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Introduction

The price elasticity of energy demand has a profound influence on the calculated effects of energy supply and price shocks upon the macroeconomy. Depending on the assumed long-run magnitude of this elasticity, policy prescriptions for energy conservation and management may differ markedly. An accurate measure of the long-run energy demand price elasticity is difficult to obtain. On this issue we are faced with complicated issues of production factor and energy substitution possibilities over dynamic long-run horizons stretching far beyond data currently available for estimation. This study investigates the long-run dynamic adjustment of total primary energy demand to energy prices and the distribution of these effects through disaggregated energy demand sectors which allow for interfuel substitution possibilities within a singular equation system of energy share equations.

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Two primary problems confound proper estimation of energy models. The first is that since 1973 energy economics has been a supply-oriented phenomenon, whereas existing tools of econometric analysis have been predominantly demand-oriented. The second problem is that data do not yet exist with which to measure the long-run consequences of the sudden energy price shocks which have altered the basic structure of simultaneous macroeconomic relationships. Neither this study, nor other existing empirical studies address these problems. For a study of this nature, the long run should be defined properly as the time period sufficient for the existing capital stock to adjust to the dramatic alteration in raw energy factor input supply availability and relative price changes. A minimum statistical sample period extending 30 years beyond the 1973 Arab oil embargo would be a conservative estimate. Obviously no empirical study can fullfill this requirement.

Balanced against the unavailability of the "true" energy model is the pressing need to evaluate the effects of energy supply and price impacts on macroeconomic variables of interest to policy makers. Even if it is necessarily tentative in character, some estimate is needed of the energy sector's increasingly important impact on aggregate domestic output and prices, on distortions in the balance of payments accounts owing to growing nominal oil import bills, and on the realignment of world trade and finance patterns due to severe energy price disturbances.

This study will focus on the determination of demand for total energy consumption at the level of primary factor input and will examine how its disaggregated shares are allocated among consumption of raw energy inputs for crude petroleum, coal and dry natural gas, allowing for interfuel substitution possibilities through relative energy price effects. The model structure used in this study provides a quantity level, and subsequently a dollar measure, of the dependence of the domestic economy on imported energy, given levels of domestic energy supply. One important conclusion resulting from this empirical investigation is that the long-run price elasticity of demand for petroleum and coal is greater than that for total primary energy consumption and extends far beyond the period in which the initial alignments for interfuel substitution have taken place.

Defining Total Energy Consumption and Allocating Primary Shares

Energy is measured in this study at the primary level: petroleum at the wellhead, coal at the mine-mouth, and dry natural gas at the tap. There are several reasons why it is difficult, if not impossible, to use energy measures further down the energy chain. First, at secondary through final levels of energy consumption, errors in measurement abound. The thermal content of final energy products, for example, will vary according to the efficiency with which different machines use the energy product. This efficiency use is by no means constant over time; machines are adapted to higher levels of efficiency at different rates in response to rapidly increasing prices of primary energy. Second, energy categories below the primary level are subject to conversion losses or gains which are difficult to measure for reasons similar to the error measurement problems of final energy product quantities. Fuss' theories of váriable coefficient putty-semiputty factor demand models which were tested with models of the electricial generation industry (Fuss,1978) yield results which indicate the non-stationarity of parameters defining secondary energy measurements. Finally, a consensus of the proper units of energy measures becomes more difficult to obtain the lower the level at which energy quantities are measured. An example of the lack of consensus on measurement of energy quantities is found in the Fritsch-Lacoste (1979) criticism of established OECD unit measurements of energy conservation.

At the primary energy factor input level, the quantity measurement of energy inputs is defined more clearly. The two ultimate uses of the model contained in this study -- derivation of the domestic oil import bill and the aggregate quantity measurement of energy as a raw factor input -- lie within this definition. With known Btu conversion factors for petroleum (BTUFL), coal (BTUC), and dry natural gas (BTUNG), we construct total energy consumption (BQET) as the sum of the three components in quadrillion Btu's (DQFLBTU, DQCBTU, DQNGBTU):

$$BQET = DQFLBTU + DQCBTU + DQNGBTU \tag{1}$$

where
$$DQFLBTU = DQFL * BTUFL * .001 * DAYSQTR$$
$$DQCBTU = DQC * BTUC$$
$$DQNGBTU = DQNG * BTUNG$$

with DQFL, DQC, and DQNG being the physical quantity measures of crude petroleum, coal, and dry natural gas in millions of barrels per day, thousands of short tons and trillions of cubic feet respectively. DAYSQTR is the number of days per quarter. We then specify this total energy quantity as a function of aggregate income and lagged energy prices in the log-linear form:

$$\ln(BQET) = a + b*\ln(GNP) + c*(L_i)*\ln(PWIFE/PNF) \tag{2}$$

where GNP is real gross national product and the total energy-weighted average subscript price variable (PWIFE) is relative to the weighted average nonfarm value-added price deflator (PNF). The operator L_i represents a distributed lag process of length i. In such a specification we ignore, by necessity, the interfactor substitution possibilities which would be contained within a fully specified factor demand system including relative price effects for other factor inputs for capital, labor and other material inputs. It is one of the fundamental premises of this study, and a source of considerable empirical contention, that such between-factor substitution possibilities as could be expressed through relative price effects cannot be empirically verified. This is due to the relatively short experience the domestic economy has had with the structural economic shifts which started in the early 1970's when raw material input prices began their quantum surge.

