather larger variation across PADD with the lowest values in the East and Midwest and the highest values in the Gulf Coast, Rockies and West. He simulates for 25 years with his estimated equations to acquire long run price elasticities. He finds, however, that the model reaches half or less of its long run value in 10 years. Given the average age of the vehicle stock, the fact that new cars are used more intensively, and the average life of a car, it is hard to believe that over half of the adjustment to a price change comes in years 11-25. However, his 10 year elasticities reported to be (-0.284, -0.375, -0.417, -0.665, -0.476), for PADD I-V resepectively, are only a bit smaller than the long run elasticities estimated in other categories. No long run income elasticities are reported. Intermediate income elasticities averaging 0.55 do not differ dramatically from intermediate run elasticities in other categories.

In the new studies we find a variety of approaches and a fair amount of variation across studies. Overall, the studies suggest a less elastic response, particularly for income, than our earlier survey Dahl and Sterner (1991a,b) suggests. Price elasticities were particularly high in 1974 to 1979 period, while income elasticities were particularly low from 1979 to 1985. Some interesting questions present themselves with these results. For example, why the low income elasticities from 1979-1985. Is it a lagged response to earlier price increases? Is it induced by government policy? Is it related to recession? Is it caused by expectations? Is it caused by omitted demographic variables? The price elasticities related to the down turn in prices since 1986 have been lower than those associated with earlier price increases.

Whereas my earlier guesstimate for a price elasticity of gasoline demand might be more elastic than -0.8 with an income elasticity greater than 1. More recent results might suggest a less elastic price response of perhaps -0.6 and a slightly inelastic income response. I would urge, however, an investigation of why the changes in the price and income elasticities over time.

I have found only two other categories for transport fuel demand, jet fuel demand summarized in C50 and total transport demand summarized in C51. Gat86 estimates the demand for jet fuel using a static model with his income variable being seat miles. In his specifications, the demand for jet fuel has gone up considerably slower than the demand for seat miles (0.68). The seat mile elasticity is highest when a fleet efficiency factor is included and lowest when no fuel price is included. Price elasticities are low but significant (-0.1/-0.15). In the same study, he estimates a demand for seat miles, which finds a very elastic income response. As we will see below in the section on the components of transportation demand, they imply that the overall demand for jet fuel is income elastic, but price inelastic. Uri85 finds a bit higher price elasticity but very low income elasticity on monthly jet fuel demand.

C51 contains estimates for total oil demand for transport.
All suggest an inelastic price response, Wir91 suggests a long run income elasticity near 1. Gat92b uses a PDL on price but not on income. On a symmetric model he finds a long run price elasticity of -0.18 and an income elasticity of 0.63. When he allows an asymmetric price response only variables with a price recovery show a significant price elasticity.

Hog89, in this same category, uses flexible functional forms on a specification that divides energy inputs into transportation, electricity, other energy products, and aggregating all other factors together. Using a

static translog he find a price elasticity of -0.67, using a symmetric generalized McFadden function he finds ex post, or short run elasticity of -0.14, and ex ante or a long run elasticity of -0.92.
C50 implies that jet fuel may have a similar price elasticity to gasoline but a smaller income elasticity. Symmetric models in C51 imply that total transport fuels may have a more elastic price and income response than for gasoline, but asymmetric models find a less elastic price response for all price changes but price recoveries.

VII. Components of the Demand for Gasoline and the Demand Elasticities for Transportation.

VII.1 Previous Surveys of Vehicle Miles Travelled and of Miles per Gallon. The most popular way to break gasoline demand into a structural model is to consider vehicle miles travelled (VMT) and the efficiency of the stock of vehicles measured as miles per gallon (MPG). In this breakdown, which is the only one I will consider in this survey, gasoline demand (G) is equal to VMT/MPG. If VMT and MPG are each modeled as a direct function of gasoline prices, then the demand elasticities are written as:

$$\varepsilon_{g,p} = \varepsilon_{vmt,p} - \varepsilon_{mpg,p}.$$

Alternatively, vehicle miles may be modeled as a function of cost per mile. If only gasoline cost is included then gasoline cost per mile equals the price of gasoline divided by miles per gallon (p/mpg). If vehicle miles are modeled as function of the cost per mile, then the relationship between elasticity of vehicle miles travelled with respect to gasoline price and costs are:

$$\varepsilon_{vmt,p} = \varepsilon_{vmt,p/mpg}\ \varepsilon_{p/mpg,p} = \varepsilon_{vmt,p/mpg}\ (1-\varepsilon_{mpg,p})$$

If cost per mile is total costs including none gasoline cost (cpm) then

$$\varepsilon_{vmt,p} = \varepsilon_{vmt,cpm}\ \varepsilon_{cpm,p} = \varepsilon_{vmt,cpm}\ (\varepsilon_{cpm,p} - \varepsilon_{mpg,p}), \text{ where } \varepsilon_{cpm,p} < 1.$$

Taylor (1977) and Bohi and Zimmerman (1984) survey six studies that have miles travelled summarized in Table 24, S114. For the six estimates for total miles travelled, the short run price elasticity varies from -0.08/-0.23 with an outlier for one car families of -0.61. The long run price elasticity varies from -0.2/-0.55. The short run demand price elasticity is higher for one car than multicar families. Short and long run income elasticities for total miles vary from 0.23/0.6 and from 0.33/0.98. Income elasticity was larger for multicar than for one car families, and price elasticity was lower when an Sk variable was included.

Table 24: Studies of Vehicle Miles Travelled and Miles per

Gallon Surveyed by Taylor (1977), Bohi and Zimmerman (1984), Dahl (1986), Oum et al. (1992), and Goodwin (1992).

#

S	VMT		Psr	Plr	Ysr	Ylr	Studies
114	Taylor (1977)	Avg	-0.30	-0.45	0.47	0.63	6
	Bohi and	Std	0.20	0.13	0.14	0.24	
	Zimmerman (1984)	Min	-0.61	-0.55	0.23	0.33	
		Max	-0.08	-0.20	0.60	0.98	
		#	6	5	4	5	
115	Dah86 (Sk)	Avg	-0.33	-0.55	0.27	0.60	10
		Std	0.16	0.05	0.16	0.06	
		Min	-0.61	-0.60	0.06	0.54	
		Max	-0.10	-0.50	0.57	0.66	
		#	8	2	8	2	
116	Dah86 (SkChar)	Avg	-0.14	-0.33	0.79	1.44	2
		Std	0.07	0.00	0.18	0.00	
		Min	-0.21	-0.33	0.60	1.44	
		Max	-0.06	-0.33	0.97	1.44	
		#	2.00	1.00	2.00	1.00	
117	Dah86 (LE)	Avg	-0.18	-0.90	0.36	2.78	2
		Std	0.18	0.90	0.30	2.12	
		Min	-0.36	-1.80	0.06	0.66	
		Max	0.00	0.00	0.66	4.90	
		#	2.00	2.00	2.00	2.00	

Table 24 (continued): Studies of Vehicle Miles Travelled and Miles per Gallon Surveyed by Taylor (1977), Bohi and Zimmerman (1984), Dahl (1986), Oum et al. (1992), and Goodwin (1992).

S	MPG		Psr	Plr	Ysr	Ylr	Studies
118	Oum et al. (1992)	Avg	-0.16	-0.26			7
	Auto Usage*	Min	-0.24	-0.28			
		Max	-0.09	-0.22			
	unspecified	(SR/LR)	-0.37				

S	Study						
		Min	-0.52				
		Max	-0.13				
119	Goodwin(1992)	Avg	-0.16	-0.31			11
	(Pg)**	Std	0.08	0.08			
	Traffic Levels						
	unspecified	(SR/LR)	-0.47				
		Std	0.33				
120	B&Z84	Avg	0.13	0.30	-0.07	-0.18	3
		Std	0.06	0.03	0.01	0.04	
		Min	0.06	0.26	-0.08	-0.21	
		Max	0.21	0.33	-0.06	-0.12	
		#	4.00	3.00	2.00	3.00	
121	Dah86	Avg	0.16	0.51	-0.06	-0.21	8
		Std	0.05	0.17	0.02	0.00	
		Min	0.06	0.32	-0.08	-0.21	
		Max	0.21	0.69	-0.03	-0.21	
		#	5	4	3	1	

E(GAS) (indirect) = E(VMT)- E(MPG)

S		Psr	Plr	Ysr	Ylr
122	Taylor (1977)	-0.17	-0.75	0.48	0.84
	Bohi and Zimmerman (1984)				
	(S114&S120)				
	Dahl (1986	-0.48	-1.05	0.33	0.81
	(S115&S121)				

* only ranges were given in this study, means were approximated as the average of the ranges.
** only means and standard deviations were given with means and standard deviations here approximated from categories for time series and for cross sections.

Bohi and Zimmerman (1984) contains some estimates for MPG as well, summarized in S120. The three studies find price elasticity to be positive and income elasticity to be negative, as expected, with averages ranging from 0.13/0.30 and from -0.07/-0.18, respectively.

In general, these authors find that consumers have responded to changing gasoline prices and changing efficiency of the fleet of vehicles. In all studies, the changes in miles travelled seems to have the larger effect both in the long run and the short run, but both responses are inelastic.

Dahl (1986) surveys 14 studies divided into three model categories in S115-S117: those that contain a stock variable (Sk), those that contain another measure of vehicle characteristics such as MPG (SkChar), and lagged endogenous models, that contain no stock variables (LE). For miles travelled, the short and long run price elasticities for Sk models average -0.32 and -0.55, while the income elasticities are 0.26 and 0.60, respectively.

When some characteristic of the stock of autos or a lagged endogenous variable is included, the VMT models appear to be quite unstable, particularly in the long run. For example, the very high long run income elasticity of 1.44 in SkChar, which is from a three equation model including vehicle miles, auto weight, and new cars, appears quite unreasonable, since it is larger than most of the total gasoline demand elasticities that have been estimated for the US. In one of the LE models, price was found insignificant with a reasonable income elasticity. In the other, which uses cost per mile including time as well as fuel costs, both long run price and income elasticities were quite unreasonable. (-1.8/4.9).

Using the more reasonable estimates from the Sk models, Dahl (1986) computes indirect long run gasoline demand elasticities of -1.05 and 0.81, respectively, in S122. Doing this same computations for the earlier studies, we find a somewhat smaller price elasticity but a similar income elasticity (-0.75/0.84).

From these indirect estimates Dahl (1986) concludes that more of the adjustment comes from miles in the short run and from miles per gallon in the long run. However, the estimated relationship between MPG & P and between MPG & Y are both less precise than the estimated relationship between VMT & P and between VMT & Y, and they all are less precise than the estimated relationship between G & P and between G & Y. This inability to break income and price elasticities of gasoline demand very accurately into their components may be the result of unpredictable behavior on the part of consumers, model misspecification, or poor data quality particularly prior to 1973. Miles travelled often comes from sampling of somewhat dubious quality and miles per gallon is gasoline consumption divided by miles travelled. If improvements in predictability of adjustment are important, resources should be spent on improving the quality of the mileage numbers.

Dahl (1986) also considers the effect of the auto stock. Increasing auto stock affects gasoline consumption through changes in miles driven. There is a high degree of variation in $\varepsilon_{VMT,Sk}$ from 0.23 to 1.07. $\varepsilon_{G,Sk}$ broken into its components, equals $\varepsilon_{VMT,Sk} - \varepsilon_{MPG,Sk}$. It is expected and assumed by many models that increasing auto stock would increase gasoline consumption through miles making $\varepsilon_{MPG,Sk} = 0$. However, $\varepsilon_{G,Sk} = 0.42$ while $\varepsilon_{VMT,Sk}$ is significantly higher at 0.58. This may be the result of collinearity, since $\varepsilon_{VMT,Sk}$ is high when the income elasticity is low with autos being a better predictor of miles than income. Alternatively, $\varepsilon_{MPG,Sk}$ may be negative which implies that additional autos tend to be smaller.

Dahl (1986) also concludes that rural households consume significantly more gasoline, drive more miles, and get better mileage, while central city households drive fewer miles and get lower mileage. Work status and location have been found to affect gasoline consumption. There is more carpooling for longer work trips. Unemployment increases miles per gallon. Increasing the work week decreases miles travelled, while adding workers to families and increasing employment increase gasoline consumption.

