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# THE ADJUSTMENT OF U.S. OIL DEMAND TO THE PRICE INCREASES OF THE 1970'S: HAVE THE CONSERVATION GAINS BEEN OVERSTATED?

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# The Adjustment of U. S. Oil Demand to the Price Increases of the 1970's: Have the Conservation Gains Been Overstated?

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Since the 1979-80 oil price doubling, U.S. oil consumption has declined by about 20%, due to price-induced conservation. This has caused self-congratulatory euphoria, especially in the first few months of 1986, when both the oil price and OPEC have been collapsing.

However, we argue in this paper that the euphoria will be short-lived. U.S. oil consumption will resume its growth and, within five to ten years, will be higher than ever before (assuming oil prices at or below those of 1985). Figure 1 presents the historic path of U.S. oil consumption and price from 1950-85, and projections of consumption to the year 2000. In the "pessimistic" projection, consumption exceeds its previous peak by 1991; in the "optimistic" case, this is delayed until 1996[1].

Combining these results with the consensus projection of declining domestic production, the outlook for rapidly growing dependence on Persian Gulf oil is both clear and disturbing. <u>Plus la change, plus la meme chose.</u>

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1 The assumptions underlying these projections are discussed in Section IV.

**Figure 1**
**US Oil Consumption & Price, 1950-85**
**& Consumption Projections to 2000**
**(with 3% GNP growth & constant price)**

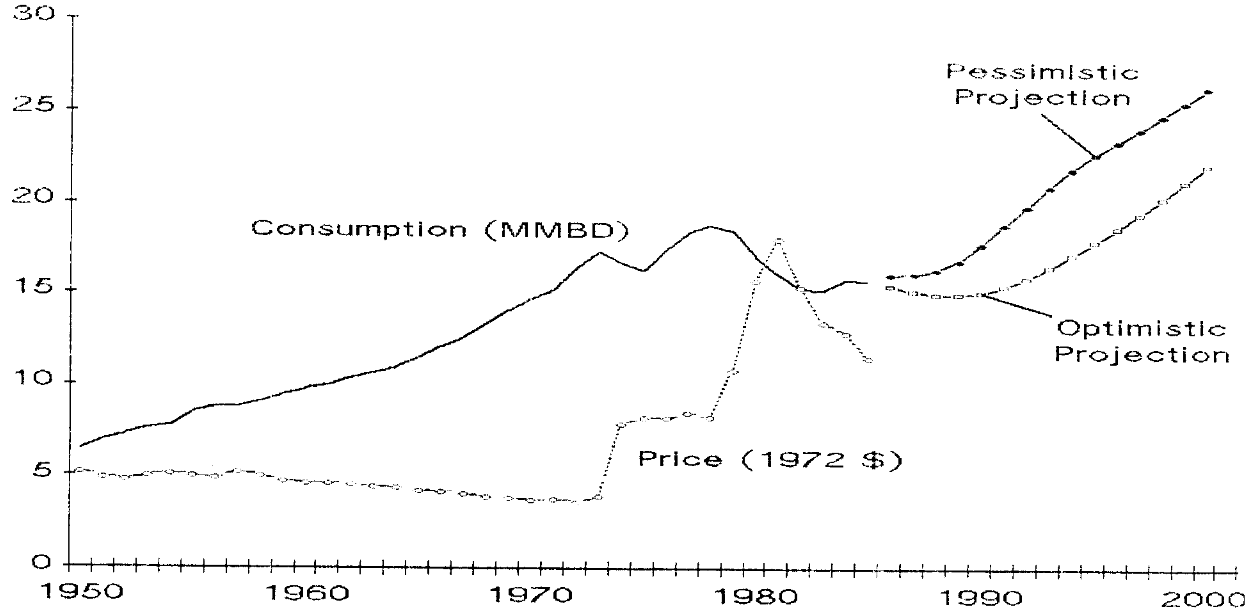
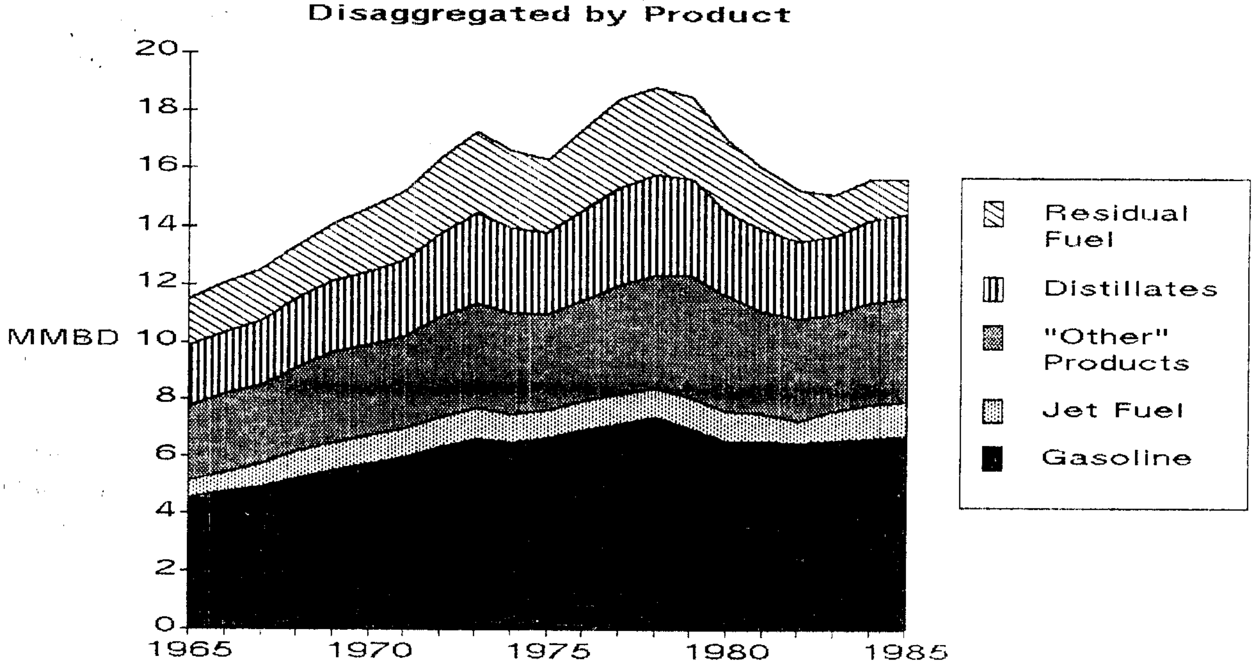



**Figure 2**
**US Oil Consumption**
**Disaggregated by Product**



Overview

This paper examines the econometric evidence about the adjustment of U.S. oil demand in response to the price increases of the 1970's, and the implications for oil demand through the year 2000. It is organized as follows. In Section I, we present the data and briefly survey the existing literature. In Section II, we describe various specifications of the demand equation, and the lagged adjustment to past price changes. In Section III, we present the main econometric results, using a variety of alternative specifications of the demand equation. We also examine the sensitivity of the results to changes in the assumptions about the length of the adjustment lag and in the data sample period. Section IV summarizes the implications for US oil demand to the year 2000 and Section V presents the conclusions.

## I Background

The basic data used in this analysis[2] is presented in Figure 1, depicting US oil consumption and price. Consumption of refined oil products, in million barrels per day (MMBD), grew steadily through the 1950's and 1960's. Only after major price increases and subsequent recessions of 1973-74 and 1979-80 was the growth slowed and then reversed. The real price of oil, measured by the Refiners' Acquisition Price in 1972 constant dollars, declined gradually during the 1950's and 1960's, before more than doubling in 1973-74 and again in 1979-81. Since then it has declined by more than 25%. The other explanatory variable, real GNP measured in 1972 dollars, grew steadily for this entire time, pausing only during recessionary periods.