Viewing energy factor inputs as weakly separable from other factor inputs into the aggregate production process allows for a specification of energy factor share demand equations as functions of relative disaggregate energy prices. The disaggregated energy share system can be specified in the translog form:

$$SHRP = a_1 + b_{11}*(L_{1i})*\ln(PWIFL/PWIFNG) + b_{12}*(L_{1j})*\ln(PWIFC/PWIFNG) \quad (3)$$

$$SHRC = a_2 + b_{21}*(L_{2i})*\ln(PWIFL/PWIFNG) + b_{22}*(L_{2j})*\ln(PWIFC/PWIFNG) \quad (4)$$

$$SHRNG = a_3 + b_{31}*(L_{3i})*\ln(PWIFL/PWIFNG) + b_{32}*(L_{3j})*\ln(PWIFC/PWIFNG) \quad (5)$$

where SHRP is DQFLBTU/BQET, SHRC is DQCBTU/BQET, and SHRNG is DQNGBTU/BQET. The lag operators L.i and L.j assume the same lag process for each relative price measure across all three equations. The energy sector prices are PWIFL for petroleum, PWIFC for coal and PWIFNG for natural gas.

From this specification in singular equation form (see Denton, 1978) we know that the estimated properties of this share system will guarantee that

$a_i = 1$ and $b_i \ (L_{ij}) = 0$ for $i = 1, 2, 3$.

The first property requires that changes in the total energy measure from either aggregate demand or total energy factor price changes will be distributed completely among all three energy factor shares. The second property ensures that an increase in the share of one energy subsector is offset by decreases in the shares of the other subsectors and that the proportions always sum to unity.

Estimated Total Energy Consumption and Share Equations

The equation for total energy consumption (BQET) was estimated over the sample period 1960 QI through 1979 QIV using a first order Cochran-Orcutt estimation technique and a second degree Almon polynomical distributed lag constrained to zero at t-n. An Arab oil embargo dummy (EMBARG = 1 in 1973 QIV and zero elsewhere) and degree day variables for extreme cold (DEGC) and extreme hot (DEGH) weather were found to be highly significant in this specification. Based on estimation experimentation with differing lag distribution and sample periods, the estimates which proved to be most acceptable in term of fit and consistent coefficient sign and significance across the distributed lag specification may be summarized as follows:

$$\ln BQET = -\underset{(-14.08)}{4.83} - \underset{(-3.38)}{.065}EMBARG + \underset{(23.95)}{.00011}\ DEGC$$

$$+ \underset{(5.81)}{.00009}\ DEGH + \underset{(21.59)}{1.065}\ \ln GNP$$

$$- \underset{(-7.55)}{.328}\ (L32)\ \ln\ (PWIFE/PNF)$$

$$+ .415\ 2t\text{-}1 \tag{6}$$

$\bar{R}^2 = .982$ Se = .023 DW = 1.97

The income elasticity in this equation is near unity and the cumulative sum of the price elasticity over the 32 quarter distributed lag is uniformly negative and significant through the 24th quarter as shown below:

t-n+1	Coefficient	Cumulative Sum	T-Statistic
1	-.019521	-.019521	-3.26
2	-.018947	-.038468	-3.64
3	-.018371	-.056839	-4.12
4	-.017793	-.074632	-4.71
5	-.017212	-.091844	-5.45
6	-.016629	-.10847	-6.35
7	-.016044	-.12452	-7.39
8	-.015456	-.13997	-8.39
9	-.014866	-.15484	-8.95
10	-.014273	-.16911	-8.74
11	-.013679	-.18279	-7.90
12	-.013082	-.19587	-6.86
13	-.012482	-.20835	-5.90
14	-.01188	-.22023	-5.10
15	-.011276	-.23151	-4.45
16	-.01067	-.24218	-3.93

t-n+1	Coefficient	Cumulative Sum	T-Statistic
17	-.010061	-.25224	-3.51
18	-.0094495	-.26169	-3.17
19	-.008836	-.27053	-2.89
20	-.0082201	-.27875	-2.65
21	-.0076018	-.28635	-2.44
22	-.0069813	-.29333	-2.27
23	-.0063583	-.29969	-2.12
24	-.0057331	-.30542	-1.98
25	-.0051054	-.31053	-1.87
26	-.0044755	-.315	-1.76
27	-.0038431	-.31885	-1.67
28	-.0032085	-.32205	-1.59
29	-.0025715	-.32463	-1.51
30	-.0019321	-.32656	-1.44
31	-.0012904	-.32785	-1.38
32	-6.4639E-4	-.32849	-1.32

In our alternative specifications for this equation we experimented in some detail with differing lag distribution shapes and lengths for the relative price term. In almost all of these attempts we discovered that the income term exhibited no significant lagged effects on consumption and that the cumulative lag sum on price increased in absolute magnitude with a longer lag length. A representative sample of these attempts is shown in Table I where lag lengths of 8 to 40 quarters are compared. In terms of the maximum lag length attempted, upwards of 60 quarter lag distributions proved possible with slightly higher lag sums indicating scope for explaining an even longer term consumption-price relationship over the most recent period for estimation. Such long lags, however, given the data currently available, truncate the sample period for purposes of obtaining explanatory power from the other determinants within the specification. The lag length of 32 was selected on the basis of overall fit of the estimated equation and conformance to significant t-ratios for the longest lag length throughout the distribution.

The alternative specifications indicate that the lagged response of energy consumption to prices is quite robust. The specification with the short two-year lag length includes some perverse positive coefficients at the head of the distribution which suggests a misspecification of the relationship when the additional lagged price effects are omitted.

