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THE ADJUSTMENT OF U.S. OIL DEMAND TO THE PRICE INCREASES OF THE 1970'S

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I Introduction

Since the 1979–80 oil price doubling, U.S. oil consumption has declined by about 20%, in part because of price–induced conservation. This has caused self–congratulatory euphoria, especially in the first few months of 1986, when both the oil price and OPEC were collapsing. However, we argue in this paper that the euphoria could well be short–lived. U.S. oil consumption will resume its growth and, within five to ten years, could be higher than ever before. Combining these results with the consensus projection of declining domestic production, the outlook for rapidly growing dependence on imported oil is disturbing. *Plus ça change, plus c'est la même chose.*

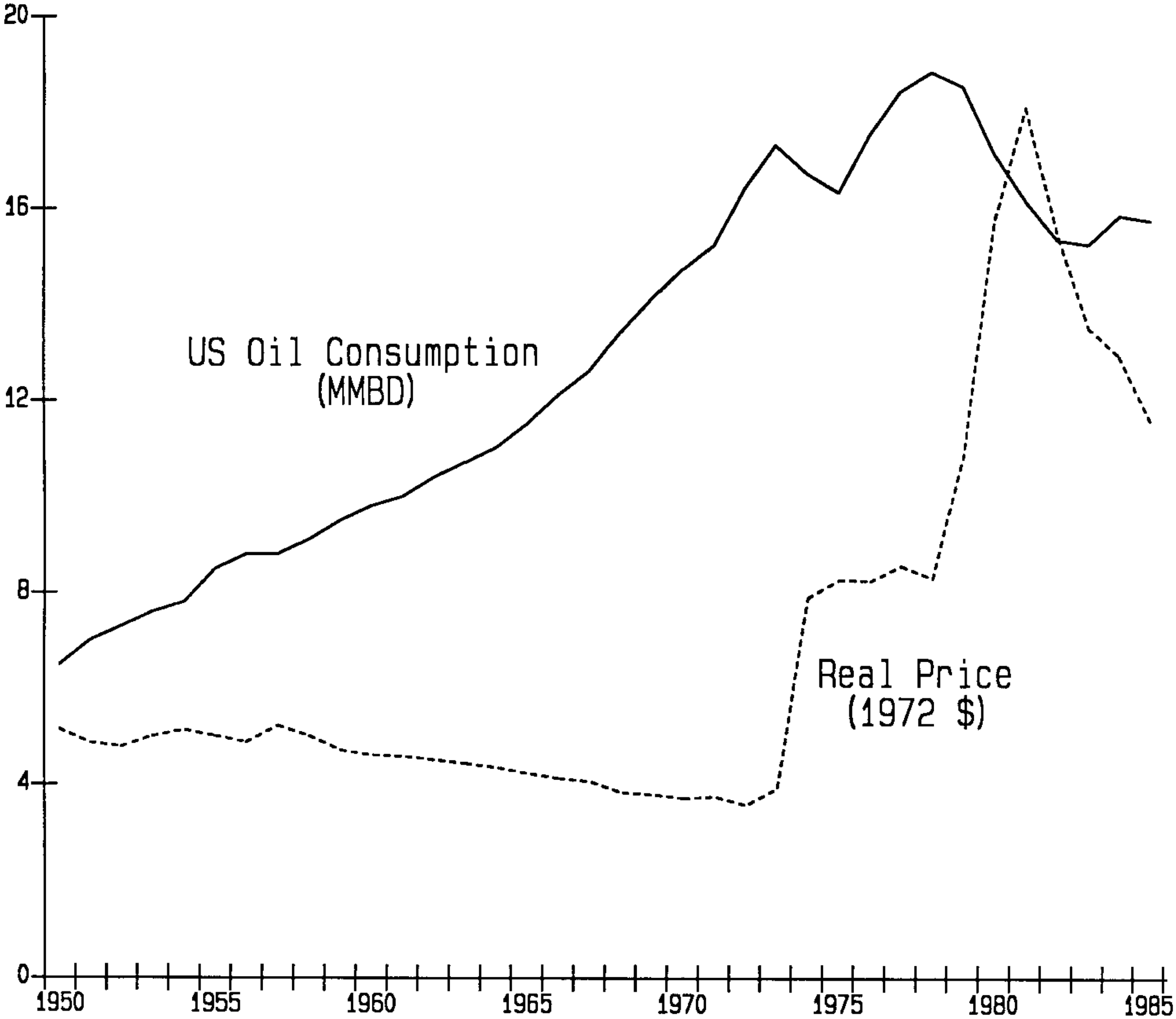
This paper examines the econometric evidence about the adjustment of U.S. oil demand in response to the price increases of the 1970's, and the implications for oil demand through the year 2000. It is organized as follows. Section II presents the data and briefly surveys the existing literature. Section III examines issues related to the specification of the demand equation, including those related to long–run price–asymmetries. Section IV presents the econometric results for a log–linear demand equation assuming no long–run asymmetry of response to price increases and declines; it also examines the contrasting assumption of complete long–run asymmetry (zero responsiveness to price declines that follow price increases). Section V summarizes the implications for US oil demand to the year 2000 and Section VI presents the conclusions.