Although in this paper we shall not address the demand for individual oil products, we present in Figure 2 the product-by-product disaggregation of oil consumption. This depicts the breakdown into the five main oil products: gasoline, jet fuel, distillates, residual fuel, and "other" oil

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2 Data sources:
Total Refined Petroleum Products is reported in the following publications of the US Department of Energy, Energy Information Administration:

- 1950-80 1980 Annual Report to Congress, p.63
- 1981-82 World Apparent Consumption of Refined Petroleum Products,
- 1984-85 ShortTerm Energy Outlook, Quarterly Projections, October 85

products. Since the peak demand year of 1978, the total has declined by nearly 20%. But most of this decline has been concentrated in residual fuel (used for electricity generation and for industrial processes); its 1985 level is 60% below its 1978 level. For distillates (used for space heating and hot water) and for "other" oil products, the 1985 levels are less than 10% below their 1978 levels. And the 1985 demand for transportation fuels (gasoline and jet fuel) is almost where it had been in 1978.

The literature on estimating energy demand elasticities has grown dramatically since the first oil price increase in 1973-74. An excellent survey can be found in Bohi(1981)[3]. Important works include those of Pindyck(1979), Hogan(1980) and Hogan(1986).

A controlled comparison of several different energy demand models was done by the Energy Modeling Forum in its study <u>Aggregate Elasticity of Energy Demand</u> (1980). From these and other results, a subsequent study by the Energy Modeling Forum, <u>World Oil</u> (1982), used a base-case assumption of -0.6 for the long-run price elasticity of crude oil demand (at the 1980 price level).

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3 This covers a variety of estimation problems and reviews the available estimates for all the major fuels. For gasoline, he cited a range of elasticity estimates from -.3 to -.8. For oil uses other than transportation, in which there are greater possibilities for substituting other fuels, he found a range of estimates that were considerably greater. See also Pindyck(1979).

To provide a sense of the current range of oil demand projections for the year 2000, consider the poll responses (from nearly a hundred modeling groups) summarized in the International Energy Workshop's July 1984 edition; see Manne and Schrattenholzer (1984). For US oil demand in the year 2000, the median projection was at a level about equal to 1980 consumption, but the range of projections from various poll respondants was from 30% below the median to about 25% above[4]. Some of these differences are attributable to disagreements about future world oil prices and GNP growth rates. But a substantial part of the disagreement stems from different estimates of the price-responsiveness of demand, as the adjustment to higher prices continues well into the 1990's.

Questions similar to ours had been addressed previously by Brown(1983) and Bopp(1984). Brown(1983) specifies a log-linear demand function; he allows lagged-price effects of up to six years[5], using data through 1979. Given the constraint that fewer years of data were available to him, his results on the lagged-price coefficients appear similar to ours:

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4 For world oil demand in the year 2000, the median projection was about 10% above 1980 levels, but the range of poll responses was even wider: from 60% below the median to about 50% above it.

5 The structure of the lagged-price coefficients is not defined clearly.

"In each equation, roughly 30% of the total long-run price impact is estimated to occur during the first year, and very little during the second, with the remainder coming three to six years after a change in the relative price of oil. ...We interpret the first-year impact on oil consumption as representing the 'easy' adjustments to oil price changes, particularly through changes in the rate of utilization of energy-using capital. The later significant impacts in years 3 to 6 would, in this interpretation, mostly reflect shifts to a more energy-efficient capital stock, requiring lags for planning and fabrication ... and for phaseout of the existing capital."[6]

The paper by Bopp(1984) specifies a log-linear demand equation with a Koyck lag[7]. It concentrates on the question of whether there was any "structural change" after either the 1973-74 or the 1979-80 price increase. He avoids alternative lagged-price specifications similar to ours, because they would have precluded his tests for structural change[8].

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6 Brown (1983, p. 29).

7 As noted below, we found such a specification to be unsatisfactory: the coefficient for lagged demand had the wrong sign and was insignificant. However, a <u>linear</u> demand function with a Koyck lag is one that we do examine in detail below.

8 The larger number of parameters used in some of our specifications, when combined with the number of parameters required for the tests of structural change, "so reduces the degrees of freedom as to greatly weaken the tests." Bopp (1984, p. 224).

## II Specification of the Demand Equation

There are two ways in which the demand specifications in this paper will differ. First is the form of the equation, whether it is linear or log-linear; and second is the specification of the structure of the lagged-price coefficients.

There are, of course, many forms for the equation by which we relate oil demand to income, price and other variables. In this paper we shall utilize either a linear function of income, price and lagged values of price:

$$\text{(1a)} \quad DEMAND_t = \alpha_0 + (\alpha_1 \; GNP_t) + \sum_{i=0}^{n} \beta_i \; (P_{t-i})$$

or a log-linear function (with constant elasticities) of these same variables:

$$\text{(1b)} \quad \log(DEMAND_t) = \alpha_0 + (\alpha_1 \; \log(GNP_t)) + \sum_{i=0}^{n} \beta_i \; \log(P_{t-i})$$

Similarly, there are a variety of ways in which the structure of the lagged-price coefficients can be specified. Below we shall discuss three cases. First will be the simplest case, in which no restrictions are placed on the form of the lagged values of the coefficients $\beta_i$. Second will be the case in which the lagged-price coefficients $\beta_i$ follow the form of a cubic polynomial distributed lag (PDL)[9]. Third will be a Koyck lag, in which the weights on past prices are assumed to decline geometrically. With a linear demand equation, this reduces to the form:

(1c) $DEMAND_t = \{(1-\lambda)(\alpha_0+(\alpha_1 GNP_t))\} + \beta_0 P_t + \lambda DEMAND_{t-1}$.

With regard to the identification problem of whether it is a demand equation that we are estimating, we believe that it is reasonable to assume (at least as a first approximation) that, within a given year, OPEC's price is set independently of the level of US oil demand. Certainly, during the period 1973-84, they have acted as the residual suppliers in the world oil market: they set the price for a given time period and produce what is demanded of them. Only during the periods of the major price increases, 1973-74 and 1979-80, has OPEC's price been changed several times within the year, at least partly in response to demand conditions.

9 That is, the coefficients follow the form of the cubic polynomial (with no end-point restrictions):

$$\beta_i = \delta_0 + (\delta_1 i) + (\delta_2 i^2) + (\delta_3 i^3)$$

In the Appendix, we describe the results of a second-order (quadratic) PDL. On the basis of the results from Section III.1 and Figure 4 below, these were determined to be not as satisfactory as those for the cubic PDL. Incidentally, a paper by Johnson and Lascar(1984) estimates the lagged effect of price upon the U.S. energy/GDP ratio, using a quadratic PDL. As will be clear from the discussion below, the structure of their lagged-price results is largely determined by the choice of a quadratic PDL and the lag-length assumed.

## III Econometric Results

In this section we discuss the econometric results for several alternative specifications: log-linear and linear demand with the lagged-price coefficients unconstrained (with a 10-year lag length), log-linear and linear demand with a cubic PDL structure for the lagged-price coefficients (with a 10-year lag length), and linear demand with a Koyck lag. We also examine the log-linear/cubic-PDL case under the assumption that the income-elasticity was equal to 1.0; this is a common estimate from cross-section and time series work in the literature.

The estimated coefficients appear in Tables 1 and 2[10]. The historical values for consumption for 1949-85 and the fitted values for several equations appear in Figure 3.

### III.1 Log-linear demand function: Unconstrained lagged-price coefficients, with 10-year lag length

For the unconstrained case, the estimated coefficients for income $\alpha_1$ and current period's price $\beta_0$ are statistically significant and have the correct sign. Also significant and with the correct sign is the coefficient for

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10 Note that we corrected for the problem of autocorrelation by using a second-order Cochrane-Orcutt autoregressive correction.

The Box-Pierce Q-statistic tests the hypothesis that the autocorrelations were "white noise". In all cases in the tables, we calculated the Q-statistic using 4 autocorrelations. See Box and Pierce (1970).