Table I

Income and Price Elasticities for Various Lag Lengths

	LAG LENGTH 8	16	24	32	40
Income Elasticity	.98 (25.9)	.97 (54.2)	1.01 (27.3)	1.07 (21.6)	1.09 (14.74)
4 qtr price elasticity	-.026 [1]	-.027	-.054	-.075	-.082
8 qtr price elasticity	-.197	-.100	-.114	-.140	-.151
12 qtr price elasticity	--	-.178	-.171	-.196	-.209
16 qtr price elasticity	--	-.220	-.221	-.242	-.256
20 qtr price elasticity	--	--	-.257	-.279	-.293
24 qtr price elasticity	--	--	-.272	-.305	-.322
28 qtr price elasticity	--	--	--	-.322	-.343
32 qtr price elasticity	--	--	--	-.328	-.356
36 qtr price elasticity	--	--	--	--	-.369
40 qtr price elasticity	--	--	--	--	-.367
T stat for sum of lagged coefficients	-.611	-12.38	-8.11	-7.56	-5.72
$\bar{R}^2$	.989	.985	.987	.982	.972

1 - Positive, insignificant coefficient for first two quarters.

Given the pronounced and robust estimated long-lagged price relationships in this equation, along with the uniformly consistant contemporaneous income responses, these estimates raise serious reservations about earlier energy consumption equations which either omit lagged responses or attempt to approximate these dynamic relationships with a partial adjustment Kóyck lagged adjustment scheme. The geometric decay imposed on such a Koyck specification assumes explicitly that consumption responses to both income and price impulses follow the same dynamic path. This assumption is intuitively difficult to accept and is countered by this study's results.

Shorter, but still significant effects of lagged price responses were found to exist in the disaggregated energy share equations for petroleum, coal and natural gas. These results, shown in Table II, are estimated over the sample period 1960 QI through 1979 QIV employing ordinary least squares with second degree ten-quarter Almon polynomical distributed lags constrained to zero at t-n. The sample period for these equations is somewhat shorter than that for the total energy consumption equation due to lack of historical data for several of the disaggregated energy price variables.

Recall that the estimated coefficients for these equations explain the change in share proportion of each energy component with respect to changes in total energy consumption.

Table IIa

Share of Petroleum in Total Energy Consumption

$$SHRP = \underset{(102.5)}{0.5237} - \underset{(-1.56)}{.01353}\ .DEMBARG - \underset{(-7.78)}{.00002}\ DEGC - \underset{(-8.08)}{.00001}\ DEGH$$

$$- \underset{(-18.71)}{0.1343}\ (L_{10})\ \ln \frac{(PWIFL)}{(PWIFNG)}$$

$$+ \underset{(14.08)}{0.0697}\ (L_{10})\ \ln \frac{(PWIFC)}{(PWIFNG)}$$

$(L_{10})\ \ln \frac{(PWIFL)}{(PWIFNG)}$

t	p	
0	-0.0307	(- 4.87)
-1	-0.0258	(- 6.77)
-2	-0.0212	(-11.62)
-3	-0.0171	(-13.71)
-4	-0.0134	(- 8.20)
-5	-0.0101	(- 4.28)
-6	-0.0072	(- 2.66)
-7	-0.0048	(- 1.79)
-8	-0.0028	(- 1.26)
-9	-0.0012	(- 0.89)

$(L_{10})\ \ln \frac{(PWIFC)}{(PWIFNG)}$

t	p	
0	-0.0126	(- 3.08)
-1	-0.0039	(- 1.55)
-2	0.0032	(2.59)
-3	0.0086	(14.08)
-4	0.0124	(12.07)
-5	0.0145	(9.73)
-6	0.0149	(8.66)
-7	0.0137	(8.06)
-8	0.0108	(7.08)
-9	0.0062	(7.43)

Se = .00805 $\bar{R}^2$ = .9328 DW = .7748

Table IIb

Share of Coal in Total Energy Consumption

$$SHRC = \underset{(36.54)}{0.18717} - \underset{(-0.05)}{0.00043}\ DEMBARG - \underset{(-3.31)}{0.00001}\ DEGC + \underset{(1.31)}{0.00001}\ DEGH$$

$$+ \underset{(10.40)}{0.074871}\ (L_{10})\ \ln \left(\frac{PWIFL}{PWIFNG}\right)$$

$$- \underset{(13.90)}{0.067313}\ (L_{10})\ \ln \left(\frac{PWIFC}{PWIFNG}\right)$$

$(L_{10})\ \ln \left(\frac{PWIFL}{PWIFNG}\right)$

t	p	
0	0.02922	(4.62)
-1	0.02162	(5.66)
-2	0.01505	(8.22)
-3	0.00929	(10.40)
-4	0.00505	(3.08)
-5	0.001602	(0.67)
-6	-0.00080	(- 0.29)
-7	-0.02161	(- 0.08)
-8	-0.00248	(- 1.12)
-9	-0.00176	(- 1.33)

$(L_{10})\ \ln \left(\frac{PWIFC}{PWIFNG}\right)$

t	p	
0	-0.02453	(- 5.23)
-1	-0.01839	(- 7.29)
-2	-0.01306	(-10.53)
-3	-0.0086	(-13.90)
-4	-0.00489	(- 4.73)
-5	-0.00202	(- 1.35)
-6	0.00002	(0.01)
-7	0.00124	(0.73)
-8	0.00165	(1.17)
-9	0.00123	(1.46)