A number of other household characteristics have been found to be influential. More children or less adults decreases gasoline consumption and miles travelled. The age of the oldest child and gasoline consumption are positively correlated. The age of the head of household tends to be negatively correlated with gasoline consumption, miles travelled, and miles per gallon. Non-nuclear one-car families consume more gasoline and get less miles per gallon. One parent and single individual households consume more gasoline. Single car households with female heads consume less gasoline, drive less miles, and get less miles per gallon. Households with nonwhite heads consume more gasoline and get less miles per gallon. Education and gasoline consumption are negatively correlated, while education and miles per gallon tend to be positively correlated. Households with more market orientation, as represented by dollars spent eating out, drive more miles. States with more days of subfreezing temperatures consume more gasoline but drive fewer miles.

Some regional differences have been found. Western households consume less gasoline, get better miles gallon, but spend more on gasoline. This higher expenditure is likely the result of higher gasoline prices and a larger percentage of vehicles using unleaded gasoline. Southern households consume more gasoline, drive more miles and get higher miles per gallon. The North Central U.S. may get higher miles per gallon, drive more miles and spend more on gasoline. In the U.S., air and train travel are not found to be good substitutes for auto travel but local transit is.

Two more recent studies look at international estimates, which are presumably for VMT. The first Oum et al. (1992) in S118 looks at seven studies for auto usage with no definition of the price variable, the second Goodwin (1992) in S119 looks at 11 studies for traffic levels with the price being the price of gasoline. Neither report any income elasticities. Both have average long run price elasticities near -0.3 which is below the averages from the earlier studies.

VII.2 New Studies for Vehicle Miles Travelled and Miles per Gallon. There are 8 new studies that consider vehicle miles travelled in Table 25, C52. The majority use fuel cost per mile (Pg/mpg) as the price variable with average short, intermediate, and long elasticities of -0.14, -0.13, and -0.25. These elasticities are similar to the recent averages of Oum et al. (1992) and Goodwin (1992), but they are less elastic than the earlier surveys. Gar91 uses a price per mile that appears to include nonfuel costs and gets a price response more elastic than -1. With gasoline 8% of fixed and variable costs for driving (Greene (1992)), the implied VMT elasticity with respect to fuel costs would be less elastic than -0.1, which is within the range of the other studies, that use only fuel costs per mile. His finding of no income elasticity whether or not vehicle per capita is includes or not is more problematic. Perhaps cost per mile or the percent of urban population, which he includes, is picking up some of the income effect.

Price elasticities with respect to fuel costs on static models tend to be fairly stable across studies averaging -0.13. Without the static asymmetric model of Gat92b, they vary from -0.11 to -0.25. In the asymmetric model, the price elasticity is found to be zero for a price fall as measured by Pcut (a price cut below a cut the previous period) but more elastic than -0.2 for a Prec (a price increase over the increase from previous periods).
(See equations 37-38, Section I) Income elastiticities, on the other hand, are more unstable. In the estimates on a LE model by Gre92, income is only significant if the lagged endogenous variable is not. He tests and concludes that a static model with serial correlation performs better than the LE model. The number of drivers is included in most of his specifications but he finds rather unstable estimates with

elasticities varying from 0.33 to 1.18. There appears to be substantial correlation between income, drivers and the lagged endogenous variable. In his preferred specification, he finds that the stock of autos or the number of drivers tends to capture the same effect with an elasticity of approximately 0.7. When both are included, the coefficients sum to approximately 0.7, but both become insignificant.

E&S93 use gasoline price instead of price per mile. With just price and income in the equation, the price elasticity is quite low at −0.03. With the addition of the auto stock variable, price elasticity increases to −0.11, close to the average of all studies, and the coefficient on income falls from 1.09 to 0.37. The sum of the income and auto stock coefficients are close to the coefficient on income without the auto stock and suggest that about 2/3 of the income effect acts though changes in the stock of autos and 1/3 through driving the given stock more. A similar result is seen in Gre92. When E&S92 add MPG to the equation, its coefficient is close to being equal and opposite in sign to the coefficient on price, and the income elasticity is lowered by roughly the size of the coefficient on MPG. We also see a drop in income elasticity from 0.92 to 0.52 in Gat90 when the number of drivers is added to the equation. Gat90 finds the VMT price elasticity for heavy trucks to be insignificant and the income elasticity to be somewhat over 1 in C53.

Table 25: New Studies on VMT and MPG Elasticities.

C	Ref	Prod	Sample	y1	y2	Ty	Psr	t(p)	Pir	Plr	Ysr	t(−1)	Pir	Plr
52	Gar91*	VMT/	US−s	87	87	C		−6.82	−1.03			−0.79	−0.09	
52	Gar91*	VMT/	US−s	87	87	C		−6.25	−1.04			0.33	0.04	
52	E&S93	VMT/	US	70	88	T		−1.22	−0.03			19.87	1.09	
52	E&S93	VMT/	US	70	88	T		−4.30	−0.11			2.22	0.37	
52	E&S93	VMT/	US	70	88	T		−4.49	−0.11			1.57	0.27	
52	Gat90	VMT	US	66	88	T		−4.40	−0.09			5.20	0.52	
52	Gat90	VMT	US	66	88	T		−2.30	−0.07			134.0	0.92	
52	Gat92b	VMT/dv	US	66	89	T		−3.90	−0.11			4.00	0.46	
52	Gat92b	VMT/dv	US	66	89	T		−3.00	−0.22			3.30	0.35	
52	Gat92b	VMT/dv	US	66	89	T		−0.10	−0.00					
52	Gat92b	VMT/dv	US	66	89	T		−2.00	−0.24					
52	Gre92	VMT	US	57	89	T	−0.10	−4.50		−0.25	0.05	0.47		0.12
52	Gre92	VMT	US	57	89	T		4.32	−0.13			2.37	0.30	
52	Gre92	VMT	US	66	89	T	−0.12	−4.38		−0.33	−0.07	−0.50		−0.20
52	Gre92	VMT	US	66	89	T		−3.71	−0.13			1.52	0.25	
52	Gre92	^VMT	US	67	89	T		−4.04	−0.13			2.77	0.41	
52	Gre92	VMT	US	66	89	T		−4.59	−0.13			3.99	0.46	
52	Gre92	VMT	US	66	89	T	−0.13	−4.49		−0.15	0.39	2.31		0.43
52	Gre92	VMT	US	66	89	T		−4.90	−0.14			1.69	0.25	
52	Gre92	VMT	US	66	89	T		−4.74	−0.14			1.91	0.32	
52	L&V87	VMT/	US−sHA	67	80	T		−2.08	−0.25			0.94	0.5	

Continued next page

52	M&M89	VMT	US	58	84	T	-0.22	-5.48		-0.26	0.25	0.95		0.30
52	Syk91	VMT	US	51	88	T		-3.34	-0.12			1.13	0.25	
					Avg		-0.14		-0.13	-0.25	0.15		0.45	0.16
					Std		0.05		0.06	0.06	0.18		0.24	0.24
					Min		-0.22		-0.25	-0.33	-0.07		0.25	-0.20
					Max		-0.10		-0.00	-0.15	0.39		1.09	0.43
					#		4		17	4	4		15	4
53	Gat90	VMT-Tk	US	66	88	T		-0.90	-0.04			6.60	1.16	
53	Gat90	VMT-Tk	US	66	88	T		-0.07	-0.03			6.40	1.18	

Table 25 (continued): New Studies on VMT and MPG Elasticities.

	C	Ref	Prod	Vsr	Vehicle t(V)	Vir	Vlr	Q(-1)	t(-1)	Model	ET	Other
	52	Gar91	VMT/		3.32	0.33				StatSk	OLS	P=ppm
	52	Gar91	VMT/							Stat	OLS	P=ppm
	52	E&S93	VMT/							Stat	OLS	P=Pg
	52	E&S93	VMT/		4.42	0.65				StatSk	OLS	P=Pg
	52	E&S93	VMT/		4.54	0.64				StatSk	OLS	P=Pg
	52	Gat90	VMT							Stat	GLS-s	P=Pg/mpg, #driv 0.65
	52	Gat90	VMT							Stat	GLS-s	P=Pg/mpg
C	52	Gat92b	VMT/dv							Stat	GLS-s	P=Pg/mpg
o	52	Gat92b	VMT/dv							StatAsym	GLS-s	P=Pg/mpg, Pmax
n	52	Gat92b	VMT/dv									P=Pg/mpg, Pcut
t	52	Gat92b	VMT/dv									P=Pg/mpg, Prec
i	52	Gre92	VMT					0.59	4.66	LE	OLS	P=Pg/mpg #driv 0.48
n	52	Gre92	VMT							Stat	OLS	P=Pg/mpg #driv 1.18
u	52	Gre92	VMT					0.64	4.39	LE	OLS	P=Pg/mpg #driv 0.53
e	52	Gre92	VMT							Stat	OLS	P=Pg/mpg #driv 1.07
d	52	Gre92	^VMT							^Stat	OLS	P=Pg/mpg #driv 0.66
	52	Gre92	VMT							Stat	GLS-s	P=Pg/mpg #driv 0.72
	52	Gre92	VMT					0.11	0.60	LE	GLS-s	P=Pg/mpg #driv 0.68
	52	Gre92	VMT		5.27	0.73				Stat-Sk	GLS-s	P=Pg/mpg
	52	Gre92	VMT		1.16	0.43				Stat-Sk	GLS-s	P=Pg/mpg #driv 0.33
	52	L&V87	VMT/		3.41	0.92				Stat-Sk	GLS-s	P=Pg/mpg
	52	M&M89	VMT	0.67	3.05		0.79	0.15	0.73	LE-Sk	3S-s	P=Pg/mpg pop 0.54
	52	Syk91	VMT		3.79	0.76				Stat-Sk	GLS-s	P=Pg/mpg pop 0.76
			Avg	0.67		0.69	0.79	0.37				
			Std	0.00		0.15	0.00	0.25				
			Min	0.67		0.43	0.79	0.11				
			Max	0.67		0.92	0.79	0.64				
			#	1		6	1	4				
	53	Gat90	VMT-Tk							Stat	GLS-s	
	53	Gat90	VMT-Tk							Stat	GLS-s	

Table 25 (continued): New Studies on VMT and MPG Elasticities.

C	Ref	Prod	Sample	y1	y2	Ty	Psr	t(p)	Pir	Plr	Ysr	t(y)	Yir	Ylr
54	Gat92b	MPG	US	66	89	T	0.00	0.90		0.14				
54	Gat92b	MPG	US	66	89	T	0.00	5.90		0.14				
54	Gat92b	MPG	US	66	89	T		4.20	0.04					
54	Gat92b	MPG	US	66	89	T	0.01	8.40		0.18				
54	Gat92b	MPG	US	66	89	T		3.90	0.03					
54	Gre90	MPG-caf	US-mfg	78	89	CT				0.08				
54	Gre90	MPG-caf	US-mfg	78	82	CT				0.12				
54	Gre90	MPG-caf	US-mfg	83	89	CT				0.06				
54	Gre90	MPG-ucaf	US-mfg	78	89	CT				0.21				
54	Gre90	MPG-ucaf	US-mfg	78	82	CT				0.17				
54	Gre90	MPG-ucaf	US-mfg	83	89	CT				0.20				
54	M&M89	MPG	US	58	84	T		4.34	0.21			7.04	0.90	
54	Syk91	MPG	US	51	88	T		0.98	0.05			1.39	0.14	
54	Syk91	MPG	US	51	88	T		1.53	0.08			2.68	0.75	
54	Syk91	MPG	US	58	88	T		2.12	0.13			2.55	0.67	
54	Syk91	MPG	US	51	88	T		1.74	0.03			2.09	0.03	
						Avg	0.00		0.08	0.14			0.50	
						Std	0.00		0.06	0.05			0.35	
						Min	0.00		0.03	0.06			0.03	
						Max	0.01		0.21	0.21			0.90	
			#				3		7	9			5	

Continued next page

Table 25 (continued): New Studies on VMT and MPG Elasticities.