Figure 3
Actual US Oil Consumption, 1950-1985
and fitted demand functions

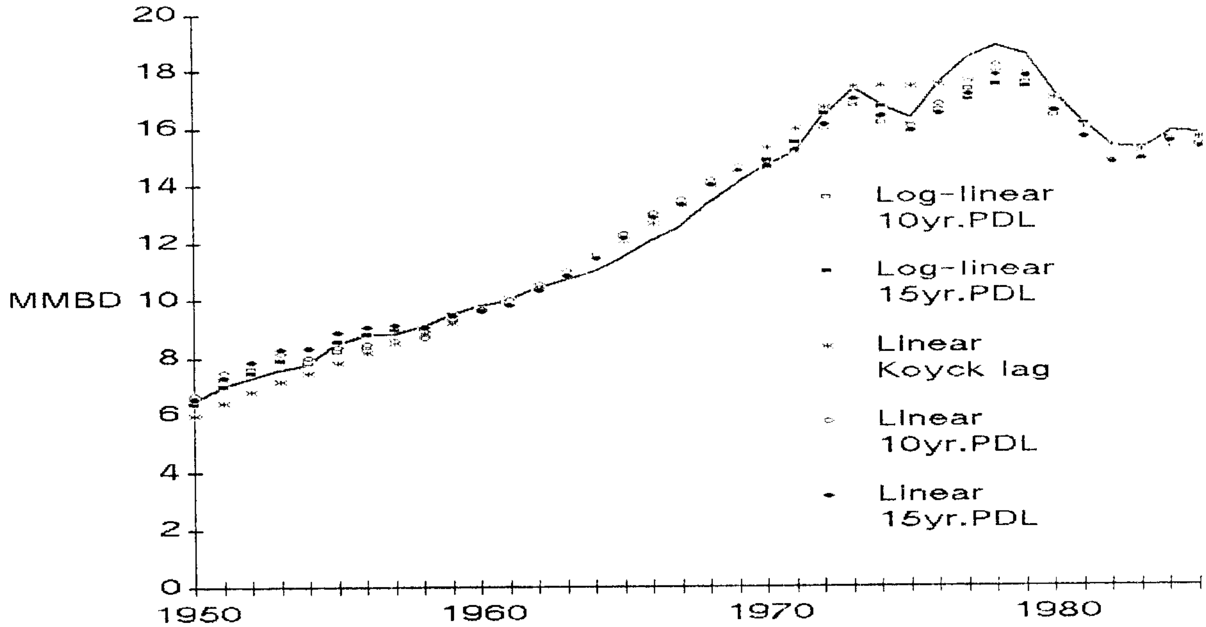
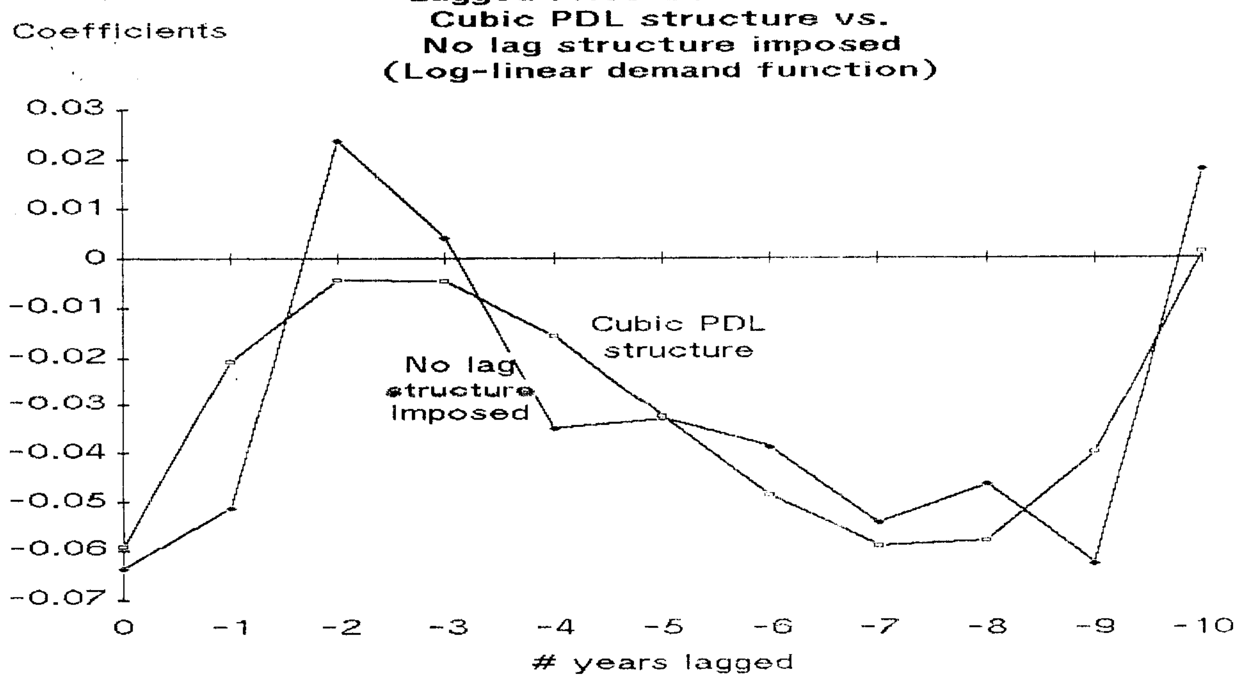



Figure 4
Lagged Price Coefficients:
Cubic PDL structure vs.
No lag structure imposed
(Log-linear demand function)



price lagged 9 years, $\beta_9$. For the other lagged-price coefficients, the signs are correct (and in some cases have t-statistics close to significance) for all except lagged-years 2, 3, and 10, which are positive but insignificant[11].

### III.2 Log-linear demand function: Cubic PDL lagged-price coefficients, with 10-year lag length

For the cubic PDL case, the results in Table 1 are similar to those of the unconstrained case. The variables GNP and current price $P_0$ have statistically significant coefficients with the correct sign. Several of the lagged-price coefficients are also significant and with the correct sign; only $\beta_{10}$ has a positive sign, but it is not statistically significant.

The values of the lagged-price coefficients in these two cases in Table 1 are compared in Figure 4. For individual years, the lagged-price coefficients differ slightly, but the overall structure can be seen to be similar in shape. It should be noted, however, that the apparent termination of lagged-price effects after 10 years may be misleading. In the

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11 In some cases, the autoregressive coefficients suggest the presence of a unit root in the lag polynomial for the error term, which would imply a non-stationary error term, with an unbounded variance, and would preclude hypothesis tests. We, therefore, also ran the regressions in first differences. These results, fortunately, provided essentially similar estimates of the coefficients and similar interpretations of our hypotheses.

cubic PDL case, this is caused by the lag-length assumption, as will be evident from work discussed in Section III.7. In the unconstrained case, the coefficient for $P_{t-10}$ is not statistically significant, the reasons for which are addressed in Section III.8.

Intuitively, this shape of a distributed lag on past prices can be interpreted in the following way. The weights on past prices decline for the first few years, after the initial short-run price response tapers off. But the weights increase for prices lagged 5 to 8 years, when the long-run, capital-stock adjustment has its effect.

## III.3 Log-linear demand function: Cubic PDL lagged-price coefficients, with 10-year lag length, and income-elasticity assumed equal to 1

In the previous equation, the income elasticity of demand was estimated to be 0.78. This estimate is somewhat smaller than other estimates in the literature[12]; the Energy Modeling Forum World Oil study, for example, used a more common value of 1.0. In a third equation, also listed in Table 1, we assumed an income elasticity of 1.0 and estimated the rest of the equation as in Section III.2.

The resulting equation had similar results, with the

12 See the references discussed in Bohi(1981) and Pindyck(1979).

constant term being more negative and the price elasticity being somewhat higher. The shape of the distribution of lagged-price coefficients was basically unchanged.

### III.4 Linear demand function: Unconstrained lagged-price coefficients, with 10-year lag length

These results are similar to the log-linear results when the lagged-price coefficients are unconstrained. In addition to having the same coefficients being significant and with the correct sign (for $GNP_t$, $P_{t-0}$, and $P_{t-9}$), also significant in the linear case are the coefficients for $P_{t-1}$ and $P_{t-8}$. But the Standard Error of the regression is about 5% higher than for log-linear case.