Se = .00807 $\bar{R}^2$ = .8271 DW = .8676

Table IIc

Share of Natural Gas in Total Energy Consumption

$$SHRNG = \underset{(52.87)}{0.28915} + \underset{(1.50)}{0.01396}\ DEMBARG + \underset{(10.33)}{0.00003}\ DEGC - \underset{(-0.48)}{0.000004}\ DEGH$$

$$+ \underset{(7.71)}{0.059455}\ (L_{10})\ \ln \frac{(PWIFL)}{(PWIFNG)}$$

$$- \underset{(-0.13)}{0.00068}\ (L_{10})\ \ln \frac{(PWIFC)}{(PWIFNG)}$$

$(L_{10})\ \ln \frac{(PWIFL)}{(PWIFNG)}$

t	p	
0	0.00152	(0.22)
-1	0.00416	(1.02)
-2	0.00617	(3.15)
-3	0.00757	(7.71)
-4	0.00834	(4.76)
-5	0.00850	(3.35)
-6	0.00804	(2.75)
-7	0.00696	(2.42)
-8	0.00526	(2.21)
-9	0.00294	(2.07)

$(L_{10})\ \ln \frac{(PWIFC)}{(PWIFNG)}$

t	p	
0	0.03722	(8.40)
-1	0.02223	(8.25)
-2	0.00986	(7.42)
-3	-0.000086	(-0.12)
-4	-0.00754	(-6.82)
-5	-0.01251	(-7.80)
-6	-0.01499	(-8.07)
-7	-0.01497	(-8.18)
-8	-0.01247	(-8.24)
-9	-0.00748	(-8.28)

Se - .00865 $\bar{R}^2$ = .9337 DW = 1.0975

For those variables which do not significantly affect the mix of the total, therefore, an estimated coefficient not statistically different from zero will result. This was found to be the case in these estimates for energy share response to income changes, but significantly different responses of energy share mix were found for the embargo and degree day variables and the relative price terms. The nonzero estimated coefficients for the embargo dummy indicate a shift from imported petroleum consumption to domestic natural gas consumption during the 1973-74 Arab oil embargo. Significant difference in share response to extreme cold weather heating requirements (DEGC) were found to increase natural gas consumption share at the expense of declining shares for petroleum and coal. Although not statistically significant, the share of coal consumption response to extreme warm weather cooling requirements (DEGH) increased over that for petroleum and natural shares.

The absence of energy share response to income effects, which resulted in zero coefficents for any aggregate activity variable included within the estimation attempts, indicates a proportional response of each energy share to changes in aggregate demand. That is, while the results from the equation for total energy consumption exhibit an estimated unitary income elasticity, the implicit income elasticity for each measure for disaggregate energy consumption is also near unity. As a consequence, in simulation mode for this model, the change in each energy sector's level of consumption will respond with equal percentage change to the unitary impact of aggregate demand on total energy consumption.

The estimated relative price coefficients for each energy sector within the share equations display two relevant features of this model. First, in that the relative price coefficients are nonzero and significant, the model yields evidence of interfuel substitution possibilities in response to changes in energy sector prices. Second, in repeated experiments, the distributed lag length on the relative price terms remains considerably shorter than the lag length estimated for response of total energy consumption to aggregate energy price changes. This latter observation suggests that alignments of the mix of energy consumption by energy sector category can occur within the ten-quarter period of the relative price changes of the energy sectors, while the response of aggregate energy consumption to total energy price changes may take as long as eight years to be completed. This suggests that interfuel substitution is possible before interfactor substitution can occur for long-run energy conservation and production. However, it is also possible that some substitutability may be possible in the very long run in fuel specific industries such as transportation. Our relatively short historical experience provides us with little empirical evidence for these occurrences.

The nature of the interfuel substitution possibilities estimated for the energy share equations can be summarized in the Table III below, summing the lagged relative price coefficients through the identity:

$$b_{i1} \ln \left(\frac{PWIFL}{PWIFNG}\right) + b_{i2} \ln \left(\frac{PWIFC}{PWIFNG}\right) = b_{i1} \ln (PWIFL) + b_{i2} \ln (PWIFC)$$

$$+ (-b_{i1} - b_{i2}) \ln (PWIFNG) \qquad (7)$$

The own price coefficient sum for each share equation is negative, implying that when an energy sector's price increases, that sector's share of total energy consumption will decrease. Positive cross-price coefficient sums in each of these equations imply that an energy sector share will increase as the prices of alternative energy sources increase. Two exceptions to this cross-price response are represented in the coefficient sums for natural gas prices within the coal share equation and for coal prices within the natural gas share equation. These two coefficient sums are small and insignificant, however.

In simulation mode for this model, total energy prices (PWIFE) are calculated as a fixed energy share weighted average of the three energy sector prices, using a 1972 base. Hence an increase in one sector's energy price will increase the total energy price variable according to that energy sector's weight.

It will consequently result in a decrease in total energy consumption and a further decrease in that energy sector's level of consumption within the energy share allocation system due to the sector's negative own-price coefficients. Cross-price effects within the energy share allocation system may or may not increase an energy sector's consumption level in response to an increase in an alternative energy sector's price. This latter effect will depend on the magnitude of the decrease in total energy consumption resulting from the impulse of the price increase in the alternative energy sector. A demonstration of these own and cross energy price effects is contained in the simulation and multiplier analysis section which follows.

Of primary interest to this study are the derived results from this energy model as they relate to imports of petroleum and products. Given an exogenous path for domestic petroleum production, the driving endogenous variable in forecasting oil imports is domestic petroleum consumption (DQFL) which, for comparison purposes in subsequent simulations, we determined through three different methods:

(i) The Changing Share System: DQFL is derived from the normalization of SHRP in the energy share system.

(ii) The Constant Share System: DQFL is calculated from the estimated parameters from the total energy equation (BQET), with the petroleum wholesale price index (PWIFL) replacing the total energy price variable (PWIFE) in equation (6).