_ _	C	Ref	Prod	Vsr	t(v)	Vir	Model	ET	Other					
	54	Gat92b	MPG				PDL	OLS	NoY					
	54	Gat92b	MPG				PDL	OLS	NoY	Pmax&Prec				
	54	Gat92b	MPG				PDL	OLS	NoY	Pcut				
	54	Gat92b	MPG				PDL	OLS	NoY	Pmax				
	54	Gat92b	MPG				PDL	OLS	NoY	Pcut+Prec				
	54	Gre90	MPG-caf				PDL	OLS	D*mfg,	CAFE	0.72	8.46		
	54	Gre90	MPG-caf				Stat	OLS	D*mfg	CAFE				
	54	Gre90	MPG-caf				Stat	OLS	D*mfg	CAFE				
	54	Gre90	MPG-ucaf				PDL	OLS	D*mfg	CAFE				
	54	Gre90	MPG-ucaf				DL	OLS	D*mfg	CAFE				
	54	Gre90	MPG-ucaf				DL	OLS	D*mfg	CAFE				
	54	M&M89	MPG		-7.43	-1.30	StatSk	OLS	speed	-0.14	-1.31	CAFE	0.00	1.35
	54	Syk91	MPG		-0.01	-.00	StatSk	GLS-s	speed	-0.13	-0.59	CAFE	0.01	0.84
	54	Syk91	MPG		-2.08	-0.97	StatSk	GLS-s	speed	-0.19	-0.82	CAFE	0.01	0.78
	54	Syk91	MPG		-2.23	-0.97	StatSk	GLS-s	speed	-0.05	-0.22	CAFE	0.01	1.24
	54	Syk91	MPG		0.50	0.00	StatSk	ARIMA	speed	-0.09	-1.42	CAFE	0.01	1.47
						-0.65								
						0.54								
						-1.30								
						0.00								
						5								

* not included in the averages.

Since the price elasticity estimates from static models are less elastic on average than the short run elasticities from the earlier surveys, these averages suggest a somewhat less elastic price response than earlier work. Income elasticities, however, are much harder to sort out. For static models they vary from 0.25 to 1.09 and are as low as -0.09 if the atypical estimates in Gar91 are included. The elasticity is 0.5 or less, if the number of drivers is included in the estimation either by using VMT per driver or including drivers on the right hand side of the equation. The income elasticity is over 1 if VMT per capita and no auto stock is used. These results suggest that in the per capita model with no stock, half of the income effect was really an increase in drivers, but the other half was attributable to income. Drivers and autos appear to pick up the same effect, and when either is included the income elasticity tends to fall to 0.5 or less. Long run price elasticities appear reasonable from the LE models averaging -0.25, but long run income elasticity is instable and varies from -0.2 to 0.43.

Moving on, there are 4 studies that consider elasticities for MPG of the auto stock. Gre90, is specifically trying to evaluate the CAFE standards, and looks at new sales by manufacturer and finds long run price elasticities that are lower on average for manufacturers that are constrained by the CAFE standards (MPG-caf) (0.09) than those that are not (MPG-ucaf) (0.19). He concludes that the CAFE standards were important for many manufacturers and were perhaps twice as influential as price.

Gat90 looks at an asymmetric price response for average MPG of the whole fleet and finds a smaller long run response for Pcut/Prec (price decreases/increases over those in the previous period equations 37 & 38 in section I) than for price increases above the previous maximum. His results are surprisingly near to the average for Gre90 even though his model is quite different and he does not include the CAFE standards. They both suggest a long run price elasticity for MPG of 0.14 on average. This is lower than the average suggested by earlier studies. However, since neither of these studies includes an income variable, which I would expect would influence consumer auto size, I would reserve judgment on whether the price elasticity has fallen or not.

There are two studies using static stock models on aggregate data. Both find a significant price response on data from 1958 to 1984. However, Syk91 does not find a significant price response on samples from 1951 to 1988 or 1958 to 1988. Both include vehicle stock per capita to check the hypothesis whether second cars might be smaller. They argue that under this hypothesis the coefficient on the stock of vehicles per capita would be negative. It is found to be negative most often, however the correlation between income and the stock of autos appears to yield a lot of instability across the coefficients for both income and the vehicle stock. As is the case for VMT, there appears to be more stability across the price coefficients than across income coefficients and the response may have fallen from the earlier surveys. Although none of the studies on aggregate data found the CAFE standards affected average fuel efficiency for the whole fleet, Gre90 found an affect when he used more disaggregate data and new car sales.

VII.3 Other Transit Demand. Work done on other transit demand is summarized in Table 26. Taylor (1977) cites one study with long run price and income elasticities of demand for airline passenger miles of -0.24/1.46, respectively in S123. More recently, Oum et al.(1992) have a fairly extensive survey of price elasticity for transit demands and Gat88 has a study of airline transit demands for the US. Since fuel is only part of the cost for transport demand, we would expect the demands for the relevant fuel to be less than the transport demand elasticity in absolute value.

Oum et al. (1992) concludes that the most recent developments in modeling transport demand have been the application of discrete choice modeling, flexible functional forms, and better linkages between empirical work and both consumer and producer theory.

They cite 12 studies of the demand for urban transit where own demand price elasticities vary from −0.01 to −1.32 with most values falling within −0.1 and −0.6. The demand elasticities of air passenger travel displays a much wider range and appears to more price elastic −0.4/−4.6 with the majority falling between −0.8 and −2.00. Demand for business travel appears to be more inelastic than for leisure travel and cross sectional data generally yields higher elasticities than time series.

Gately (1988) (S130−S132) finds all his estimates for long run price elasticity for air transport to be less elastic than −0.44 with no evidence of significant price responsiveness for business travels and income elasticities to be always 1 or greater. They are significantly higher for aggregate air travel on a sample from 1966 to 1986 than on shorter subsamples for business and personal travel from 1973 to 1986.

Table 26: Demand Price Elasticities for Transportation by Mode from Taylor (1977), Oum et al. (1992), and Gately (1988).

S	Taylor (1977)		Pir	Yir
123	Air PMT	Avg	−0.25	1.46
		#	1	1

S	Oum et al. (1992)		Price Elasticity Pir	# Studies
124	Urban Transit	Max	−0.01	15
		Min	−1.32	
125	Air Travel	Max	−0.40	13
		Min	−4.60	
126	Intercity Rail	Max	−0.12	9
		Min	−1.54	
127	Discrete Choice			16
	Auto	Max	−0.08	
		Min	−2.03	
	Bus	Max	−0.01	
		Min	−0.69	
	Rail	Max	−0.22	
		Min	−1.20	
	Air	Max	−0.18	
		Min	−0.62	
128	Rail Freight	Max	−0.02	11
		Min	−3.50	
129	Truck Freight	Max	−0.14	6
		Min	−2.96	

S	Gately (1988)		Psr	Plr	Ysr	Ylr
130	Air Travel	Max	−0.00*	−0.09	1.90	3.57
		Min	−0.20	−0.05	1.34	2.93
131	Air Travel (bs)	Max	0.00	0.00	1.77	2.55
		Min	−0.00	0.00	1.34	1.00
132	Air Travel (ps)	Max	−0.00	0.00	2.46	3.66
		Min	−0.44	−0.44	1.12	1.12

* All estimates not significant at the 10% level or more are considered to be zero. ps is personal travel and bs is business travel.

Oum et al. (1992) find the elasticity of demand for intercity rail (S126) to be between −0.12 to −1.54. Business travel appears to have an elasticity less than 1 in absolute value, while other types of travel appear to have much more mixed results.

They report on 16 aggregate discrete choice models in S127. They include auto, bus, rail and air travel and tend to find less elastic price response than from reduced form demand models. This is consistent with the earlier finding on appliance choice models. Those that report conventional travel demand elasticities find that elasticities for urban auto travel vary from −0.01 to −2.03 with more studies appearing to have elasticities less elastic than −0.62, those for intercity auto travel vary from −0.08 to −.96 with most studies more elastic than −0.7. The price elasticity for urban bus transportation demand varies from −0.01 to −.58 and for intercity bus transportation it varies from −0.32 to −.69. The price elasticity for urban rail demand varies from −0.22 to −0.57, for intercity rail from −0.32 to −1.20, and for intercity air travel from −0.18 to −0.62.

They report on 11 studies of rail freight (S128) and 6 studies of truck freight demand (S129) by selected commodity and functional form and find a wide variety of elasticities. Rail freight demand elasticities vary from −0.02 to −3.5 and truck freight elasticities vary from −0.14 to −2.96. Variation in elasticities increases the more disaggregate the data and leads the authors to caution researchers to consider the appropriate degree of aggregation.

Goodwin (1992) also surveys public transport costs. He finds the following average price elasticities: bus −0.41; subway short run −0.4, subway long run more elastic than −0.6, subway short run/long run −0.2/−0.4 if both subway and bus fares change their prices together, rail −0.79, and a cross price elasticity of public transport with respect to petrol prices of averaging 0.34 with a range of 0.08/0.8.

Both Oum et al. (1992) and Goodwin (1992) conclude that transport price elasticities are more elastic than conventional wisdom believes.

VIII. Energy Substitutability

The earliest work surveying energy substitutability is Bohi (1981). He includes 8 studies that consider substitution in manufacturing or electricity generation. Apostolakis (1990b) includes another 4 studies. Since they are all on data prior to 1980 I combine all studies and show the averages, standard deviations, and ranges for these estimates in Table 27, S132,S133.

In almost all cases the cross elasticities on average are nonnegative except for the cross elasticity of electricity with respect to the price of coal (El-C) in industry and all are less than 1 on average. The averages suggest that coal and oil show the largest responses to changes in other fuel prices with cross elasticities ranging from 0.63 to 0.91 and from 0.69 to 0.92.

Natural gas average response to other fuel prices is smaller ranging from 0.17 to 0.25. Whereas electricity seems to show the least response to other fuel prices with cross elasticities varying from −0.06 to 0.11.

Apostolakis concluded from estimates by industry that substitutability appeared to be the case in most industries with the strongest substitution between oil - coal, oil - electricity, and oil - gas. There is a mix of responses between electricity - gas, gas - coal, and coal - electricity with some industries having them as substitutes and some as complements.

The averages from all studies here show a somewhat less mixed response with coal-oil and coal-natural gas probably showing the largest substitution, natural gas –electricity and natural gas - oil somewhat less substitutability, electricity - oil showing the least substitubility, and coal–electricity showing mixed results.

Bohi (1981) finds coal demand does not respond to natural gas prices but does respond to oil prices (0.69) in electricity generation in S133.

There is, however, wide variation within categories with the standard deviation greater than the mean in a number of the categories. Further, natural gas shortages and interruptible service could be biasing the substitution across all fuels.

In a somewhat newer survey, Waverman (1992) considers issues of substitutability. He begins with a discussion of what sort of cross price elasticity might be necessary for goods to be good substitutes. He argues that a cross price of elasticity of 1 might be a good benchmark and then considers a number of studies done in the 1980's, to see if they imply cross price elasticities that are greater or less than 1.

Table 27: Intermediate and Long Run Cross Price Elasticities of Demand Surveyed by Bohi (1981), Apostolakis (1990b), and Waverman (1992).