### III.5 Linear demand function: Cubic PDL lagged-price coefficients, with 10-year lag length

Again, the results are similar to those of the log-linear case, with somewhat higher t-statistics and one more lagged-price coefficient now being significant (for $P_{t-1}$). But the Standard Error of the regression is also higher, by about 15% than for the log-linear case.

Table 1

Results for 10-year lag length:
Log-linear demand functions

| | Variable | Log-linear, with Unconstrained Coefficients | | Log-linear, with Cubic Polynomial Distributed Lag | | Log-linear, with Cubic Polynomial Distributed Lag & income elas. = 1.0 | |
|---|---|---|---|---|---|---|---|
| | | Coeff. | t-stat. | Coeff. | t-stat. | Coeff. | t-stat. |
| $\alpha_0$ | C | -1.582 | -1.37 | -2.198 | -2.47 | -3.766 | 34.96 |
| $\alpha_1$ | log $GNP_t$ | 0.691 | 4.74 | 0.774 | 6.59 | 1.0 (by assumption) | |
| $\beta_0$ | log $P_t$ | -0.064 | -2.38 | -0.059 | -2.76 | -0.049 | -2.32 |
| $\beta_1$ | log $P_{t-1}$ | -0.051 | -1.89 | -0.020 | -1.55 | -0.024 | -2.00 |
| $\beta_2$ | log $P_{t-2}$ | 0.024 | 0.97 | -0.004 | -0.31 | -0.015 | -1.19 |
| $\beta_3$ | log $P_{t-3}$ | 0.004 | 0.17 | -0.005 | -0.33 | -0.018 | -1.38 |
| $\beta_4$ | log $P_{t-4}$ | -0.035 | -1.43 | -0.016 | -1.32 | -0.027 | -2.42 |
| $\beta_5$ | log $P_{t-5}$ | -0.033 | -1.35 | -0.032 | -2.95 | -0.039 | -3.69 |
| $\beta_6$ | log $P_{t-6}$ | -0.039 | -1.53 | -0.049 | -3.88 | -0.051 | -3.91 |
| $\beta_7$ | log $P_{t-7}$ | -0.054 | -1.91 | -0.059 | -3.98 | -0.057 | -3.64 |
| $\beta_8$ | log $P_{t-8}$ | -0.046 | -1.53 | -0.058 | -3.71 | -0.054 | -3.24 |
| $\beta_9$ | log $P_{t-9}$ | -0.062 | -2.21 | -0.040 | -2.52 | -0.037 | -2.16 |
| $\beta_{10}$ | log $P_{t-10}$ | 0.018 | 0.65 | 0.001 | 0.05 | -0.003 | -0.13 |
| $\Sigma \beta_i$ | | -0.338 | | -0.341 | | -0.374 | |
| | AR(1) | 1.325 | 6.40 | 1.207 | 6.62 | 1.146 | 6.58 |
| | AR(2) | -0.373 | -1.94 | -0.276 | -1.64 | -0.285 | -1.79 |
| Price elasticity | | -0.338 | | -0.341 | | -0.374 | |
| Income elasticity | | 0.691 | | 0.774 | | 1.0 | |
| Adjusted $R^2$ | | 0.998 | | 0.998 | | 0.965 | |
| Standard Error of regression | | 0.018 | | 0.018 | | 0.019 | |
| Box-Pierce stat.[13] | | 4.46 | | 2.73 | | 4.04 | |

Data Period 1949 - 1985: 37 Observations

[13] In all cases reported, the Q-statistic for the residuals from the regression was not significant at the 5% level, indicating non-rejection of the hypothesis that the underlying errors were "white noise".

## III.6 Linear demand function: Koyck lagged-price coefficients

In this case, all coefficients are significant and have the expected sign. But the Standard Error of the regression is about two-thirds higher than for the other linear demand equations.

The long-run price response of this equation is given by $\beta/(1-\lambda)$; here, these values from Table 2 make that ratio equal to -0.183. The mean lag, within which half of the total long-run price adjustment has been completed, is given by the ratio $\lambda/(1-\lambda)$. Here, the value would be about 11 years.

We also tried a log-linear demand equation with a Koyck lag, but the coefficient for $DEMAND_{t-1}$ had the wrong sign and was insignificant.

Table 2

Results for 10-year lag length:
Linear demand functions

| | Variable | Linear, with Unconstrained Coefficients Coeff. | t-stat. | Linear, with Cubic Polynomial Distributed Lag Coeff. | t-stat. | Linear, with Koyck Lag Coeff. | t-stat. |
|---|---|---|---|---|---|---|---|
| $\lambda\alpha_0$ | C | 10.71 | 1.30 | 8.072 | 2.50 | 0.690 | 4.70 |
| $\lambda\alpha_1$ | $GNP_t$ | 0.009 | 5.32 | 0.011 | 7.87 | 0.0016 | 2.64 |
| $\beta_0$ | $P_t$ | -0.181 | -4.22 | -0.141 | -4.96 | -0.015 | -7.08 |
| $\beta_1$ | $P_{t-1}$ | -0.132 | -2.59 | -0.049 | -2.17 | | |
| $\beta_2$ | $P_{t-2}$ | 0.051 | 1.06 | -0.011 | -0.41 | | |
| $\beta_3$ | $P_{t-3}$ | -0.020 | -0.40 | -0.012 | -0.46 | | |
| $\beta_4$ | $P_{t-4}$ | -0.107 | -1.91 | -0.040 | -1.77 | | |
| $\beta_5$ | $P_{t-5}$ | -0.088 | -1.72 | -0.082 | -3.83 | | |
| $\beta_6$ | $P_{t-6}$ | -0.031 | -0.57 | -0.125 | -5.01 | | |
| $\beta_7$ | $P_{t-7}$ | -0.089 | -1.18 | -0.157 | -5.20 | | |
| $\beta_8$ | $P_{t-8}$ | -0.169 | -2.01 | -0.165 | -4.79 | | |
| $\beta_9$ | $P_{t-9}$ | -0.244 | -3.03 | -0.135 | -3.31 | | |
| $\beta_{10}$ | $P_{t-10}$ | 0.075 | 1.05 | -0.056 | -0.93 | | |
| $\Sigma\ \beta_i$ | | -0.935 | | -0.973 | | -1.83[14] | |
| $\lambda$ | $DEMAND_{t-1}$ | | | | | 0.918 | 21.59 |
| | AR(1) | 1.550 | 8.12 | 1.281 | 7.19 | 0.272 | 1.59 |
| | AR(2) | -0.570 | -3.04 | -0.330 | -1.89 | -0.476 | -2.67 |
| Price elasticity | | | | | | | |
| @ 1985 price | | -0.723 | | -0.739 | | -1.064 | |
| @ half of '85 price | | -0.266 | | -0.270 | | -0.347 | |
| Income elasticity | | | | | | | |
| @ 1985 income level | | 0.739 | | 0.882 | | 1.071 | |
| Adjusted $R^2$ | | 0.998 | | 0.997 | | 0.993 | |
| Standard Error of regression | | 0.019 | | 0.215 | | 0.320 | |
| Box-Pierce statistic | | 4.19 | | 0.81 | | 1.08 | |

Data Period 1949 - 1985: 37 Observations

14 This is the long-run price response, $\beta/(1-\lambda)$.

## III.7 The Effect of Different Lag Lengths on the Lagged-Price Coefficients

Given the uncertainty about the true length of the period of lagged adjustment, we re-estimated the demand equation, assuming alternative lag lengths of 8, 12, and 15 years respectively. We did this for both the log-linear and linear demand functions, assuming that the lagged-price coefficients were either unconstrained or followed a cubic PDL structure. (With a Koyck lag, the length of the adjustment period is estimated by the equation, rather than assumed.)

With the lagged-price coefficients unconstrained, the results were the same for both the log-linear and the linear equations. The log-linear results are displayed in Figure 5. Changing the period of adjustment does not have much effect on the lagged-price coefficients for the first 8 years. However, when the lag is lengthened, the coefficients for prices lagged 10 or more years fluctuate fairly dramatically. But none of the coefficients beyond year 9 is statistically significant.