(iii) The Simple Contemporaneous Single Equation: DQFL is calculated from a simple log linear demand function with a contemporaneous income elasticity of .94 and price elasticity of .13.

The rationale behind using the constant share version is that, for forecasting purposes, all of the necessary price and value data contained in the full energy model may not be available. If relative prices in the three subsectors remain unchanged over the lag length in the share equations, the constant share assumption for petroleum demand is equivalent to the changing share assumption. The single contemporaneous equation is one which is representative of many earlier demand studies of petroleum imports. Contrasting the multiplier results from the first two systems with that employing a contemporaneous price elasticity yields a comparative measure of the potential cumulative loss in explaining declining oil import demand from lagged increases in the world price of oil over the last decade.

Model Simulation Results

Several multiplier simulations were performed to estimate the effects of price increases for petroleum, natural gas and coal, as well as an increase in real GNP. All simulations were run during the historical period starting in 1960 QI and ending in 1979 QIV.

Since real GNP enters the energy demand equation only on a concurrent basis and does not affect the relative shares of the three energy subcomponents, the level of total energy consumption, as well as the levels of petroleum, coal and natural gas consumption, increase proportionately to the rise in income according to the income elasticity. Thus, a permanent one per cent income increase lead to a 1.065 per cent increase in energy usage over the entire period. This result is, of course, identical in the 'constant share' version. In the single equation petroleum model, the increase is .94 per cent, due to the lower estimated elasticity.

A one per cent petroleum price shock (all other energy prices held constant), leads to a -.16 per cent cumulative effect on total energy demand (Table IV). This is roughly half of the energy demand response that would occur if all energy prices were increased by 1 per cent, reflecting the historical share of petroleum in total energy consumption. However, consumption of petroleum falls by .24 per cent after 4 quarters and .43 per cent after 32 quarters, as a result of a decreasing share of petroleum in total energy consumption in conjunction with diminished total energy usage. The relative share of petroleum falls by .0013 percentage points, with corresponding increases in coal and natural gas shares. However, the level of natural gas consumption is virtually unaffected after 32 quarters (as a larger share is offset by reduced energy consumption), while coal consumption is increased by .24 per cent. (Note that coal and gas shares increase almost equally in percentage points, but the percentage increase in the share ratios is greater in the case of coal).

The constant share model was simulated shocking petroleum prices by one per cent in order to contrast the results to the case of a one per cent shock in the petroleum price in the changing share system. The changing share simulation leads to a substantially larger fall in petroleum consumption (and much more rapid drop in the first few quarters) than with the constant share model. Thus, although the aggregate energy price index is shocked by a smaller amount in the changing share case, petroleum consumption drops more rapidly due to interfuel substitution. Note, however, that since the primary energy substitution occurs between petroleum and coal, environmental constraints could limit the amount of interfuel substitution, particularly in the short run, in response to a large change in relative factor prices. Thus, the speed and degree of substitution must be accepted with a certain amount of skepticism.

A one per cent increase in coal price (ceteris paribus), results in a .06 per cent fall in total energy usage (Table V). The relative share of natural gas and the level of natural gas consumption increase initially, but become insignificant after 8 quarters. Coal consumption falls by .36

per cent after 8 quarters and .42 per cent after 32 quarters, reflecting a reduced share of coal usage compounded with lower energy consumption. The level of petroleum consumption is only slightly affected by the coal price increase. The small weight of coal in the historical period (about 18 per cent) reduces the amount of interfuel substitution resulting from a coal price shock.

Shocking the natural gas price by one per cent (Table VI) reduces total energy consumption by .11 per cent after 32 quarters, natural gas consumption by .30 per cent, coal consumption by .50 per cent, and has almost no long run effect on petroleum consumption (although petroleum consumption does increase by .20 per cent after 4 quarters). Thus, as in the case of a petroleum shock, the simulation results show no enduring substitutability between petroleum and natural gas. This is not too surprising, since these two fuels are often associated products in production, and hence may be complements in supply even if they are eventually substitutes in demand.

Concluding Remarks

We have found that energy consumption responds increasingly over time to price changes, although a substantial range of lag lengths yield reasonable econometric results. Since length lags may indeed be a proxy for changes in the capital stock which occur over long periods, a five to ten year lag is eminently reasonable and may in fact underestimate the long range effects. Shares of different fuels in total energy consumption have been found to respond to relative fuel prices, particularly with regards to substitutability between petroleum and coal. However, the existence of price controls on certain fuels, historically and currently, as well as environmental constraints on certain fuel usage, may yield a different pattern of interfuel substitution from that observed in the past. In short, our limited experience with regards to large energy price changes suggests that long term energy forecasts are highly uncertain.