II Background

The basic data used in this analysis are presented in Figure 1, depicting US oil consumption and the real oil price[1]. Consumption of refined oil products, measured in

[1] Oil consumption is reported in the following publications of the US Department of Energy, Energy Information Administration: *Annual Report to Congress*, and *Monthly Energy Review*. Price (measured by the Refiners' Acquisition Price in 1972 $) is reported in *Monthly Energy Review*. GNP (measured in 1972 $) is from the US Department of Commerce, *National Income and Product Accounts*.

Figure 1
US Oil Consumption
and Real Price, 1950-85



million barrels per day (MMBD), grew steadily through the 1950's and 1960's. Only after major price increases in 1973–74 and 1979–80, and the subsequent recessions, was demand growth slowed and then reversed. The real price of oil declined gradually during the 1950's and 1960's, before increasing sharply in 1973–74 and again in 1979–81; but it declined by one–third between 1981 and 1985, and then collapsed in the first quarter of 1986, falling to about half its 1985 level. The other explanatory variable, real GNP, grew steadily for this entire time, pausing only during recessionary periods.

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)[2]; important works include those of Pindyck(1979) and Hogan(1980),(1986). An important, broad–based study was done by the Energy Modeling Forum in *Aggregate Elasticity of Energy Demand* (1980); this was a controlled comparison of several different energy demand models. From these and other results, a subsequent study by the Energy Modeling Forum, *World Oil* (1982), used a base–case assumption of –0.6 for the long–run price elasticity of crude oil demand (at the 1980 price level).

Questions similar to those examined in this paper have been addressed previously by Brown(1983) and Bopp(1984)[3]. Brown(1983) specifies a log–linear demand function; he

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[2] 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).

[3] Bopp's paper specifies a log–linear demand equation with a Koyck lag. It examines the question of whether there was any "structural change" after either the 1973–74 or the 1979–80 price increase. He avoids lagged–price specifications similar to what we use below, because they would have precluded his tests for structural change. As noted in Gately–Rappoport(1986), we found the *log–linear*, Koyck specification to be unsatisfactory: the coefficient for lagged demand had the wrong sign and was insignificant. However, a *linear* demand function with a Koyck lag does not have such unsatisfactory results.

allows lagged–price effects of up to six years, using data through 1979. Given the constraint that fewer years of data were available to him, his results on the distribution of the lagged–price coefficients are similar to what shall be presented below:

> "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."[4]

However, there has been considerable disagreement about the future course of oil demand, even before the 1986 price collapse. Consider the poll responses from nearly a hundred modeling groups as 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 respondents was from 30% below the median to about 25% above[5]. 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.

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4 Brown (1983, p. 29). The assumed structure of the lagged–price coefficients is not defined clearly.

5 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.

III Specification of the Demand Equation

In this section we discuss several issues, including the following: the form of the demand function and the structure of lagged–price adjustment; the identification problem; and the question of price–asymmetries and the reversibility of demand reductions.