In view of the price data, however, this should not be surprising. As can be seen in Figure 1, oil price remained relatively constant for most of the period under consideration, only increasing significantly in 1974 and beyond. Since our last year of data is 1985, price lagged 12 years (and beyond) contains no years of high prices; and price lagged 10 years contains only two years of high prices, 1974 and 1975. Thus, it is impossible to obtain reliable estimates of the

Figure 5
Effect upon lagged price coefficients
of different lag lengths:
Cubic PDL lag structure imposed
(Log-linear demand function)

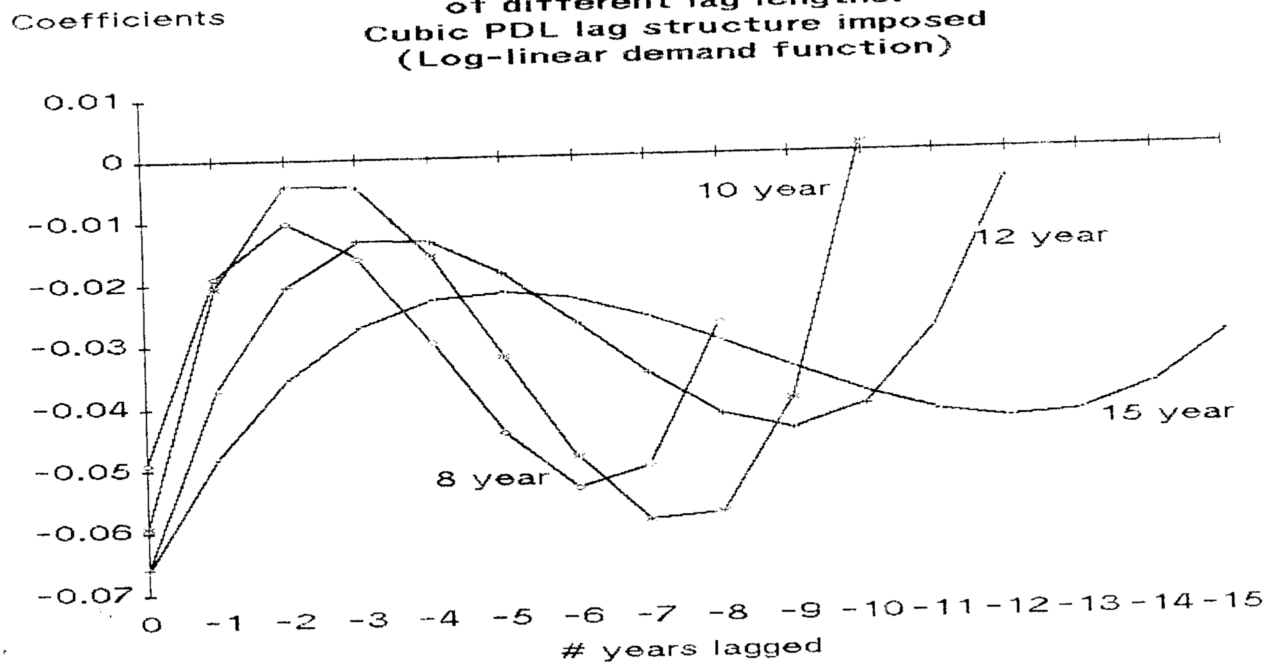
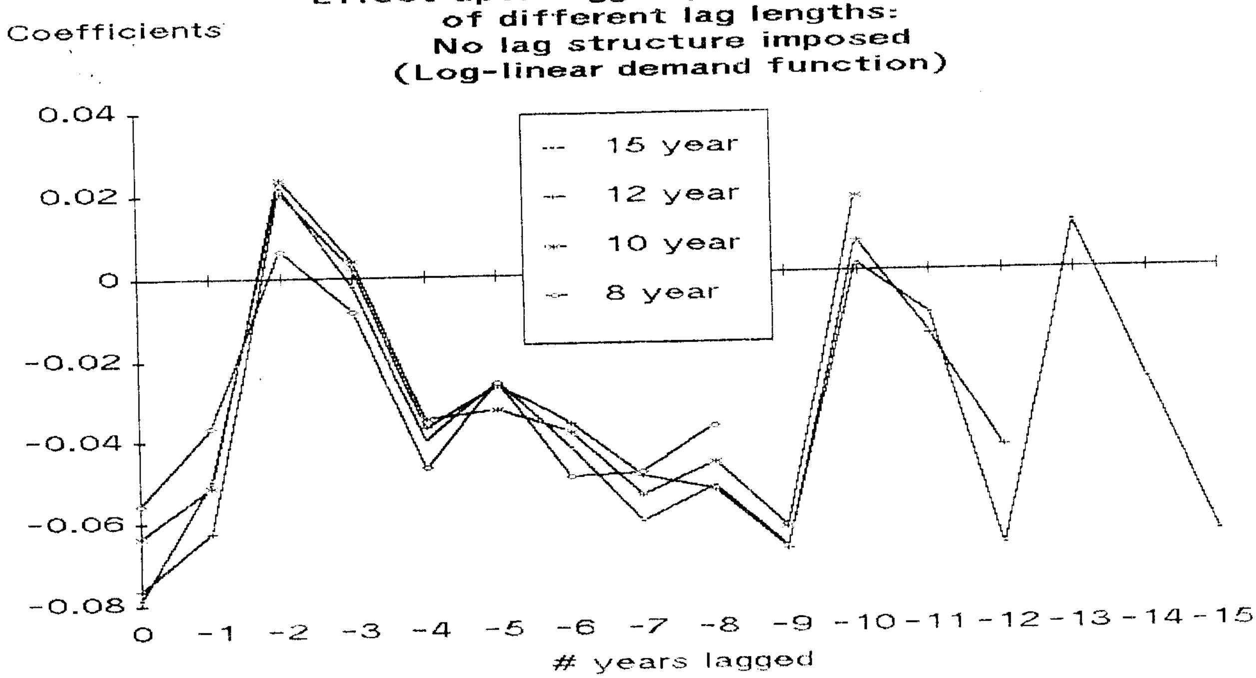



Figure 6
Effect upon lagged price coefficients
of different lag lengths:
No lag structure imposed
(Log-linear demand function)



coefficients for years lagged 11 or more. And even the estimate for price lagged 10 years is not very reliable, because it is based on only two high-priced data points.

If we assume a cubic PDL structure for the lagged-price coefficients, then we see in Figure 6 (for a log-linear demand function[15]) that changing the lag length has no effect on the basic shape of the lag structure. However, reducing the lag length causes the coefficients to be "squeezed together" horizontally, so that the values of all the coefficients are changed, even for the early years. This illustrates the crucial importance of the assumed lag length when a PDL structure is imposed.

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15 The results for a linear demand function were qualitatively the same.

## III.8 The Effect of Different Data-Sample Periods on the Lagged-Price Coefficients

In order to determine the sensitivity of the lagged-price coefficients to changing the data-sample period, we re-estimated the equation using different data-sample periods[16]. First we dropped data year 1985, then successively dropped additional years back through 1981 as well.

We did this for the five equations presented above. Again, for given assumptions about the structure of the lagged-price coefficients, there were no qualitative differences between the log-linear and the linear cases. Hence, we shall discuss only the results related to different assumptions about the lag structure.

Assuming unconstrained lagged-price coefficients with a 10-year lag length, the effects of changing the data-sample period are graphed in Figure 7 (for log-linear demand). Dropping data year 1985 has little effect: there is little difference between using 1949-85 and 1949-84. Similarly for data year 1984. But when 1983 is also dropped, using the period 1949-82, the lagged-price coefficients for years lagged 8, 9 and 10 are affected dramatically. Similarly for using the even shorter period 1949-81.

There is a similarity between this "flapping tail" of the distribution of Figure 7 to that of Figure 5, and they have

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16 In all instances, our first year of data was 1949.