Table III
Summary of Estimated Coefficients and
Static/Dynamic Simulation Properties

	Const	Y	Pe	Pp	Pc	Png	$\bar{R}^2$	Se	Dw	RMSES	RMSED
BQET	-4.833	1.065	$-.328_{L32}$	$-.159_{L32}$	$-.059_{L32}$	$-.110_{L32}$	.9820	.0203	1.836	1.99	2.12
SHRP	.524	-	-	$-.134_{L10}$	$.0697_{L10}$	$.0640_{L10}$	.9328	.0080	.775	.74	.74
SHRC	.187	-	-	$.0749_{L10}$	$-.0673_{L10}$	$-.0067_{L10}$	.8271	.0081	.868	.74	.74
SHRNG	.289	-	-	$.0595_{L10}$	$-.0007_{L10}$	$-.0588_{L10}$	.9337	.0086	.934	.86	.86
Ep	-	-	-	-	-	-	-	-	-	0.0	2.40
Ec	-	-	-	-	-	-	-	-	-	0.0	4.67
Eng	-	-	-	-	-	-	-	-	-	0.0	3.63
Dpe	-4.833	1.065	-	$-.328_{L32}$	-	-	-	-	-	1.66	6.31
Dpz	-3.81	.94	-	-.13	-	-	-	-	-	2.52	7.83

Table IV
Effects of a 1% Increase in Petroleum Prices
(Percentage Difference from Control)

Variable \ Quarters Out	1	2	3	4	5	6	7	8	12	16	20	24	28	32
BQET	-0.01	-0.02	-0.03	-0.04	-0.04	-0.05	-0.06	-0.07	-0.09	-.12	-.13	-.15	-.16	-.16
SHRP	-0.03	-0.06	-0.08	-0.09	-.11	-.12	-.12	-.13	-.13	-.13	-.13	-.13	-.13	-.13
SHRC	0.03	0.05	0.07	0.08	0.08	0.08	0.08	0.08	0.07	0.07	0.07	0.07	0.07	0.07
SHRNG	0.00	0.01	0.01	0.02	0.03	0.04	0.04	0.05	0.06	0.06	0.06	0.06	0.06	0.06
Ep	-0.08	-.13	-.19	-.24	-.29	-.30	-.32	-.35	-.39	-.40	-.41	-.42	-.44	-.43
Ec	.13	.20	.26	.32	.35	.32	.30	.32	.31	.30	.29	.27	.24	.24
Eng	-0.00	-0.00	0.01	0.02	0.03	0.06	0.09	0.08	0.07	0.05	0.04	0.03	0.02	0.03
Dpe	-0.02	-0.04	-0.06	-0.07	-0.09	-0.11	-0.12	-0.14	-0.19	-0.24	-0.28	-0.30	-0.32	-0.33
Dpz	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13	-0.13

Table V
Effects of a 1% Increase in Coal Prices
(Percentage Difference from Control)

Variable \ Quarters Out	1	2	3	4	5	6	7	8	12	16	20	24	28	32
BQET	-0.00	-0.01	-0.01	-0.01	-0.02	-0.02	-0.02	-0.03	-0.04	-0.04	-0.05	-0.05	-0.06	-0.06
SHRP	-0.01	-0.02	-0.01	-0.00	0.01	0.02	0.04	0.05	0.07	0.07	0.07	0.07	0.07	0.07
SHRC	-0.02	-0.04	-0.06	-0.06	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07
SHRNG	0.04	0.06	0.06	0.07	0.06	0.05	0.03	0.02	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00
Ep	-0.02	-0.04	-0.04	-0.02	0.00	0.03	0.05	0.09	0.11	0.10	0.09	0.08	0.08	0.08
Ec	-0.12	-0.20	-0.25	-0.32	-0.36	-0.34	-0.34	-0.36	-0.40	-0.42	-0.44	-0.43	-0.42	-0.42
Eng	0.09	0.18	0.22	0.19	0.15	0.14	0.09	0.03	-0.04	-0.05	-0.05	-0.06	-0.06	-0.06
Dpe	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dpz	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table VI
Effects of a 1% Increase in Natural Gas Prices
(Percentage Difference from Control)

Variable \ Quarters Out	1	2	3	4	5	6	7	8	12	16	20	24	28	32
BQET	-0.01	-0.01	-0.02	-0.02	-0.03	-0.04	-0.04	-0.05	-0.07	-0.08	-0.09	-0.10	-0.11	-0.11
SHRP	0.04	0.07	0.09	0.10	0.09	0.10	0.10	0.08	0.07	0.07	0.07	0.07	0.07	0.06
SHRC	-0.00	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
SHRNG	-0.04	-0.06	-0.08	-0.09	-0.09	-0.09	-0.08	-0.07	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06
Ep	0.09	0.14	0.17	0.20	0.20	0.17	0.14	0.13	0.08	0.06	0.04	0.03	0.03	0.02
Ec	-0.03	-0.05	-0.06	-0.08	-0.08	-0.08	-0.08	-0.08	-0.11	-0.12	-0.14	-0.14	-0.14	-0.15
Eng	-0.11	-0.22	-0.29	-0.28	-0.28	-0.31	-0.31	-0.25	-0.23	-0.25	-0.26	-0.28	-0.28	-0.30
Dpe	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dpz	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

APPENDIX

ADDQFL — Historical discrepancy in identity for imports of oil in millions of barrels per day.

ADJPEMP — Historical adjustment variable to rectify data errors in the linkage equation from PEMP to its component part PUVFL. (ADJPEMP = PEMP/((1,LAG(PEMP,1)) * (PUVFL/(1,LAG(PUVFL,1))

ADJPWIFE — Historical adjustment variable to rectify data errors in the linkage equation for PWIFE to its component parts PWIFC, PWIFNG, and PWIFL. (ADJPWIFE = PWIFE/(EXP(.49*LOG(PWIFL)+.18*LOG(PWIFC)+.33*LOG(PWIFNG))

ADJPWIFL — Historical adjustment variable to rectify data errors in the linkage equation from PWIFL to its component parts PUVIFLD and PEMP. (ADJPWIFL = PWIFL/(EXP.65*LOG(PUVIFLD)+.35*LOG(PEMP))

BQET — Total energy consumption in quadrillion Btu* (the sum of DQFLBTU, DQCBTU, and DQNGBTU).