S		εQ-P	Avg	Std	Min	Max	#
				Apostolakis (1990b)			
132 -i	C-El	0.63	1.30	-1.35	3.55	10	
-i	C-Ng	0.81	0.59	0.00	1.66	6	
-i	C-O	0.91	0.88	-0.01	3.06	14	
-i	El-C	-0.06				1	
-i	El-Ng	0.10	0.30	-0.55	0.52	13	
-i	El-O	0.11				1	
-i	Ng-C	0.25	0.40	-0.25	0.95	10	
-i	Ng-El	0.20	0.15	0.00	0.35	4	
-i	Ng-O	0.17	0.32	-0.32	0.58	5	
-i	O-C	0.69	0.35	0.14	1.01	4	
-i	O-El	0.92	0.99	-0.38	3.65	15	
-i	O-Ng	0.75	0.69	-0.72	2.14	16	
		Bohi (1981)					
133 -e	C-Ng	0.00	0.00	0.00	0.00	2	
-e	C-O	0.69	0.30	0.38	0.99	2	
		Waverman (1992)					
134 -i	C-El	0.91	0.47	0.44	1.38	2	
-i	C-Ng	-0.82	0.19	-1.01	-0.62	2	
-i	C-O	0.37	0.26	0.11	0.63	2	
-i	El-C	-0.13	0.27	-0.40	0.14	2	
-i	El-Ng	0.53	0.18	0.32	0.79	5	
-i	El-O	-0.01	0.05	-0.05	0.04	2	
-i	Ng-C	-0.26	0.06	-0.32	-0.20	2	
-i	Ng-El	0.65	0.02	0.63	0.67	2	
-i	Ng-O	0.13	0.09	0.04	0.22	2	
-i	O-C	0.10	0.07	0.03	0.17	2	
-i	O-El	0.04	0.08	-0.04	0.11	2	
-i	O-Ng	0.08	0.02	0.05	0.10	2	
135 -e	C-Ng	1.29	1.35	-0.08	3.39	4	
-e	O-Ng	0.41	0.56	-0.16	1.31	4	
136 -r	El-Ng	0.18	0.16	0.01	0.45	9	
-r	Ng-El	0.72	0.73	-0.01	1.45	2	
-r	O-Ng	0.96	0.77	0.19	1.73	2	
137 -c	El-Ng	-0.11	0.16	-0.30	0.09	3	

In this more recent survey of studies done in the 1980's there are long run elasticities from 7 studies for the US, half of which have data beyond 1980. For the industrial sector, results appear more mixed than for the earlier surveys. The average elasticity El-C is still negative but those for C-Ng, El-O, and Ng-C become negative as well. For the averages, all the oil cross price elasticities (O-C, O-El, O-Ng, C-O, El-O, Ng-O) fall substantially, the natural gas - electricity elasticities increase (El-Ng, Ng-El) and the coal - natural gas (C-Ng, Ng-C) elasticities change from positive to negative.

In these newer studies the averages suggest the largest substitution is between electicity and natural gas, next largest is the substitution between coal and oil, and then between oil and natural gas. All other substitution patterns are mixed (coal - electricity, coal - natural gas, and oil - natural gas.) With less studies than the earlier surveys, there tends to be less variation across studies.

For electricity generation, the cross elasticity of coal with respect to the price of natural gas rose on average from being insignificant in the earlier survey to 1.29 with elasticity appearing to rise over the decade of the 1980s. Oil also responded to the price of natural gas with a more elastic response than in the industrial sector (0.41 versus 0.08). However, there are large variations across these studies particularly for coal.

In the residential sector, all average cross price elasticities suggest substitutability across fuels with oil showing the largest response to natural gas prices, natural gas showing a somewhat smaller response to electricity prices, and electricity showing the lowest response to natural gas prices.

The averages suggest little substitution of electricity in response to natural gas prices in the commercial sector in S137.

Overall, the averages from all surveys support Waverman (1992)'s conclusion that the long run cross price elasticities are less than 1. Oil substitution may have decreased from earlier, natural gas and electricity subsitution may have increased, coal elasticities have become much more mixed. However, there appears to be considerable variation across estimates in both the earlier and later surveys and estimates have become more mixed recently with more negative cross price elasticities leading one to be cautious in coming to actual estimates for the cross elasticities. Further, most studies are rather dated with only one study that includes data past 1985.

IX. Conclusions

Since the 1973 oil embargo, there have been a plethora of energy studies designed to capture demand elasticities. These studies use a variety of models, which have increased in sophistication. They have been done on a variety of data sets which have increased in quantity and quality. They have been done at a variety of levels of aggregation that have tended to become increasingly less aggregated. The data has been badgered by econometric techniques ranging from the simple to the increasingly complex. And yet despite our attempts, it appears that demand elasticities are like snowflakes, no two are alike. Some are close many are not. The long run seems to elude us. In time series long enough to allow complete adjustment there may be to much structural change to capture long run adjustments. In dynamic models, which appear to be rather unstable, collinearity may be the culprit. In cross sections which contain enough variation to yield long run estimates, nonincluded variables may be biasing our price and income elasticities. Further, given the large variations in elasticities across time and regions, it may be that we are attributing to elasticities demographic, political, and structural changes that our models are too simple to capture.

Looking back to early surveys, they also found a great deal of variation across studies and often found it hard to come to strong conclusions on price and income elasticities as well. There appeared to be more consistency in residential energy demand studies and in gasoline demand studies. With the additional studies surveyed here, we do not yet appear to be converging to a consensus in many instances. However, we can suggest elasticities in some cases, make some general conclusions about data and models, and suggest areas where further work might be useful.

Before recapping suggested elasticities, there are a few overall conclusions that one might come to. Elasticities in recent studies tend to be smaller in absolute value, than those from the earlier studies. Studies on cross section data tend to find a more elastic response than those on time series. For the residential sector, studies on household data appear to get consistently low income elasticities relative to aggregate data. Simple dynamic models appear to be unstable. There appears to be some asymmetries across increases and decreases in prices. More products appear to be price and income inelastic. There are wide differences in estimated elasticities across industries as well as wide differences across estimates for aggregate industrial demands. Demands in the commercial sector appear to be even more erratic than those in the industrial sector.

Moving on, we consider the evidence by product and sector and attempt to develop summary elasticities. Table 28 contains these conclusions for overall elasticities based on the information in this survey.

	Range	Range	Range	Range	Summary Statistics						Source:	
						Pir			Yir		Table	
	Psr	Pir&Plr	Ysr	Yir&Ylr	Psr		Plr	Ysr		Ylr	C or S	
E	-.09/-.52	-.04/-1.75	--	.27/1.14	<-0.3		<-0.5	--	1.05?	--	1,2	S1,C1
E-r	-.15	-.37/-.66	1.17	.08/1.45	-0.15		<-0.5	?		?	2	C3
E-i	-.09/-.66	.23/-.99	--	.69/1	<-0.2		<-0.5	--	0.73?	--	2	C6
E-ii	0/-1.09	0/-1.10	--	.89							2	C7
El	-.05	-.61/-1.31	--	--	?		-1	--		--	6	C8
El-r	+.57/-.97	+.77/-2.2	-.02/.93	-.09/1.64	<-0.5		-0.7/-0.9	<0.2?		<0.87?	6,7	C9-11
El-c	0/-.82	+3.36/-4.74	-.45/.26	-21.12/1.39	-0.22?		-0.82?	??		??	8	C12
El-i	+.06/-1.03	+17.4/-3.55	.01/.28	-1.01/1.44	-0.25?		-1.33?	.1?		?	8	C13
El-ii	-.03/-1.51	-.11/-2.5	-.1/.82	.25/1.63							8	C14
Ng	--	-.03/-.49	--	.62/.79	--	<-.27?	--	--	>.71?	--	14	C16
Ng-r	+.02/-.88	+1.86/-3.44	.01/.44	.06/.80	?		?	?		<.8	14,15	C17-20
Ng-c	-.16/-.37	1.92/-2.68	-.33/.3	-2.19/1.95	-.26?		-.99?	?		?	16	C21
Ng-e	--	-.1/-1.89	--	--	--		-.72?	--		--	16	C22
Ng-i	-.26/-.63	.71/-5.28	.13/.78	.46/3.08	-.51?		?	?		?	16	C23
Ng-ii	-.08/-1.63	-.12/-10.0	.14/1.74	.32/4.46							16	C24
C-e	--	-.12/-.9	--	--	--		<-.9	--		--	18	C26
C-i	-.02/-1.62	+.08/-1.12	--	--	?		?	--		--	18	C27
C-ii	-.84	-.28/-2.52	--	--							18	C28
O	-.04/-.25	-.25/-.94	--	0.31/1.13	?		>-.25?	--		>.70?	20	C29-30
O-r	-.10/-.59	-.62/-3.5	-.08/.21	-.28/2.28	<-.3		?	?		?	20	C31-32
O-c	-.07/-.19	-.3/-3.5	.2	4.39	-0.13		?	?		?	20	C33
O-e	--	-.08/-3.11	--	--	--		?	--		--	20	C34
O-i	-.13/-.21	-.08/-.44	--	--	?		?	--		--	20	C35
O-ii	-.28/-.58	-.36/-4.05	--	--							20	C36-39
O-ntr	.03/-.19	.1/-2.35	.03/0.38	.82/1.47	-0.07?		-.65?	.21?		1.22?	20	C41
G	-.00/-.36	.00/-1.99	.09/0.65	.09/1.22	-0.20		-0.60	<0.5		0.80?	23	C42-49
J	--	-.1/-.39	--	.07/.68	--	-0.2	--	--	0.36?	--	23	C50
O-t	0/-0.14	0/-.92	--	.63/1.1	-0.03?		-0.39?	--		1.06?	23	C51
VMT	.10/-.22	-0/-.33	-.07/.39	-0.2/1.09	-0.14		-0.25	0.15		0.3?	25	C52
MPG	.00/.01	.03/.21	--	--	0		0.14	--		--	25	C54

Where results appeared fairly consistent and I feel the averages provide reasonable estimates for elasticities I include a point estimate or a range. If the averages appear reasonable with intermediate estimates between short and long run with no contradictions between categories, but with large variations across studies, I include the averages with a question mark behind them. Where averages appear unreasonable, studies are exceptionally erratic, or there are contradictions across categories I put a question mark. If no estimates are surveyed for a category a dash is placed. For estimates on industries (-ii) only the range of elasticities across industries is included.

If we look at the results sector by sector, we find that the averages for earlier surveys suggested that for total energy demand and for total energy demand in all sectors we find that the short run price elasticity was less elastic than −0.32, the intermediate and long run were less elastic than −0.5 and income elasticity is slightly inelastic in all sectors. For newer studies of energy demand the average econometric price elasticities in general tend to agree with the earlier surveys. Income elasticities appear to vary more. On aggregate data they are as high as 1.14, but more often appear to be slightly inelastic. On disaggregate data for the residential sector we see small income elasticities that are characteristic of household data averaging 0.08 or less. We also see a lower elasticity for energy for heating in the household sector than for overall household energy use.

There appears to be considerable variation in price elasticity across various industries (0/−1.10). These large differences suggest that we might get biased estimates in aggregate data if we ignore structural change. It also suggests that more work might help us to understand whether some the variations in elasticities for aggregate energy demand across different time periods and different models are the result of structural change or model choice. Almost no income elasticities are estimated for the industrial sector. Early studies begin the debate on whether capital and energy are substitutes or complements, but no studies appear to have as yet resolved this issue.

In the earliest studies of electricity demand, Taylor concluded that long run price elasticities for the various sectors were between −1 and −2, but income elasticities were rather too erratic to come to any general conclusions. With additional studies, he revises the price elasticity downward and concludes, that the short run elasticity is −0.2 and the long run is −0.9. Bohi (1981) and Bohi and Zimmerman (1984) conclude that short/long run residential electricity demand elasticities are −0.2/−0.7, but there is too much variation across income elasticities and across price elasticities in the industrial and commercial sector to come to any conclusions.

The recent studies on the aggregate price elasticity for electricity using both econometric and a backcasting technique suggest a price elasticity near −1. Price elasticity may be lower in the 1970s than in the 1950s and 1960s. Income elasticities may be lower after 1974. There may be an asymmetric response to price cuts below previous minimums and income increases above previous maximums.

More recent estimates support the earlier long run elasticity of −0.7 for the residential sector as does the estimates aggregated from elasticities on appliance stock. Although there is a wide discrepancy between income elasticities with household data suggesting the long run income elasticity is less than 0.4, while most studies on aggregate data suggest that it is higher than 0.4 but less than 1. There is less price elasticity in the summer and higher price elasticity in the winter.

Commercial and industrial studies continue to be rather erratic. More recent studies might suggest that price response in the commercial sector is inelastic and price response in the industrial sector is elastic. Income response in the industrial sector is probably inelastic. There is even wider variations across long run price elasticities estimated for various industries than was the case for total energy demand (−0.11/−2.50).

Earlier studies of time of day pricing for the residential sector found average price elasticities for pk, offpeak, and midpeak of −0.23, −0.34, and −0.39, respectively with the peak offpeak cross elasticity on average negative. These are own elasticities are somewhat consistent with other short run price elasticities. Most studies for the residential sector suggest that peak load pricing is not effective since the change in welfare is smaller than the metering costs.

A more recent study for industrial demand suggested, however, that own elasticities were much lower and less than 0.09 in absolute value with cross elasticities between time periods very small but on average positive. These own price elasticities on two firms appear small compared to the short run averages of other electricity demand by industry in C14, but they are within the range of estimates.