Figure 7
Effect upon lagged price coefficients
of different data-sample periods:
Cubic PDL lag structure imposed
(Log-linear demand function)

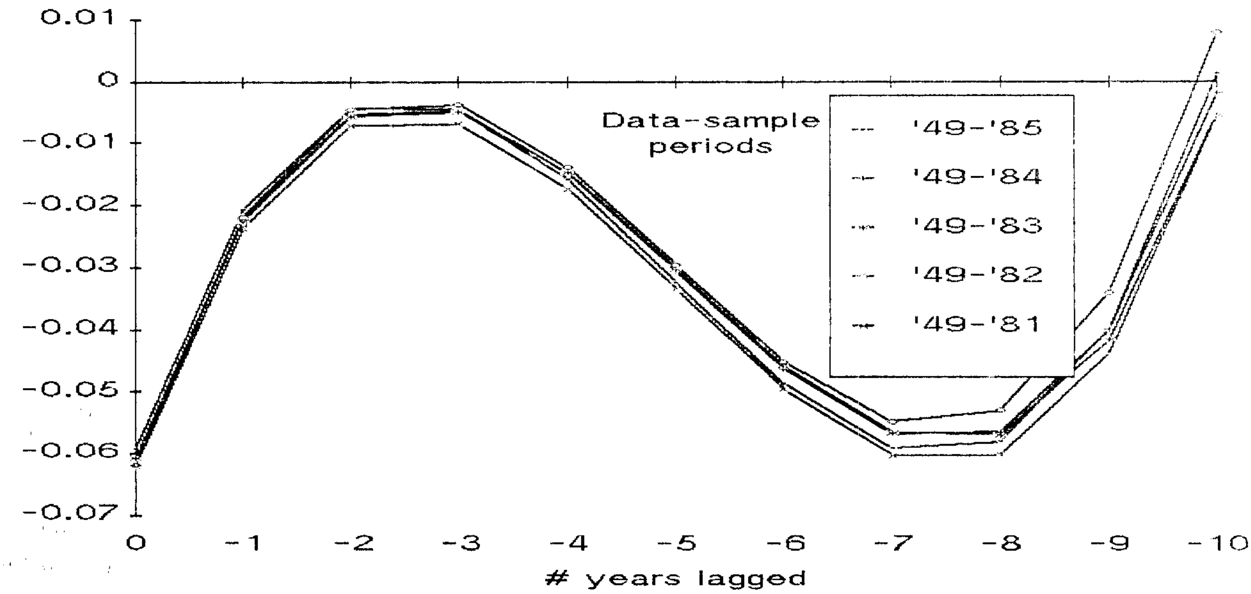
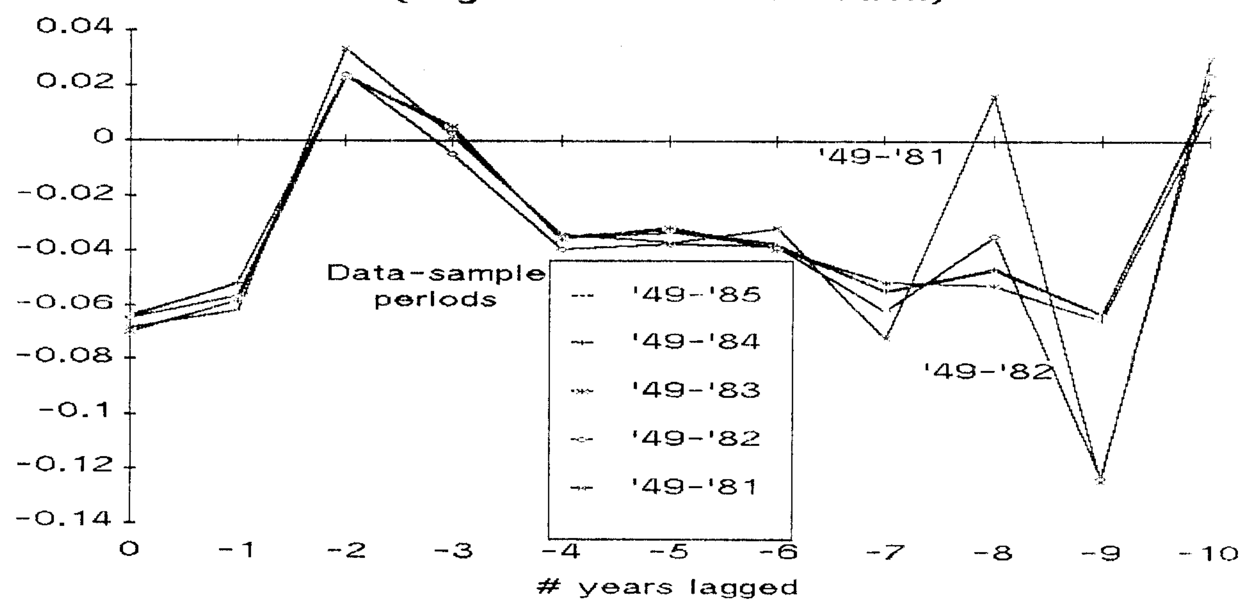



Figure 8
Effect upon lagged price coefficients
of different data-sample periods:
No lag structure imposed
(Log-linear demand function)



the same cause. Using a data sample of 1949-1981, we have no high-priced data points for price lagged 8 or more years. For 1949-82, we have only a single high-priced data point for price lagged 8 years.

In contrast, using a cubic PDL structure for the lagged-price coefficients, we see in Figure 8 (for log-linear demand) that changing the data-sample period has virtually no effect upon any of the coefficients. Again, this illustrates the strong effect upon the coefficients imposed by the PDL specification.

We also examined the effect of changing the data-sample period on the Koyck-lag results (for the linear demand equation). Here the effect was dramatic, as can be seen in Table 3. As we successively drop the most recent year in the data sample (going from right to left in Table 3), we get the following results. (We emphasize the first three columns, with data including at least 1983, because several of the coefficients were insignificant prior to that.) There is a fall in the coefficient for $DEMAND_{t-1}$, while the coefficient for current $P_t$ gets larger in absolute value. The long-run price response falls sharply, matched by an equally sharp decrease in the mean adjustment lag. In fact, the nature of the equation changes so significantly as to call into question the stability of the coefficients and the correctness of the specification.

Table 3

The Effect of Different Data-Sample Periods on Coefficients of the Koyck-lag Linear Equation

| | | --- Last data year used in estimation --- | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1985 | 1984 | 1983 | 1982 | 1981 | 1980 |
| $\lambda\alpha_0$ | C | 0.69 | 0.64 | 0.64 | 1.59* | 0.61* | 0.51* |
| $\lambda\alpha_1$ | $GNP_t$ | 0.0016 | 0.0033 | 0.0047 | 0.0105 | 0.0094 | 0.0115 |
| $\beta_0$ | $P_t$ | -0.15 | -0.18 | -0.21 | -0.15 | -0.24 | -0.21 |
| $\lambda$ | $DEMAND_{t-1}$ | 0.92 | 0.80 | 0.70 | 0.11* | 0.35 | 0.17* |
| Long-run price response: | $\beta/(1-\lambda)$ | -1.84 | -0.90 | -0.68 | -0.17 | -0.37 | -0.025 |
| Mean adjustment lag (in years): | $\lambda/(1-\lambda)$ | 11.3 | 3.9 | 2.3 | 0.1 | 0.5 | 0.2 |

* denotes insignificant coefficient

## IV Implications for U. S. Oil Consumption to year 2000

The econometric conclusions of this paper are as follows. The length of lagged adjustment is at least 10 years and the adjustment process is still going on, because major price increases occurred as recently as 1979-80. The ultimate length of the lag remains uncertain. With regard to the distribution of lagged-price coefficients, it is fairly well characterized by a cubic polynominal-distributed-lag. The weights on past prices decline when the initial, short-run price-response tapers off after 2-3 years, but then the weights increase for prices lagged 4 to 9 years. For prices lagged 10 or more years, the weights are still uncertain.

What do these results imply for US oil demand out to the year 2000? This depends, of course, on our assumptions about GNP growth, the level of real oil prices, the amount of remaining adjustment to past oil price changes, and the form of the demand equation.