BTUC — Btu* conversion factor for coal, trillion Btu/short ton. (DQCBTU = BTUC * DQC).

Sources:

1960-1972 — Calculated from annual consumption data in thousand short tons (from the Department of the Interior, Bureau of Mines, as reported in the Survey of Current Business) and in quadrillion Btu (U.S. Department of the Interior, W.G. Dupree and J.A. West, "United States Energy through the Year 2000," Appendix B, December 1972, and U.S. Department of the Interior, Bureau of Mines, Supplement to the 1973 annual petroleum statement).

1973-1979 — U.S. Department of Energy, Monthly Energy Review.

BTUFL — Btu* conversion factor for petroleum and products, million Btu/barrel. (DQFLBTU = BTUFL * DQFL * DAYSQTR).

*/ A Btu, or British thermal unit, is a unit for measuring heat. It is the amount of heat necessary to raise a pound of water one degree Fahrenheit.

Sources:

1960-1972 Calculated from annual consumption data in million barrels (U.S. Department of the Interior, Bureau of Mines, Minerals Yearbooks and annual petroleum statements) and in quadrillion Btu (U.S. Department of the Interior, W.G. Dupree and J.A. West, "United States Energy through the Year 2000," Appendix B, December 1972, and U.S. Department of the Interior, Bureau of Mines, Supplement to the 1973 annual petroleum statement).

1973-1979 U.S. Department of Energy, Monthly Energy Review.

BTUNG Btu* conversion factor for dry natural gas, thousand Btu/cubic foot. (DQNGBTU = BTUNG * DQNG)

Sources:

1947-1972 Calculated from annual consumption data in trillions of cubic feet and trillion Btu (U.S. Department of the Interior, W.G. Dupree and J.A. West, "United States Energy through the year 2000," Appendix B, December 1972, and U.S. Department of the Interior, Bureau of Mines, Supplement to the 1973 annual petroleum statement).

1973-1979 U.S. Department of Energy, Monthly Energy Review.

DAYSQTR Number of days in each quarter (taking account of the extra day in the first quarter of each leap year).

DEGC Cold weather heating degree days (to account for heating requirements). A heating degree day is the number of degrees by which the average temperature falls short of 65 degrees Fahrenheit each day of the quarter.

Sources:
U.S. Department of Commerce, National Oceanographic and Atmospheric Administration, Environmental Data Service.

State, Regional, and National Monthly and Seasonal Heating Degree Days Weighted by Population (July 1931 - June 1979). November 1979.

*/ A Btu, or British thermal unit, is a unit for measuring heat. It is the amount of heat necessary to raise a pound of water one degree Fahrenheit.

Monthly State, Regional, and National Heating Degree Days Weighted by Population (July 1978 - April 1980), July 7, 1980.

DEGH Hot weather cooling degree days (to account for cooling requirements). A cooling degree day is the number of degrees by which the average temperature rises above 65 degrees Fahrenheit each day of the quarter.

Source:
U.S. Department of Commerce, National Oceanographic and Atmospheric Administration, Environmental Data Service:

State, Regional and National Monthly and Seasonal Cooling Degree Days Weighted by Population (January 1931 - December 1977), April 1978.

Monthly State, Regional, and National Cooling Degree Days Weighted by Population (January 1978 - December 1979), February 28, 1980.

Monthly State, Regional, and National Cooling Degree Days Weighted by Population (January 1979 - April 1980) July 7, 1980.

DQC Consumption of bituminous and lignite coal in thousands of short tons. Data in the quarterly sum of monthly figures.

Sources:

1960-1976 U.S. Department of the Interior, Bureau of Mines (as reported by the U.S. Department of Commerce, Bureau of Economic Analysis, Business Statistics: The Biennial Supplement to the Survey of Current Business from 1963 through 1977).

1977-1979 U.S. Department of Energy (as reported monthly by the U.S. Department of Commerce, Bureau of Economic Analysis, Survery of Current Business).

DQCBTU Consumption of bituminous and lignite coal in quadrillion Btu*. (DQCBTU = DQC * BTUC).

*/ A Btu, or British thermal unit, is a unit for measuring heat. It is the amount of heat necessary to raise a pound of water one degree Fahrenheit.

DQFL Consumption of crude petroleum and products in millions of barrels per day. Data is the quarterly average of monthly figures.

Sources:

1947-1965 U.S. Department of the Interior, Minerals Yearbook from 1948 through 1966.

1966-1975 U.S. Department of the Interior, Bureau of Mines, Annual petroleum statements.

1976-1978 U.S. Department of Energy, Annual petroleum statements.

1979 U.S. Department of Energy, Monthly petroleum statements.

DQFLBTU Consumption of crude petroleum and products in quadrillion Btu*. (DQFLBTU = DQFL * BTUFL * .001 * DAYSQTR).

DQNG Consumption of dry natural gas in trillions of cubic feet. Quarterly data for the period 1947 - 1972 is derived from annual figures, using the average quarterly pattern from 1976 - 1979. Data from 1973 - 1979 is the quarterly sum of monthly figures.

Sources:

1947-1969 U.S. Department of the Interior, W.G. Dupree and J.A. West, "United States Energy through the Year 2000," December 1972.

1970-1972 U.S. Department of the Interior, Bureau of Mines, "Crude Petroleum, Petroleum Products, and Natural Gas Liquids: December 1975 (Supplement)" and February 1977 press release.

1973-1979 U.S. Department of Energy, Monthly Energy Review.

DQNGBTU Consumption of dry natural gas in quadrillion Btu*. (DQNGBTU = DQNG * BTUNG).