The earliest survey on natural gas demand notes the wide variation on estimates for income and price elasticities, but concludes that the short run price elasticity is -0.15 and the long run elasticity is more elastic than -1. Somewhat later surveys find demand less price and income elastic on microdata than on aggregate data, conclude that residential price is inelastic and is likely to be less elastic than for the electricity sector, but they come to no conclusion for the commercial and industrial sector.

More recent studies are as erratic as ever. Aggregate demand for natural gas on a static model suggest a price elasticity of -0.27 and an income elasticity of 0.71. For the residential sector estimates on both aggregate and disaggregate data suggest an inelastic income response, but again the estimates are significantly smaller on household data. Price elasticities are rather more erratic. Studies on aggregate data and household data suggest that demand is price inelastic, whereas a study on household data that divides them into households in the interstate gas market and households in the intrastate market find an elastic response. I believe that this elastic response is the result of not including the price of substitutes in the model and am more inclined to believe the studies that get an inelastic price response.

There is wide variation across price and income elasticities in the industrial, electricity generation, and commercial sector. All averages on aggregate data suggest an inelastic price response, whereas the estimates by industry tend to suggest an elastic price response. Studies that do not take gas availability into account get very high variations across regions. One also needs to be cautious in coming to any conclusions in the natural gas industry because of supply constraints.

Coal has been the least studied fossil fuel. The earliest survey of coal demand concluded in favor of a short run price elasticity of -0.4 and a long run elasticity between -0.7 and -0.9. A later survey concluded that demand in the industrial sector might be price elastic but that there was too much structural change to determine the actual price elasticity. The early studies find a much less elastic response separately for coking and steam coal use than when they are aggregated suggesting aggregation problems.

There are only a few new studies for coal demand, and they are mixed as well. From them I would be inclined to believe that the price elasticity in the electricity generation sector is less elastic than -0.9 and that it was lower from 1974-1975 than from 1970-1973.

Most of the averages from the industrial sector suggest an inelastic price response, but the estimates are too erratic to come to any general conclusion. The logit model may capture a smaller price response than the translog model. A second generation dynamic translog model, that takes into account the ex post fixed nature of the capital stock, tends to be very erratic for coal demand. No income elasticities are estimated in the new studies.

Moving on to nontransportation oil demand, none of the earlier surveys come to any conclusions about the fuel oil market and elasticities appear to be sensitive to the level of sectoral aggregation. Averages in these studies, however, might suggest that industrial and electricity generation demand is more price elastic than the residential and commercial demand.

For the newer studies, the averages for total oil demand suggest an inelastic price (-0.5) and an income response that may be near to being elastic (>.8). However, the derived natural of oil demand suggests to me that elasticities for total oil demand or total oil product demand with respect to total oil price would be biased. The only studies, that used total oil products and product price are on quarterly or monthly data and probably do not capture long run demands. They suggest the price elasticity is more elastic than −0.25 and income elasticity is more elastic than 0.75. They also suggest that price elasticities may have been lower prior to 1973, and that income elasticities may be lower in the 1980s than earlier.

For nontransport oil use in the residential sector, we see the characteristic low income elasticity on household data (<0.4). The one long run estimate on aggregate data is 2.28. We find very erratic price elasticities across model types. All models and data types suggest a long run price elasticity more elastic than −0.62, which is probably more elastic than for electricity and natural gas. How much more is unclear for simple dynamic models suggest an elastic price response on aggregate data but not on household data, whereas static or static stock models suggest an elastic price response on household data and an inelastic response on aggregate data.

Estimates for nontransport oil demands are rather erratic in the other sectors as well. In electricity generation, studies on time series data tend to get an inelastic response, studies on cross sections or cross sections time series get an elastic response, except in plants that only burn oil and natural gas. There appeared to be more substitution to coal than to oil with the 1973 oil embargo.

For the commercial and industrial sector, estimates on aggregate data using translog and logit models suggest that demand is price inelastic, a simple dynamic model for heating oil in these sectors is very erratic. Studies by industry find an inelastic price response in the food industry, an elastic response in agriculture, and an elastic response in metals post 1973 but an inelastic response pre 1973.

Total oil demand in the nontransport sector is found on average to be price inelastic and income elastic. Price elasticities are not found to be symmetric with a larger response to increases in the maximum price (−0.7) and an insignificant price response to price cuts and price recoveries.

As in the earlier survey work it is difficult to come to many conclusions about the magnitudes of elasticity for nontransport oil demand.

Moving on to transportation fuels, gasoline has been a heavily studied product and there appears to be enough consistency across studies so that survey work has consistently come up with summary statistics. Earlier work suggested that the short run price elasticity was from −0.2 to −0.03, the long run elasticity was from −0.6 to −0.9. International cross sections suggested it might be even higher. Short and long run income elasticities might be near 0.5 and 1.2. The most recent studies suggest that price and income elasticities have fallen and a reasonable guess for the short/long run price and income elasticities might be −0.2/−0.6 and 0.5/0.8. Price elasticity is found to be lower for price cuts than for price increases.

There are only a limited number of studies of non gasoline transportation fuel. Early studies for fuels for truck, bus and rail found price elasticities less elastic than −0.55, with truck demand income elastic and bus and rail demand quite income inelastic. A more recent study on jet fuel demand found and average price elasticity of −0.21 and average income elasticity of 0.36. Recent studies on total demand for oil for transportation found a long run price elasticity of −0.39 and long run income elasticity of 1.06 with larger elasticities for price recoveries than for price increases above the maximum and price cuts.

Studies have broken gasoline demand into two components, vehicle miles travelled and miles per gallon. Representative elasticities from earlier surveys prior to 1987 are short and long run price and income elasticities for vehicle miles travelled of –0.28/–0.5 and 0.34/0.62. Those for miles per gallon might be 0.16/0.44 and –0.07/–0.2. They imply that the gasoline price and income elasticities are –0.44/–0.94 and 0.41/0.82. These indirect estimates find a similar long run price but a somewhat smaller income elasticity than was found on aggregate data in the earlier studies. Newer studies surveyed in the 1990s or surveyed here suggest that price and income elasticities have fallen for vehicle miles travelled with representative price elasticities probably nearer –0.15/–0.27. Income elasticities have fallen, but estimates are more erratic and sensitive to whether drivers or autos are included in the model or not. It appears that about half of the income elasticity can be attributed to the number of drivers or the stock or auto and the other half attributed to an income effect, which suggests that income elasticities for vehicle miles travelled are 0.15/0.31.

For miles per gallon, the suggested short and long run price elasticities are 0.00/0.14, which are also smaller than from earlier studies. The only study that includes an income variable also includes a stock of autos so we do not get useable income elasticities. The implied long and short run gasoline price elasticities from these new studies are –0.31/–0.58, which are rather similar to the estimates from aggregate data.

For many other travel modes, there appears to be rather wide variation in elasticities. Bus transport appears to be price inelastic. Demand appears to be more price elastic for personal than for business travel and air transport is income elastic.

The last price elasticities considered were elasticities of substitution between fuels. Early surveys suggested that in the industrial sector, coal and oil showed the largest responses to the prices of other fuels with average cross price elasticities between 0.63 and 0.92, natural gas price responses were somewhat smaller with cross elasticities between 0.17 and 0.27, and electricity showed the smallest response of all with cross price elasticities between –0.06 and 0.11. With the more recent studies, oil elasticities appeared to fall and ranged between 0.04 and 0.10. Substitutability between natural and electricity increased with the more recent surveys with their average cross elasticities ranging between 0.53 and 0.65, whereas earlier they ranged between 0.10 and 0.20. Coal and natural gas cross price elasticities turned from positive to negative and results became more mixed than earlier.

In the electricity generation sector, coal became more responsive to natural gas prices in more recent studies. Only the most recent survey contained any cross price information in the commercial and residential sector. In the commercial sector, they found little evidence that there was substitution for electricity in response to changes in natural gas prices. In the residential sector, electricity showed a small but stable response to natural gas prices averaging 0.18 over 9 estimates. Natural gas demand showed a much larger response to electricity prices (0.72), but with much larger variation across only two estimates. Oil showed an even larger response (0.96) to natural gas prices but even larger variation across the two estimates. Overall, however, there tended to be rather wide variation in cross price elasticities across studies and across time to come up with representative elasticities.

Having concluded what I can from more than 20 years of energy demand estimates, I end with a few challenges for other researchers in the area. I have often found documentation substandard or too vague. I would urge clear documentation of model, data, estimation technique, and all appropriate coefficients and test statistics. Including these in the Tables as well as the text would be useful for the reader of the study. I have found a rather disappointing amount of variation across studies and would urge others to explain why as they go on to do yet more studies. Since studies vary across time periods, regions, and model types, it would be useful to do more systematic study of the affect of these parameters on elasticities and do hypothesis testing on them. Resolving the differences between income elasticities for aggregate versus disaggregate data for the residential sector would also be useful. One suspects the answer lies in demographic changes captured by aggregate models but not in the disaggregate data. The effect of structural change and industrial activivity on the industrial sector still eludes us. The best way to capture long run adjustment is still a mystery as well. Finally, it would be useful to determine whether some of the wilder shifts in elasticities are the result of multicollinearity in the data, missing parameters, or perhaps simultaneous system bias.

Appendix
Variable Definitions for all Tables and Text:

Ref stands for reference: References are abbreviated as the first three letters of the last name of one author, the first initial for the first author followed by & and the first initial of the second author for two authored pieces, and the first three initials of the first three authors for pieces with more than two coauthors. Only first initials of authors names are capitalized. The three letter abbreviations are followed by the last two digits of the year of publication. A q signifies that the estimates were quoted from a secondary source. The source is designated after the reference in the bibliography.

-=a dash indicates a subcategory
/after a variable neme=per capita
@mean=elasticity is computed at the mean
%Urb=is the percent of population in urban areas
#=number of estimated elasticities in each category
2Eq-Sh=estimated using a share model and two equations
2Eq=estimated in a two equation model
2S-all = estimated by two stage least squares using equations from all energy sectors
2S-sect = two stage least squares using equations in this energy sector
2S=estimated by two stage least squares
3S-s=estimated by three stage least squares with a correction for serial correlation
3S=estimated by three stage least squares
-ae=all electric home
-ag=agriculture
ARIMA=estimation using an autoregressive moving average
-Asym=asymmetric model
Avg=the average of the estimated elasticities in the category
-bl=black head of household
BN=estimated with a Balestra-Nerlove function
-bv=beverages
BxCx-s=Box Cox Estimation with a correction for serial correlation
C#=product demand category #
C=coal consumption
-c=commercial
C=cross section
-c&i=commerical and industrial
-cac=central air conditioner constrained by CAFE standards

CAFE=Corporate average fuel efficiency standards
-cd=clothes dryer
CES bkct Klf=# backcasting assuming a constant elasticity of substitution production function
-ck=cooking
-ch=basic chemicals + fertilizer
Cost Min=used a cost minimization model
-ct=cement
CT=cross section time series
-ctv=color television stock
-cw=clothes washer
D* indicates a dummy variable
D=diesel fuel consumption
DL=non constrained distributed lag
Drol=estimated using a Drollas (1984) model
/dv indicates per driver
-dw=dishwasher
Dyn Sk=dynamic stock model
Dyn=dynamic
-e=electricity generation
E=total energy consumption
EC-RC=estimated using error components random coefficients
EC-SUR=estimated using error components seemingly unrelated regressions
EC=estimated using error componenets seemingly unrelated regressions
El=electricity consumption
Elws=wholesale purchases of electricity
ET is the estimation technique:
Ex=expenditure system model
Ex-l linear expenditure system
Ex-AIDS=almost ideal demand system
Ex-Rot=Rotterdam expenditure system model
F-fuel consumption
-fd=food and beverage
FIML=full information maximum likelihood
-fm=fabricated metals
Fo-hv=consumption of heavy-end fuel oils
Fo-lt=consumption of light-end fuel oils
Fo=fuel oil consumption
-fr=freezer
-fu=furniture
G/Sk=gasoline consumption divided by the stock of autos
G=gasoline consumption
Gl=generalized Leontief
-gl=glassware
GLS-h=generalized least squares with a correction for heteroskedasticity
GLS-s2=generalized least squares with a correction for second order serial correlation
GLS=generalized least squares
-h=correction for heteroskedasticity when under ET
-h=household survey data when under Sample
HL=estimated by Hildreth Lu
-ht=heating
HT=Houthhaker and Taylor model
-hv=heavy
-hw=highway fuel consumption
-hy=produced by hydroelectricity