In Figures 9, 10 and 11, we present the results of some alternative assumptions about the level of real oil prices for 1986-2000 and the amount of GNP growth annually, for each of three demand specifications: linear demand with a Koyck lag, and both linear and log-linear demand with a cubic PDL and 10-year lag length. In Figure 12 we present results for two additional specifications, under the assumption of 3% GNP growth and constant real oil prices (after a 20% cut in 1986); these are the basis of the "optimistic" and "pessimistic"

Figure 9
Projected US Oil Consumption:
Constant Real Price, 1985-2000
and Zero GNP Growth, 1986-2000

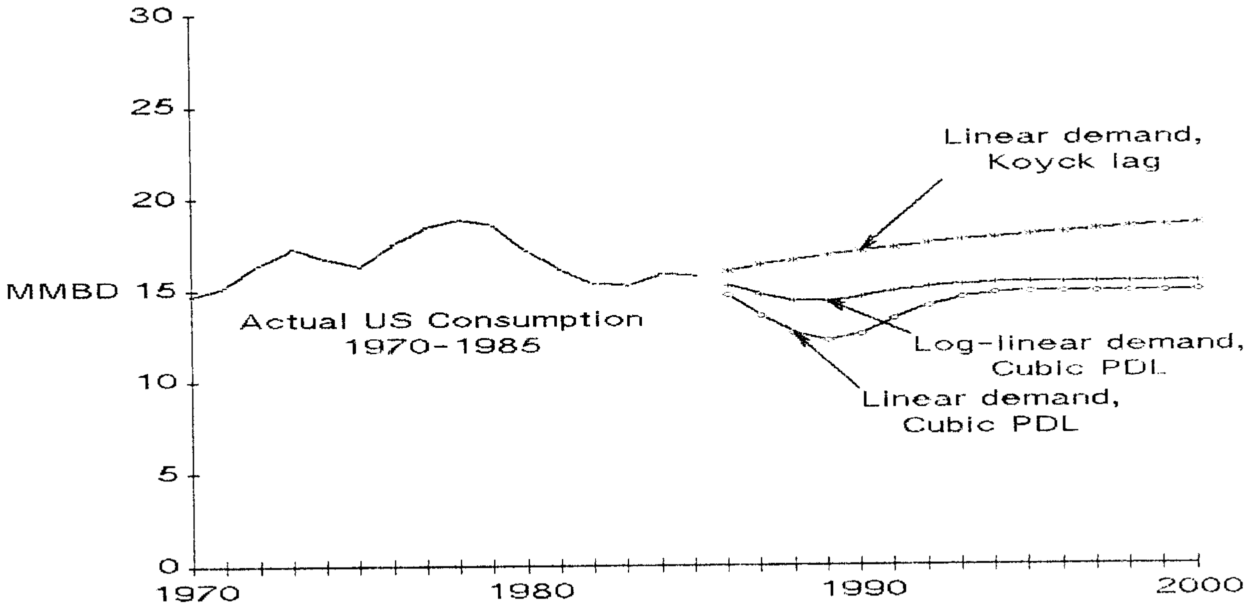
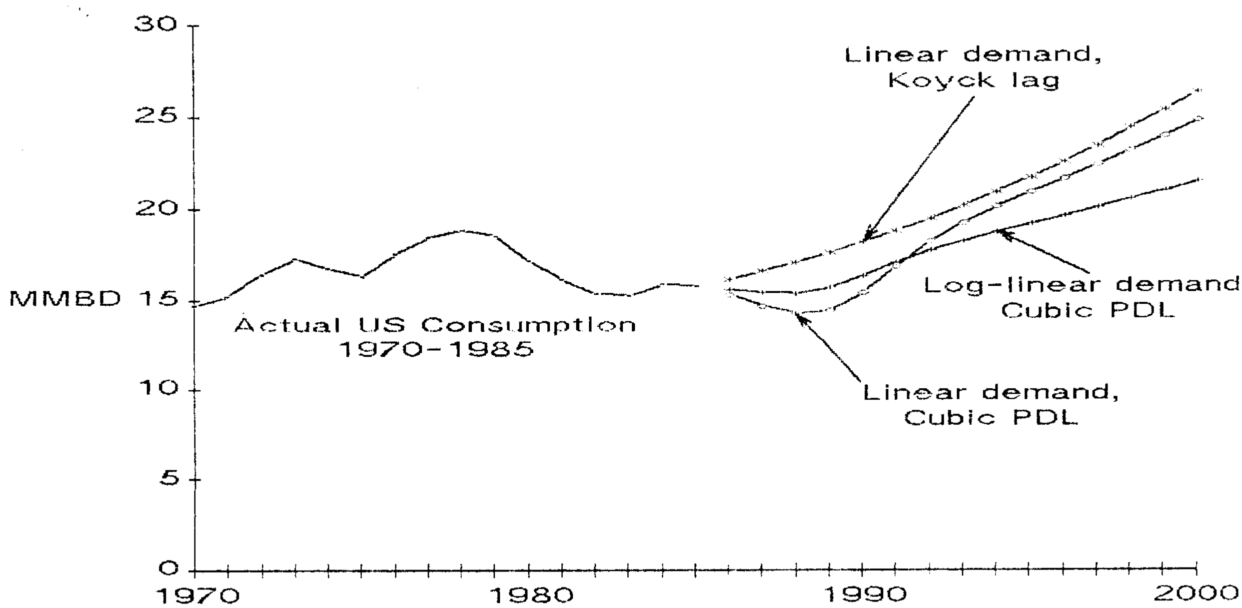



Figure 10
Projected US Oil Consumption:
Constant Real Price, 1985-2000
and 3% GNP Growth, 1986-2000



projections in Figure 1.

Figure 9 makes projections for each of these three demand specifications, under the following assumptions: that real oil prices remain constant through year 2000 at their 1985 level (that is, assuming no price decline in 1986), and that there is zero GNP growth between 1986 and 2000. This latter assumption is not intended as a realistic possibility, of course, but as an illustration of the pure effect of lagged prices, gradually working their way through the demand equation over time. The results are as follows. With the case of linear demand and cubic PDL, demand continues to decline until 1989 (reflecting the adjustment to the 1979-80 price increase); it then increases between 1989 and 1994 (reflecting the response to the price declines of 1981-85), after which time it remains constant. For the log-linear case, the results are qualitatively the same as the preceding, but the quantitative effects of decline and partial recovery are not as pronounced. For the Koyck lag case, however, demand does not decline at all: it increases from 1986 onward though at a diminishing rate. This somewhat surprising result occurs because the largest lagged-price coefficients are the most recent, and weight more heavily the effects of the 1981-85 price declines.

Figure 10 presents a somewhat more realistic case, in which GNP growth is 3% annually from 1986 to 2000. It makes the same assumption about constant real prices from 1985 through 2000 (no price cut in 1986). The results are qualitatively the same as in Figure 9, with GNP growth causing demand to be proportionately higher. The only important qualitative difference from Figure 9 is that the linear/cubic-PDL case has higher demand in the 1990's than the log-linear/cubic-PDL case, because it has a higher income elasticity (.97 versus .77). For all three demand equations, consumption exceeds, by the early 1990's, its previous maximum level of 1978. And projected consumption continues to increase with GNP growth throughout the 1990's, because there is no further lagged-price adjustment.

Having shown the equations' sensitivity to differences in GNP growth, we illustrate in Figure 11 the effect upon demand of a 20% real price cut in 1986, followed by constant real price through year 2000. We continue to assume 3% GNP growth annually. Again, the results for the three specifications are qualitatively the same as in Figure 10. But with lower prices, consumption by the year 2000 is projected to be about 10% higher for each demand specification.