EMBARG Dummy variable for Arab oil embargo of 1973 QIV (1974 QI = 1, elsewhere = 0).

EMPV F.A.S. value of U.S. imports of crude petroleum and products, in billions of current dollars, Census basis for the period 1957 - 1968, International Accounts basis for the period 1969 - 1979.

Sources:

1957-1968 U.S. Department of Commerce, Bureau of the Census and Bureau of Economic Analysis, worksheets from Ms. Rebecca Bethea.

1969-1979 U.S. Department of Commerce: Bureau of Census, FT990 and FT900, and Bureau of Economic Analysis, worksheets from Ms. Ann Fisher, Mr. Howard Murad, and Ms. Rebecca Bethea.

IDQ Quarterly data vector.

IQFL F.A.S. quantity of U.S. imports of crude petroleum and products in millions of barrels per day. Data are Census basis for the period 1957 - 1968, and International Accounts basis for the period 1969 - 1979.

Sources:
Same as for EMPV. Note: Data for 1969-1972 are calculated dividing International Accounts basis value by Census basis unit value.

LPRIC Log of PWIFC, the producer price index for coal.

LPRING Log of PWIFNG, the index of the wellhead price of dry natural gas.

LPRIP Log of PWIFL, the producer price index for petroleum products.

LRPFL Log of the relative price of energy, used in the changing share equation. The relative price of energy is the producer price index of energy (PWIFE) divided by the non-farm value-added price deflator (PNF).

LRPFLE Log of the relative price of petroleum, used in the constant share equation. The relative price of petroleum is the producer price index of petroleum products (PWIFL) divided by the U.S. GNP deflator (PGNP).

LXGNP Log of U.S. Real GNP in 1972 dollars (XGNP).

NIN Quarter counter.

PEMP Unit value index for imports of crude petroleum and products, 1972 = 100.

Sources:
Same as for EMPV.

PGNP U.S. GNP deflator, 1972 = 100.

Source:
U.S. Department of Commerce, Bureau of Economic Analysis.

PNF U.S. non-farm value-added price deflator, 1972 = 100.

Source:
U.S. Department of Commerce, Bureau of Economic Analysis.

PUVC F.O.B. mine price for bituminous and lignite coal in dollars per short ton.

Sources:

1947-1973 U.S. Department of the Interior, Bureau of Mines (as reported by the Executive Office of the President, Council on Wage and Price Stability, <u>A Study of Coal Prices</u>, March 1976).

1974-1976 U.S. Department of Energy, <u>Coal -- Bituminous and Lignite in 1976</u>, December 18, 1978.

1977-1979 U.S. Department of Energy, Mr. Charles Vannoy.

PUVIC Index of F.O.B. mine price for bituminous and lignite coal, 1972 = 100.

Sources:
Same as for PUVC.

PUVFL Average price for U.S. imports of petroleum and products in dollars per barrel. Calculated from Census-basis F.A.S. volume and value data for the period 1957-1972, and from International Accounts basis F.A.S. volume and value data for the period 1973-1979

Sources:
Same as for EMPV.

PUVFLD Average domestic price of crude oil at the wellhead in dollars per barrel. Quarterly data for the period 1947-1973 are annual data interpolated. Data for the period 1974-1979 are the quarterly sums of monthly figures.

Sources:

1947-1973 U.S. Department of Energy, Energy Information Administration (as reported by the American Petroleum Institute, <u>Basic Petroleum Data Book</u>).

1947-1979 U.S. Department of Energy, <u>Monthly Energy Review</u>.

PUVIFLD Index of average domestic price of crude oil at the wellhead, 1972 = 100.

Sources:
Same as for PUVFLD.

PUVNG Domestic wellhead price of natural gas, |/million Btu. Quarterly data for the period 1947-1973 are annual data interpolated. Data for the period 1974-1979 are the quarterly sums of monthly figures.

Sources:

1947-1973 American Petroleum Institute, Basic Petroleum Data Book, Section VI, Table 7. Price calculated by the API from natural gas production and value data from the U.S. Department of the Interior, Bureau of Mines.

1974-1979 U.S. Department of Energy, Monthly Energy Review.

PWIFC Producer price index for coal, 1972 = 100.

Source:
U.S. Department of Commerce, Bureau of Economic Analysis.

PWIFE Producer price index for energy, 1972 = 100. Includes coal, electric power, gas fuels, and refined petroleum products.

Source:
U.S. Department of Commerce, Bureau of Economic Analysis.

PWIFL Producer price index for refined petroleum products, 1972 = 100.

Source:
U.S. Department of Commerce, Bureau of Economic Analysis.

PWIFNG Index of average domestic wellhead price of natural gas, 1972 = 100.

Sources:
Same as for PUVNG.

SHRC Share of coal in total energy consumption.
(SHRC = DQCBTU/BQET).

SHRNG Share of natural gas in total energy consumption.
(SHRNG = DQNGBTU/BQET).

SHRP Share of petroleum in total energy consumption.
(SHRP = DQFLBTU/BQET).

SQFL Domestic petroleum production in millions of barrels per day. Includes production of crude petroleum, lease condensate, natural gas liquids, other hydrocarbons and hydrogen refinery input, and processing gain.

Sources:
Same as for DQFL.

UPUVFLD Differential between the domestic average wellhead price and the average imported price of oil (UPUVFLD = PUVFLD/PUVFL).

UPWIFC Differential between the producer price index for coal and the index for the F.O.B. mine price of coal (UPWIFC = PWIFC/PUVIC).

XGNP U.S. real GNP, in billions of 1972 dollars.

Source:
U.S. Department of Commerce, Bureau of Economic Analysis.