-i=industry
-ii estimates for separate industries
^indicates the data was first differenced,
INL3S=iterative nonlinear three stage least squares
INV.V=estmated using an inverted V model
ISUR=iterative seemingly unrelated regressions
IV=instrumental variables
J=jet fuel consumption
K=kerosene consumption
klf# indicates a capital life of # years
LE-DL=lagged endogenous and a other lagged valued
LE^1=inverted V model with lagged variables and lagged endogenous variables
LE^2=inverted V model two lagged endogenous variables
LE=estimated with a lagged endogenous model
LE-L#=estimated with a lagged endogenous model with a # period lag
-le=leather & substitutes
LE-Sk=estimated with a lagged endogenous and a stock of vehicle
Lg=estimated assuming logit model
LgCO+tNgEl=Lg on coal, oil including transportation, natural gas, and electricity
LgElNgOGD=Lg on electricity, natural gas, oil for stationary use, gasoline, and diesel
LPG=liquid petroleum gas consumption
-lt=light
m=monthly data
-m#=indicates month #(1=Jan,2=Feb)
-ma=machinery except electrical
Max= the maximum of the estimated elasticities in the category
-me=electrical machinery
-mf=manufacturing
-mi=mining
Min=the minimum of the estimated elasticities in the category
ML-s=estimated by maximum likelihood with a correction for serial correlation
ML=maximum likelihood
-mm=metals and machinery
Model is the estimation model
-mp=mineral products
MPG=miles per gallon
MPH=miles per hour
-mpk=mid peak load demand
-mt=metals including basic metal, aluminum, and copper
-mx=manufactured exports
-nae=not all electric home
-nbl=nonblack head of household
NEl=non electricity energy consumption
-nf=non-fossil fuel
Ng=natural gas consumption
-ngh=non gas heating
NL=estimated by nonlinear techniques
NL3S=nonlinear three stage least squares
-nm=nonmetallic products including cement, glass, ceramics, and other similar products
nr=not reported
ns=not significant
-ntr=non transportation demand
O+t=oil stationary uses plus transport

O=total oil consumption
OLS?=no specific estimation technique was stated but OLS
OLS-h=ordinary least squares with a correction for heteroskedasticity
OLS=ordinary least squares
OL-Sk=estimated including a stock of automobiles and other lagged -om=other
Op=total oil product consumption
-opk=off peak load demand
Ot=other similar products
-ot=other
P=Pg/mpg=price is the price of gasoline divided by miles per gallon
P=Pg=price variable used is the price of gasoline
P=ppm=price equals total price per mile
Pa=the price of automobiles
-pa=paper
Pcut=price cuts below previous prices
PDL:P#=a polynomial distributed lag with a # period lag on
Pir is the intermediate run price elasticity from static models
Pl=price of labor
-plnt=plant data
Plr is the long run price elasticity from dynamic models
Pmax=maximum price
Pmpk=price of mid peak demand
PMT=passenger miles travelled on airlines
Po = price of oil
Pop=price of oil products used
Popk=price of offpeak demand
-pp=paper and pulp
Ppk=price for peak load demand
-pr=printing & publishing
Prec=price recovery
PrimCom=estimtated by principal components
Prof max=used a profit maximization model
Prod designates the product demanded
Psr is the short run price elasticity from dynamic models
-pw=plastic ware
Q-1 is the coefficient on the lagged endogenous model
q=quarterly data
QQCD=Quasi Quadratic Cobb douglas model
-r=region (under sample category)
-r=residential (under product category)
-r&c=residential and commercial
-r1=residual 1 refrigerator
-rac=portable or room air-conditioner
-rb=rubber products
-rf=petroleum refining
RIDGE=estiamted by ridge regressions
-rMAt=Mid Atlantic region
-rNE=North Atlantic region
-rNY=regions in New York
-rr=fuel consumption for rail transport
-rSAt=South Atlantic region
-rSE=South East region
-rSW=South West region
-ru=rural
-rWNC=West North Central Region

s=estimated with a correction for first order serial (under estimation technique)
s=significant (under tstatistic)
-s=state data (under sample)
-s#=indicates the number of states used in the estimation
s3=estimated with a correction for serial correlation for third -
sa=intrastate
-se=services
SgElNelOtrOth=symmetric generalized McFadden cost function model with electric, non electric, transportation fuels, and all other inputs
sh for shoes change to leather le?
Sh-2Eq=Two equation fuel share model
Sh-LE=Fuel share model with a lagged endogenous model
Sh=the dependent variable is a fuel share equation
-sHA=Hawaii
-si=interstate
Sk=Stock
speed=speed limit
Stat-Sk= static model with an included stock variable
Stat= no lagged values included in the estimation
Stat3Eq=Static three equation model
StatAsym=static asymmetric model
Std=the standard deviation of the estimated elasticities in the category measured as $\Sigma(X_i-)^2/\#$
-sum=summer
SUR-s=estimated by seemingly unrelated regressions with a correction for serial correlation
SUR=estimated by seemingly unrelated regressions
t(p) is the t-statistic on the estimated coefficient for price
t(y) is the t-statistic on the estimated coefficient for income
t(-1) is the t-statistic on the lagged endogenous variable
-t=fuels used for transportation
T=time series
-tb=tobacco
-te=transport equipment
-Tk=heavy trucks
Tl=estimated with a static translog model
Tl2=estimated with a second generation dynamic translog model
Tl3=estimated with a third generation dynamic translog model
TlCO+tNgEl=Tl with coal, oil including transportation use, natural gas, and electricity
TlCO=Tl with coal and oil
TlCOEl=Tl with coal, oil, and electricity
TlCOElNg=Tl with coal, oil, electricity, and natural gas
TlCONg=Tl with coal, oil, and natural gas
TlCONgNHyElws=Tl with coal, oil, natural gas, nuclear, hydroelectricity and wholesale electricity purchases
TlElFfKL=Tl with electricity, fossil fuels, capital and labor
TlElNelOtrOt Tl with electric, non-electric, oil for tranportation fuels and all other inputs
TlGDLpFoNgEl=Tl with gasoline, diesel, lpg, fuel oil, natural gas, and electricity
TlKLE=Tl with capital, labor, and energy
TlKLEM=Tl with capital labor, energy, and materials
TlKLFfEl=Tl with capital, labor, fossil fuels, and electricity
-tr=transport and communication industry

-tx=cotton&textiles
-ucaf=manufacturers not constrained by CAFE standards
-ur=consumed in urban areas
TlKLMElFf=estimated using capital, labor, materials, electricity and fossil fuels
-ucaf manufacturers not constrained by CAFE standards
-ut=utilities
/V = divided by vehicle stock
VMT=vehicle miles traveled
-wd=wood, wood products, wood furniture
-wgt=weighted
-wh=water heater
-win=winter
/Y=divided by gdp
y1 is the first year of the estimation period
y2 is the last year of the estimation period
Yir is the intermediate income elasticity from static models
Ylr is the long run income elasticity from dynamic models
Ysr is the short run income elasticity from dynamic models

Table A1: Demand for Electricity and Natural Gas Elasticities by Appliance Stock (All Models are StatSk)

Ref	Product	Sample	y1	y2	Typ	t(p)	Pir	t(Y)	Yir	ET
H&W81	El-r-ck	US-s46	60	72	CT	ns	-0.15	ns	-2.16	EC-RC
H&W81	El-r-ck	US-s46	60	72	CT	s	-3.85	ns	-8.80	EC
H&W81	El-r-ck	US-s46	60	72	CT	ns	1.07	ns	-2.94	GLS-h
H&W81	El-r-ck	US-s46	60	72	CT	ns	0.24	ns	-2.88	GLS-h
BGH81	El-r-ck	US-h	72	73	CT	1.23	1.36	-2.49	-1.44	OLS
BGH81	El-r-ck	US-h	72	73	CT	0.57	-0.43	-2.84	-0.91	2S
H&W81	El-r-rac	US-s46	60	72	CT	s	-1.82	ns	2.86	EC
H&W81	El-r-rac	US-s46	60	72	CT	s	-1.78	ns	-0.91	GLS-h
H&W81	El-r-rac	US-s46	60	72	CT	s	-1.55	ns	0.27	GLS-h
H&W81	El-r-rac	US-s46	60	72	CT	s	-1.57	ns	0.82	EC-RC
BGH81	El-r-rac	US-h	72	73	CT	3.74	-2.02	3.13	0.22	OLS
BGH81	El-r-rac	US-h	72	73	CT	1.57	-1.87	2.40	0.17	2S
H&W81	El-r-cac	US-s46	60	72	CT	ns	-0.62	ns	0.24	GLS-h
H&W81	El-r-cac	US-s46	60	72	CT	ns	135.19	ns	0.49	EC-RC
H&W81	El-r-cac	US-s46	60	72	CT	ns	0.74	ns	0.02	EC
H&W81	El-r-cac	US-s46	60	72	CT	ns	0.01	ns	0.48	GLS-h
BGH81	El-r-cac	US-h	72	73	CT	5.74	-1.21	4.20	0.38	2S
BGH81	El-r-cac	US-h	72	73	CT	6.82	-1.27	4.39	0.39	OLS
H&W81	El-r-cd	US-s46	60	72	CT	ns	-2.31	ns	-2.59	EC
H&W81	El-r-cd	US-s46	60	72	CT	ns	-0.25	ns	1.93	GLS-h
H&W81	El-r-cd	US-s46	60	72	CT	ns	-0.43	ns	1.32	EC-RC
H&W81	El-r-cd	US-s46	60	72	CT	ns	0.86	ns	3.77	GLS-h
BGH81	El-r-ctv	US-h	72	73	CT	1.19	0.42	0.44	0.10	OLS
BGH81	El-r-ctv	US-h	72	73	CT	1.38	0.50	0.20	0.04	2S

Table A1 (continued): Demand for Electricity and Natural Gas Elasticities by Appliance Stock All Models are StatSk

Ref	Product	Sample	y1	y2	Typ	t(p)	Pir	t(Y)	Yir	ET
H&W81	El-r-cw	US-s46	60	72	CT	s	9.39	ns	29.37	EC-RC
H&W81	El-r-cw	US-s46	60	72	CT	ns	-2.16	ns	-26.31	EC
H&W81	El-r-cw	US-s46	60	72	CT	ns	6.46	ns	27.45	GLS-h
H&W81	El-r-cw	US-s46	60	72	CT	s	8.75	ns	20.41	GLS-h
BGH81	El-r-cd	US-h	72	73	CT	4.50	-1.82	2.41	0.50	2S
BGH81	El-r-cd	US-h	72	73	CT	2.99	-1.25	3.37	0.81	OLS
BGH81	El-r-dw	US-h	72	73	CT	0.07	-0.04	1.03	0.34	2S
BGH81	El-r-dw	US-h	72	73	CT	0.75	-0.36	1.44	0.46	OLS
H&W81	El-r-fr	US-s46	60	72	CT	ns	-2.77	ns	2.99	EC
H&W81	El-r-fr	US-s46	60	72	CT	ns	-0.33	ns	-0.89	EC-RC
H&W81	El-r-fr	US-s46	60	72	CT	ns	-0.17	ns	0.18	GLS-h
H&W81	El-r-fr	US-s46	60	72	CT	ns	-0.54	ns	-1.19	GLS-h
BGH81	El-r-fr	US-h	72	73	CT	1.84	-0.80	-0.18	-0.04	2S
BGH81	El-r-fr	US-h	72	73	CT	1.34	-0.62	0.66	0.15	OLS
BGH81	El-r-rf1	US-h	72	73	CT	4.25	-0.94	-2.30	-0.07	OLS
BGH81	El-r-rf1	US-h	72	73	CT	5.71	-0.60	-2.86	-0.11	2S
BGH81	El-r-rf2	US-h	72	73	CT	4.52	-3.48	-0.73	-0.32	OLS
BGH81	El-r-rf2	US-h	72	73	CT	3.05	-2.80	-0.94	-0.44	2S
H&W81	El-r-ht	US-s46	60	72	CT	s	-0.99	ns	-0.93	GLS-h
H&W81	El-r-ht	US-s46	60	72	CT	s	-0.55	ns	-0.80	GLS-h
H&W81	El-r-ht	US-s46	60	72	CT	ns	-0.40	ns	-0.06	EC
H&W81	El-r-ht	US-s46	60	72	CT	s	-1.03	ns	-0.91	EC-RC
BGH81	El-r-ht	US-h	72	73	CT	4.63	-1.19	1.18	0.20	OLS
BGH81	El-r-ht	US-h	72	73	CT	3.13	-0.93	1.54	0.26	2S
BGH81	El-r-wh	US-h	72	73	CT	0.75	0.16	1.33	0.14	2S
BGH81	El-r-wh	US-h	72	73	CT	1.21	0.22	1.23	0.14	OLS
H&W81	El-r-wh	US-s46	60	72	CT	ns	-0.37	ns	1.42	EC-RC
H&W81	El-r-wh	US-s46	60	72	CT	ns	-2.31	ns	0.98	EC
H&W81	El-r-wh	US-s46	60	72	CT	s	-0.97	ns	0.16	GLS-h
H&W81	El-r-wh	US-s46	60	72	CT	s	-0.48	ns	1.48	GLS-h
BGH81	El-r-wgt	US-h	72	73	Avg	-38.12	-0.88	15.56	0.21	OLS
BGH81	El-r-wgt	US-h	72	73	Avg	-19.85	-0.55	14.70	0.20	2S
H&W81	El-r	US-s46	60	72	Avg	ns	-0.19	ns	0.09	GLS-h
H&W81	El-r	US-s46	60	72	Avg	s	-0.40	ns	0.38	GLS-h
H&W81	El-r	US-s46	60	72	Avg	ns	-1.11	ns	-0.55	EC
H&W81	El-r	US-s46	60	72	Avg	ns	5.17	ns	0.54	EC-RC