In Figure 12 (the basis for projections in Figure 1), we make the same assumptions as in Figure 11: 3% GNP growth and a 20% real price cut in 1986, followed by constant real price to the year 2000. We use two alternative specifications. One is as "optimistic" as we can make it. Using a log-linear demand function, with an estimated income elasticity of .77, we assume a lag-length of 20 years: the lagged coefficients for the first eight years are those from the cubic PDL in Section

**Figure 11**
**Projected US Oil Consumption:**
**20% Price Cut in '86, then Constant**
**and 3% GNP Growth, 1986-2000**

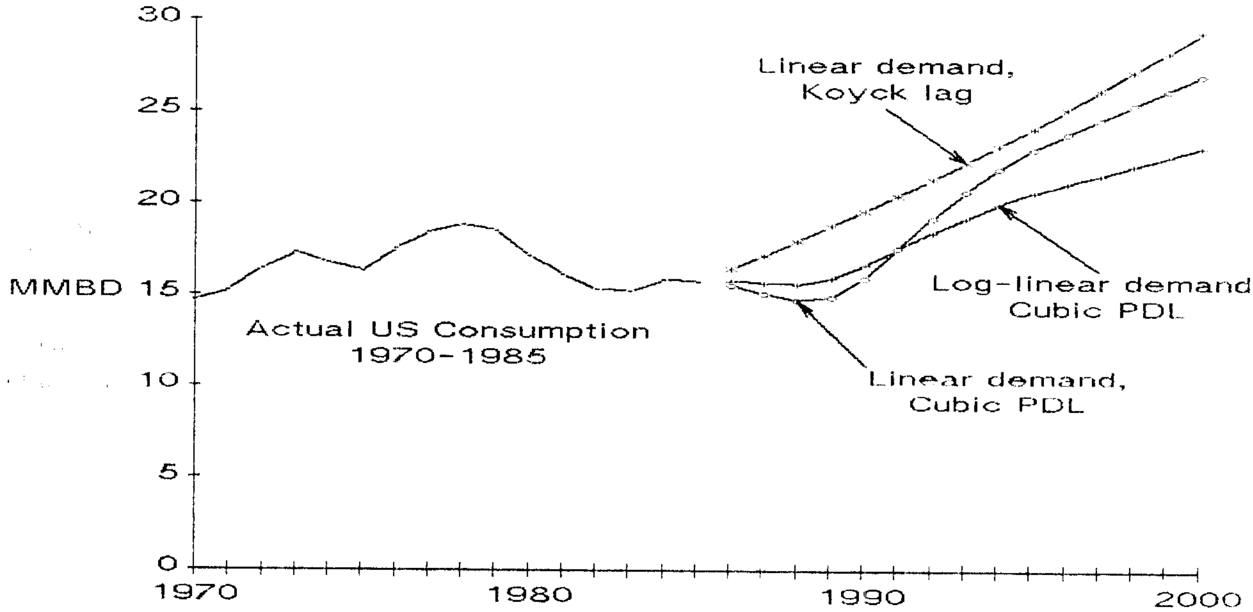
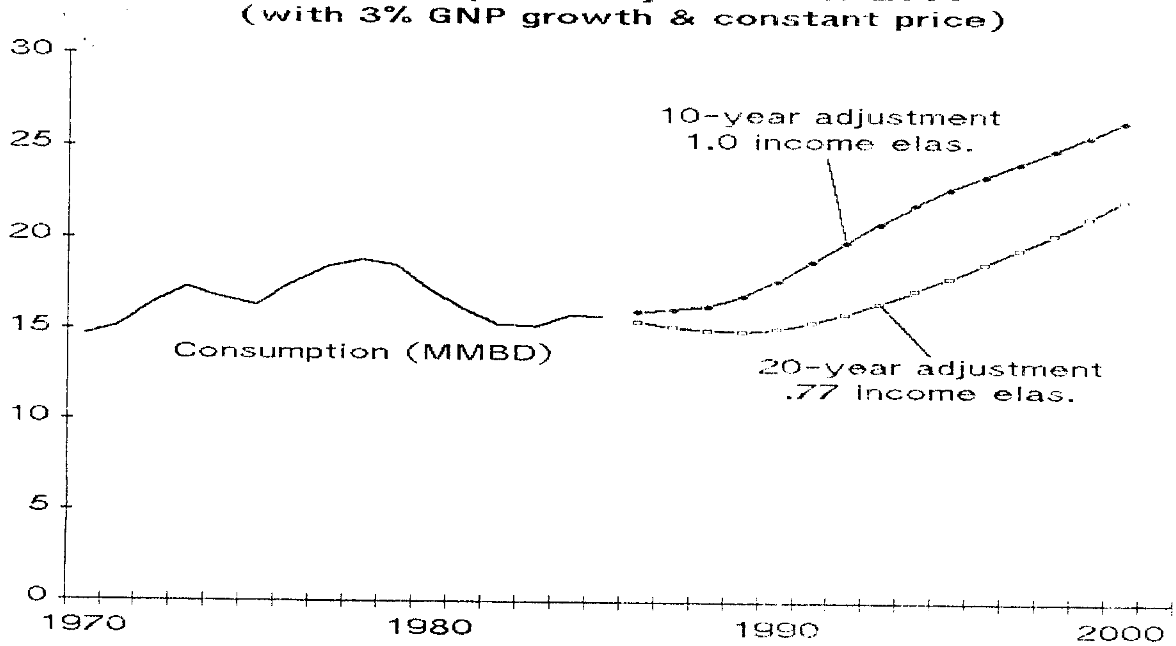



**Figure 12**
**US Oil Consumption, 1950-85**
**& Consumption Projections to 2000**
**(with 3% GNP growth & constant price)**



III.2, and for years lagged nine or more, they decline linearly, to zero by year twenty. In the "pessimistic" case, we assume the specification in Section III.3: log-linear/cubic PDL with a 10-year lag-length and unitary income elasticity. In the latter case, by 1991 consumption reaches its 1978 peak level, and continues to increase throught the 1990's. In the "optimistic" case, the result is qualitatively the same, but the timing is extended: it takes until 1996 for consumption to reach its 1978 level.

## V Conclusions

It seems clear that oil consumption will soon resume its growth and be at historically high levels by the mid-1990's. There is, of course, some uncertainty about what is the most appropriate functional specification and parameter values for the demand function. Nonetheless, different assumptions within the range of uncertainty all yield the same qualitative result: oil demand increasing significantly during the 1990's, reaching levels well above the previous peak of 1978.

Given that virtually all observers agree that U.S. domestic oil production will be declining for the next 15 years, this implies that we will again become dependent upon imported oil, which will come increasingly from the Persian Gulf. This would bring us full-circle from a decade ago, and as vulnerable as we were in 1979-80 to oil supply interruptions, either intended or accidental.

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APPENDIX

Table A1

Results for 10-year lag length:
Log-linear demand function, Quadratic PDL

| | Variable | Log-linear Quadratic PDL Coeff. | t-stat. |
|---|---|---|---|
| $\alpha_0$ | C | -3.310 | -5.02 |
| $\alpha_1$ | log GNP | 0.925 | 9.79 |
| $\beta_0$ | log $P_t$ | -0.032 | -1.52 |
| $\beta_1$ | log $P_{t-1}$ | -0.033 | -2.60 |
| $\beta_2$ | log $P_{t-2}$ | -0.034 | -3.79 |
| $\beta_3$ | log $P_{t-3}$ | -0.034 | -3.58 |
| $\beta_4$ | log $P_{t-4}$ | -0.034 | -3.04 |
| $\beta_5$ | log $P_{t-5}$ | -0.033 | -2.80 |
| $\beta_6$ | log $P_{t-6}$ | -0.031 | -2.83 |
| $\beta_7$ | log $P_{t-7}$ | -0.029 | -2.90 |
| $\beta_8$ | log $P_{t-8}$ | -0.026 | -2.36 |
| $\beta_9$ | log $P_{t-9}$ | -0.023 | -1.37 |
| $\beta_{10}$ | log $P_{t-10}$ | -0.019 | -0.72 |
| | AR(1) | 1.172 | 6.43 |
| | AR(2) | -0.293 | -1.79 |

| | |
|---|---|
| Adjusted R-squared | .997 |
| Standard Error of regression | 0.020 |
| Box-Pierce statistic | 2.75 |

Data Period 1949 - 1985: 37 Observations