Table A2: Residential Electricity Demand by Season or Month

Ref	Product	Sample	y1	y2	Typ	Psr	t(p)	Pir	Plr	Ysr	t(Y)	Yir	Ylr	Q(-1)	t(Q-1)	Model	ET
AFM82	El-r-m1	US-h	75	75	Cm	-0.48	<0.05%			0.10	<0.05%	0.10				StatSk	OLS
Gar83a	El-r-m1	US-h	78	79	CTm	-0.40	-3.80			0.05	1.76	0.05				Stat3Eq	2S
Gar86	El-r-m1	US-rS-h	78	79	CTm	-1.82				0.18						Stat3Eq	2S
Gar86	El-r-m1	US-rNE-h	78	79	CTm	-0.40				0.09						Stat3Eq	2S
Gar86	El-r-m1	US-rNC-h	78	79	CTm	-1.82				0.18						Stat3Eq	2S
Gar86	El-r-m1	US-rW-h	78	79	CTm	-0.49				0.18						Stat3Eq	2S
Gar86	El-r-m1	US-rS-h	78	79	CTm	-1.82				0.18						Stat3Eq	2S
AFM82	El-r-m10	US-h	75	75	Cm	-0.29	<0.05%			0.03	ns	0.03				StatSk	OLS
Gar83a	El-r-m10	US-h	78	79	CTm	0.05	0.61			-0.05	-1.86	-0.05				Stat3Eq	2S
Gar86	El-r-m10	US-rW-h	78	79	CTm	-0.46				0.12						Stat3Eq	2S
Gar86	El-r-m10	US-rS-h	78	79	CTm	-1.46				0.12						Stat3Eq	2S
Gar86	El-r-m10	US-rNC-h	78	79	CTm	-1.46				0.12						Stat3Eq	2S
Gar86	El-r-m10	US-rS-h	78	79	CTm	-1.46				0.12						Stat3Eq	2S
Gar86	El-r-m10	US-rNE-h	78	79	CTm	0.00				0.00						Stat3Eq	2S
AFM82	El-r-m11	US-h	75	75	Cm	-0.42	<0.05%			0.08	ns	0.08				StatSk	OLS
Gar83a	El-r-m11	US-h	78	79	CTm	-0.40	-5.06			0.02	1.00	0.02				Stat3Eq	2S
Gar86	El-r-m11	US-rS-h	78	79	CTm	-1.24				0.11						Stat3Eq	2S
Gar86	El-r-m11	US-rS-h	78	79	CTm	-1.24				0.11						Stat3Eq	2S
Gar86	El-r-m11	US-rNC-h	78	79	CTm	-1.24				0.11						Stat3Eq	2S
Gar86	El-r-m11	US-rNE-h	78	79	CTm	-0.31				0.04						Stat3Eq	2S
Gar86	El-r-m11	US-rW-h	78	79	CTm	-1.24				0.11						Stat3Eq	2S
AFM82	El-r-m12	US-h	75	75	Cm	-0.48	<0.05%			0.08	ns	0.08				StatSk	OLS
Gar83a	El-r-m12	US-h	78	79	CTm	-0.31	-3.71			0.02	0.72	0.02				Stat3Eq	2S
Gar86	El-r-m12	US-rNC-h	78	79	CTm	0.00				0.09						Stat3Eq	2S
Gar86	El-r-m12	US-rW-h	78	79	CTm	0.00				0.09						Stat3Eq	2S
Gar86	El-r-m12	US-rS-h	78	79	CTm	0.00				0.09						Stat3Eq	2S
Gar86	El-r-m12	US-rS-h	78	79	CTm	-0.72				0.32						Stat3Eq	2S
Gar86	El-r-m12	US-rNE-h	78	79	CTm	-0.28				0.04						Stat3Eq	2S
AFM82	El-r-m2	US-h	75	75	Cm	-0.32	<0.05%			0.09	ns	0.09				StatSk	OLS
Gar83a	El-r-m2	US-h	78	79	CTm	-0.49	-5.67			0.08	3.50	0.08				Stat3Eq	2S
Gar86	El-r-m2	US-rNE-h	78	79	CTm	-0.44				0.10						Stat3Eq	2S
Gar86	El-r-m2	US-rW-h	78	79	CTm	-0.06				0.14						Stat3Eq	2S
Gar86	El-r-m2	US-rNC-h	78	79	CTm	-1.90				0.14						Stat3Eq	2S
Gar86	El-r-m2	US-rS-h	78	79	CTm	-1.90				0.14						Stat3Eq	2S
Gar86	El-r-m2	US-rS-h	78	79	CTm	-1.90				0.33						Stat3Eq	2S
AFM82	El-r-m3	US-h	75	75	Cm	-0.29	<0.05%			0.12	<0.05%	0.12				StatSk	OLS

Gar83a	El-r-m3	US-h	78	79	CTm	-0.26	-2.82			0.02	0.59	0.02		Stat3Eq	2S		
Gar86	El-r-m3	US-rNC-h	78	79	CTm	-1.51				0.16				Stat3Eq	2S		
Gar86	El-r-m3	US-rNE-h	78	79	CTm	-0.23				0.00				Stat3Eq	2S		
Gar86	El-r-m3	US-rW-h	78	79	CTm	-0.08				0.16				Stat3Eq	2S		
Gar86	El-r-m3	US-rS-h	78	79	CTm	-1.51				0.16				Stat3Eq	2S		

Table A2 (continued): Residential Electricity Demand by Season or Month

Ref	Product	Sample	y1	y2	Typ	Psr	t(p)	Pir	Plr	Ysr	t(Y)	Yir	Ylr	Q(-1)	t(Q-1)	Model	ET
Gar86	El-r-m3	US-rS-h	78	79	CTm	-1.51				0.16				Stat3Eq	2S		
AFM82	El-r-m4	US-h	75	75	Cm	-0.43	<0.05%			0.09	<0.05%	0.09				StatSk	OLS
Gar83a	El-r-m4	US-h	78	79	CTm	-0.59	-6.52			0.16	4.70	0.16				Stat3Eq	2S
Gar86	El-r-m4	US-rNE-h	78	79	CTm	-0.41				0.08						Stat3Eq	2S
Gar86	El-r-m4	US-rS-h	78	79	CTm	-0.50				0.15						Stat3Eq	2S
Gar86	El-r-m4	US-rW-h	78	79	CTm	-0.50				0.15						Stat3Eq	2S
Gar86	El-r-m4	US-rNC-h	78	79	CTm	-0.50				0.15						Stat3Eq	2S
Gar86	El-r-m4	US-rNC-h	78	79	CTm	-0.50				0.15						Stat3Eq	2S
AFM82	El-r-m5	US-h	75	75	Cm	-0.44	<0.05%			0.16	<0.05%	0.16				StatSk	OLS
Gar83a	El-r-m5	US-h	78	79	CTm	-0.30	-3.68			0.04	1.37	0.04				Stat3Eq	2S
Gar86	El-r-m5	US-rW-h	78	79	CTm	-0.91				0.11						Stat3Eq	2S
Gar86	El-r-m5	US-rNC-h	78	79	CTm	-0.90				0.11						Stat3Eq	2S
Gar86	El-r-m5	US-rNE-h	78	79	CTm	-0.23				0.00						Stat3Eq	2S
Gar86	El-r-m5	US-rS-h	78	79	CTm	-0.90				0.11						Stat3Eq	2S
Gar86	El-r-m5	US-rS-h	78	79	CTm	-0.90				0.11						Stat3Eq	2S
AFM82	El-r-m6	US-h	75	75	Cm	-0.60	<0.05%			0.09	ns	0.09				StatSk	OLS
Gar83a	El-r-m6	US-h	78	79	CTm	-0.08	-0.93			0.08	2.65	0.08				Stat3Eq	2S
Gar86	El-r-m6	US-rS-h	78	79	CTm	-0.43				0.14						Stat3Eq	2S
Gar86	El-r-m6	US-rS-h	78	79	CTm	-0.43				0.14						Stat3Eq	2S
Gar86	El-r-m6	US-rNE-h	78	79	CTm	0.00				0.00						Stat3Eq	2S
Gar86	El-r-m6	US-rW-h	78	79	CTm	-0.43				0.14						Stat3Eq	2S
Gar86	El-r-m6	US-rNC-h	78	79	CTm	-0.43				0.14						Stat3Eq	2S
AFM82	El-r-m7	US-h	75	75	Cm	-0.40	<0.05%			0.28	ns	0.28				StatSk	OLS
Gar83a	El-r-m7	US-h	78	79	CTm	0.04	0.41			0.07	2.22	0.07				Stat3Eq	2S
Gar86	El-r-m7	US-rS-h	78	79	CTm	-0.56				0.00						Stat3Eq	2S
Gar86	El-r-m7	US-rS-h	78	79	CTm	-0.56				0.22						Stat3Eq	2S
Gar86	El-r-m7	US-rNE-h	78	79	CTm	0.00				0.00						Stat3Eq	2S
Gar86	El-r-m7	US-rW-h	78	79	CTm	-0.56				0.00						Stat3Eq	2S
Gar86	El-r-m7	US-rNC-h	78	79	CTm	-0.56				0.00						Stat3Eq	2S
AFM82	El-r-m8	US-h	75	75	Cm	-0.45	<0.05%			0.08	ns	0.08				StatSk	OLS
Gar83a	El-r-m8	US-h	78	79	CTm	-0.17	-0.16			0.09	2.51	0.09				Stat3Eq	2S

Gar86	El-r-m8	US-rNC-h	78	79	CTm 0.00				0.00						Stat3Eq	2S
Gar86	El-r-m8	US-rW-h	78	79	CTm 0.00				0.00						Stat3Eq	2S
Gar86	El-r-m8	US-rS-h	78	79	CTm 0.00				0.21						Stat3Eq	2S
Gar86	El-r-m8	US-rS-h	78	79	CTm 0.00				0.00						Stat3Eq	2S
Gar86	El-r-m8	US-rNE-h	78	79	CTm-0.21				0.00						Stat3Eq	2S
AFM82	El-r-m9	US-h	75	75	Cm -0.12	ns			0.06	ns	0.06				StatSk	OLS
Gar83a	El-r-m9	US-h	78	79	CTm-0.13	-1.74			0.06	2.07	0.06				Stat3Eq	2S
Gar86	El-r-m9	US-rNC-h	78	79	CTm-0.76				0.11						Stat3Eq	2S
Gar86	El-r-m9	US-rNE-h	78	79	CTm-0.19				0.00						Stat3Eq	2S
Gar86	El-r-m9	US-rS-h	78	79	CTm-0.76				0.11						Stat3Eq	2S

Table A2 (continued): Residential Electricity Demand by Season or Month

Ref	Product	Sample	y1	y2	TypPsr	t(p)	Pir	Plr	Ysr	t(Y)	Yir	Ylr	Q(-1)	t(Q-1)	Model	ET
Gar86	El-r-m9	US-rS-h	78	79	CTm-0.76				0.25						Stat3Eq	2S
Gar86	El-r-m9	US-rW-h	78	79	CTm-0.08				0.11						Stat3Eq	2S
Gar84b	El-r-sum	US-rW-h	78	79	CTm-0.90	-1.79			-0.03	-0.00	-0.03				Stat3Eq	2S
Gar84b	El-r-sum	US-rNC-h	78	79	CTm-0.06	1.93			0.23	1.66	0.23				Stat3Eq	2S
Gar84b	El-r-sum	US-rNE-h	78	79	CTm-0.51	-3.02			0.13	3.34	0.13				Stat3Eq	2S
Gar84b	El-r-sum	US-rS-h	78	79	CTm-0.05	2.31			0.26	2.52	0.26				Stat3Eq	2S
Gar84c	El-r-sum	US-h	78	79	CTm-0.49			-1.10	0.18			0.41			Stat3Eq	2S
Gar83a	El-r-sum	US-rW-h	78	79	CTm-0.98	-2.30			-0.04	-2.46	-0.04				Stat3Eq	2S
Gar83a	El-r-sum	US-rW-h	78	79	CTm-0.28	-1.29			0.13	3.94	0.13				Stat3Eq	2S
Gar83a	El-r-sum	US-rNC-h	78	79	CTm-1.30	-5.15			0.03	0.88	0.03				Stat3Eq	2S
Gar83a	El-r-sum	US-rNE-h	78	79	CTm-0.16	-0.59			0.12	2.25	0.12				Stat3Eq	2S
Gar83a	El-r-sum	US-rS-h	78	79	CTm-0.33	-1.54			0.23	6.16	0.23				Stat3Eq	2S
Gar83a	El-r-sum	US-h	78	79	CTm-0.05	-1.11			-0.04	-2.11	-0.04				Stat3Eq	2S
Gar83a	El-r-sum	US-SMSA-	78	79	CTm-0.17	-2.79			-0.09	-3.15	-0.09				Stat3Eq	2S
Gar83a	El-r-sum	US-nSMSA	78	79	CTm-0.18	-3.12			0.04	1.35	0.04				Stat3Eq	2S
Gar83a	El-r-sum	US-rNE-h	78	79	CTm-0.03	2.19			0.21	1.58	0.21				Stat3Eq	2S
Gar83a	El-r-sum	US-rS-h	78	79	CTm-0.06	2.46			0.30	3.33	0.30				Stat3Eq	2S
Gar83a	El-r-sum	US-rNC-h	78	79	CTm-0.52	-3.21			0.12	3.05	0.12				Stat3Eq	2S
Gar84b	El-r-win	US-rNE-h	78	79	CTm-1.49	-2.92			0.20	0.01	0.20				Stat3Eq	2S
Gar84b	El-r-win	US-rS-h	78	79	CTm-1.78	-1.08			0.32	2.11	0.32				Stat3Eq	2S
Gar84b	El-r-win	US-rNC-h	78	79	CTm-0.21	4.14			0.04	-2.43	0.04				Stat3Eq	2S
Gar84b	El-r-win	US-rW-h	78	79	CTm-1.24	0.82			-0.05	-3.66	-0.05				Stat3Eq	2S
Gar84c	El-r-win	US-h	78	79	CTm-0.79			-1.84	0.18			0.31			Stat3Eq	2S
Gar83a	El-r-win	US-rNC-h	78	79	CTm-1.54	-6.98			0.13	3.60	0.13				Stat3Eq	2S
Gar83a	El-r-win	US-rW-h	78	79	CTm-0.13	-0.78			0.15	3.92	0.15				Stat3Eq	2S
Gar83a	El-r-win	US-nSMS-	78	79	CTm-0.17	-2.53			0.20	6.83	0.20				Stat3Eq	2S

Gar83a	El-r-winUS-rNE-h	78	79	CTm	-0.67	-4.88		0.03	0.75	0.03	Stat3Eq	2S
Gar83a	El-r-winUS-rS-h	78	79	CTm	-0.91	-2.17		0.15	3.66	0.15	Stat3Eq	2S
Gar83a	El-r-winUS-rS-h	78	79	CTm	-1.80	-1.09		0.35	4.48	0.35	Stat3Eq	2S
Gar83a	El-r-winUS-SMSA-	78	79	CTm	-0.57	-8.35		0.08	3.77	0.08	Stat3Eq	2S
Gar83a	El-r-winUS-rNC-h	78	79	CTm	-2.70	-4.79		-0.03	-0.62	-0.03	Stat3Eq	2S
Gar83a	El-r-winUS-rNE-h	78	79	CTm	-0.17	4.71		0.01	-2.09	0.01	Stat3Eq	2S
Gar83a	El-r-winUS-rW-h	78	79	CTm	-1.72	-0.63		-0.07	-3.02	-0.07	Stat3Eq	2S
Gar83a	El-r-winUS-h	78	79	CTm	-0.41	-7.12		0.08	5.40	0.08	Stat3Eq	2S
Gar83a	Ng-rJan US-h	79	80	CTm		4.76	-0.41		3.06	0.11	Stat2Eq	2S
Gar83a	Ng-rJan US-h	78	80	CTm		-11.55	-0.46		3.26	0.11	Stat	OLS
Gar83a	Ng-rJan US-h	79	80	CTm		-6.87	-0.65		0.74	0.06	Stat3Eq	2S
Gar83a	Ng-rJul US-h	79	80	CTm		-0.63	-0.05		3.00	0.13	Stat3Eq	2S
Gar83a	Ng-rJul US-h	79	80	CTm		-12.70	-0.34		6.60	0.17	Stat	OLS
Gar83a	Ng-rJul US-h	79	80	CTm		-1.47	-0.11		6.08	0.16	Stat2Eq	2S

Table A3: Demand for Natural Gas Elasticities by Appliance Stock

Ref	Product	Sample	y1	y2	Type	Psr	t(p)	Pir	Plr	Ysr	t(Y)	Yir	Ylr	Q(-1)	t(Q-1)	Model	ET
BGH82	Ng-r-cac	US-h	72	73	CTq		-2.79	-1.87			0.20	0.11				Stat	IV
BGH82	Ng-r-cac	US-h	72	73	CTq		-2.20	-1.61			0.26	0.14				Stat	OLS
BGH82	Ng-r-cd	US-h	72	73	CTq		-0.71	-0.76			-0.25	-0.19				Stat	IV
BGH82	Ng-r-cd	US-h	72	73	CTq		0.58	0.65			0.16	0.11				Stat	OLS
H&W81	Ng-r-cd	US-s	60	75	CT		s	-7.14			s	-16.04				StatSk	EC-RC
H&W81	Ng-r-cd	US-s	60	75	CT		s	-0.66			s	-1.02				StatSk	EC
H&W81	Ng-r-cd	US-s	60	75	CT		ns	-1.05			ns	-0.55				StatSk	GLS-h
BGH82	Ng-r-ck	US-h	72	73	CTq		-3.77	-0.44			-3.84	-0.29				Stat	OLS
BGH82	Ng-r-ck	US-h	72	73	CTq		-9.66	-0.79			-4.15	-0.25				Stat	IV
H&W81	Ng-r-ck	US-s	60	75	CT		s	-0.73			s	-0.42				StatSk	EC
H&W81	Ng-r-ck	US-s	60	75	CT		s	-1.02			s	-4.66				StatSk	GLS-h
H&W81	Ng-r-ck	US-s	60	75	CT		s	1.30			ns	-0.31				StatSk	EC-RC
A&W86	Ng-r-ck	US-h-sa	80	80	C		-5.50	-1.98			0.22	0.08				Stat	OLS
A&W86	Ng-r-ck	US-h-si	80	80	C		-6.00	-1.50			0.85	0.11				Stat	OLS
A&W86	Ng-r-ck	US-h-si	80	80	C		-48.67	-1.46			1.00	0.03				Stat	OLS
BGH82	Ng-r-ht	US-h	72	73	CTq		-8.44	-0.86			2.47	0.09				Stat	OLS
BGH82	Ng-r-ht	US-h	72	73	CTq		-9.74	-0.89			2.88	0.11				Stat	IV

H&W81	Ng-r-ht	US-s	60	75	CT		ns	-0.02			s	-0.17				StatSk	EC-RC
H&W81	Ng-r-ht	US-s	60	75	CT		ns	-0.05			s	-0.16				StatSk	EC
H&W81	Ng-r-ht	US-s	60	75	CT		ns	-0.09			ns	0.23				StatSk	GLS-h
A&W86	Ng-r-ht	US-h-sa	80	80	C		-7.70	-0.77			3.67	0.11				Stat	OLS
A&W86	Ng-r-ht	US-h-sa	80,82		CT	-0.83	-5.93		-1.69	0.14	3.50		0.29	0.51	6.38	LE	OLS
A&W86	Ng-r-ht	US-h-sa	80	80	C		-5.64	-0.79			3.67	0.11				Stat	OLS
A&W86	Ng-r-ht	US-h-sa	80	80	C		-4.60	-0.69			1.83	0.11				Stat	OLS
A&W86	Ng-r-ht	US-h-si	80	80	C		-15.50	-0.62			10.00	0.10				Stat	OLS
A&W86	Ng-r-ht	US-h-si	80,82		CT	-0.09	-1.50		-0.16	0.07	3.50		0.12	0.42	14.00	LE	OLS
A&W86	Ng-r-ht	US-h-si	80	80	C		-10.83	-0.65			8.50	0.17				Stat	OLS
A&W86	Ng-r-ht	US-h-si	80	80	C		-10.33	-0.62			0.50	0.01				Stat	OLS
A&W86	Ng-r-ht	US-h-si	80,82		CT	-0.19	-2.38		-0.33	0.07	3.50		0.12	0.42	14.00	LE	OLS
A&W86	Ng-r-ngh	US-h-si	80,82		CT	-2.17	-15.50		-2.28	0.07	1.17		0.07	0.05	1.25	LE	OLS
A&W86	Ng-r-ngh	US-h-si	80,82		CT	-1.89	-13.50		-1.95	0.05	0.71		0.05	0.03	0.75	LE	OLS
A&W86	Ng-r-ngh	US-h-si	80	80	C		-47.33	-1.42			1.00	0.03				Stat	OLS
A&W86	Ng-r-ngh	US-h-sa	80	80	C		-9.94	-1.79			3.92	0.51				Stat	OLS

Table A3 (continued): Demand for Natural Gas Elasticities by Appliance Stock

Ref	Product	Sample	y1	y2	Type	Psr	t(p)	Pir	Plr	Ysr	t(Y)	Yir	Ylr	Q(-1)	t(Q-1)	Model	ET
H&W81	Ng-r-wh	US-s	60	75	CT		s	-1.08			ns	0.52				StatSk	EC-RC
H&W81	Ng-r-wh	US-s	60	75	CT		s	-1.64			ns	0.58				StatSk	EC
H&W81	Ng-r-wh	US-s	60	75	CT		ns	-0.05			ns	0.72				StatSk	GLS-h
BGH82	Ng-r-wh	US-h	72	73	CTq		-6.13	-0.67			8.07	0.55				Stat	IV
BGH82	Ng-r-wh	US-h	72	73	CTq		-4.43	-0.49			7.74	0.47				Stat	OLS
BGH82	Ng-r-wgt	US-h	72	73	CTq		-12.60	-0.68			6.82	0.15				StatSk	OLS
BGH82	Ng-r-wgt	US-h	72	73	CTq		-17.03	-0.83			7.08	0.16				StatSk	IV
H&W81	Ng-r	US-s	60	75	CT		ns	-0.15			ns	0.02				StatSk	GLS-h
H&W81	Ng-r	US-s	60	75	CT		ns	-0.30			ns	-0.05				StatSk	EC
H&W81	Ng-r	US-s	60	75	CT		ns	-0.21			ns	-0.21				StatSk	EC-rc

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