III.1 Form of the Equation and Structure of Lagged–Price Adjustment

There are several ways in which the demand specifications in this paper will differ. These include is the form of the equation (whether it is linear or log–linear) and also the specification of the structure of the lagged–price coefficients.

We assume a log–linear function of income and price:

$$\text{(1)} \qquad \log(\text{Demand}_t) = \alpha_0 + \alpha_1 \log(\text{GNP}_t) + \sum_{i=0}^{n} \beta_i \log(P_{t-i}).$$

We examine two alternative ways in which the structure of the lagged–price coefficients β_i can be specified. First will be the simplest case, in which no restrictions are placed on their structure. Second will be the case in which the lagged–price coefficients follow the form of a cubic polynomial distributed lag (PDL):

$$\text{(2)} \qquad \beta_i = \delta_0 + (\delta_1\, i) + (\delta_2\, i^2) + (\delta_3\, i^3)$$

In both cases we assume a lag–length of ten years[6] and impose no end–point restrictions. Two alternative specifications are examined in the Appendix: a log–linear function with a quadratic PDL structure and a linear demand function with unconstrained lagged–price coefficients.

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 that, within a given

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[6] In Gately–Rappoport(1986) we examined the effects of alternative lag–lengths, as well as the sensitivity of the model's results to changes in the data–sample period. This paper is available on request.

year, OPEC's price is set independently of the level of US oil demand. Certainly, during the period 1973–85 OPEC has acted as the residual supplier in the world oil market: it sets 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.

III.2 Price Asymmetry and Demand Reversibility

Declining oil prices since 1981, and especially the price collapse in the first quarter of 1986, have raised the question about whether these price declines could reverse the demand reductions brought about by the price increase of the 1970's. A similar question is whether we should expect the demand response to price declines to be symmetric to the demand response to previous price increases.

Some recent papers have started to address these issues. Sweeney(1986)[7] provides some useful distinctions that help to clarify the issues involved:

> "*Long–run asymmetries* arise when the long–run equilibrium demand function is itself a function of the price history. In particular, the demand function towards which the system tends is lower when the system has gone through a period of higher prices.
>
> *Dynamic asymmetries* arise when the rate of adjustment toward the long–run equilibrium differs in response to price decreases from the rate of adjustment in response to the initial price increases. In particular, the rate of adjustment toward the long–run equilibrium is slower in response to a price decrease which follows a prior price increase."[8]

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7 See also the papers of Bye(1986), and Watkins and Waverman(1986). In the literature on agricultural supply there has been work on questions of irreversibilities and asymmetric price–responsiveness, but without the complication of lagged adjustment; see Traill, Colman, and Young(1978).

8 Sweeney(1986, p. 2).

He observes that long–run asymmetries and distributed–lag demand functions of finite length are mutually incompatible. That is, the assumption of a distributed–lag demand function precludes any long–run asymmetries (although it does imply dynamic asymmetries). Thus, if long–run asymmetries are important, then a distributed–lag demand function cannot be appropriate, at least if applied to an estimation period in which price reductions follow price increases, or if used for projection purposes.

The quantitative importance of such long–run asymmetries remains to be seen. Some conservation, of course, is irreversible, such as that resulting from improvements in insulation. But some demand reduction could be reversed by lower prices. For example, gasoline demand could increase due to increased automobile usage or the abandonment of the 55 MPH speed limit.

IV Econometric Results

In this section, we shall first assume that *no* long–run asymmetries exist, and then assume that the asymmetries are *complete*: that there has been zero responsiveness to the recent price declines. These polar cases are intended to bracket the range of projections.

IV.1 Econometric Results: No Long–run Asymmetry

In Table 1 are presented the estimated coefficients for two versions of equation (1), assuming no long–run asymmetry of response to price changes. These two are the case of no lag–structure imposed on the lagged–price coefficients and the case of a cubic PDL structure (with no end–point restrictions imposed)[9]. Also in Table 1 are results for

[9] Note that we corrected for the problem of autocorrelation by using a second–order Cochrane–Orcutt autoregressive correction. The Q–statistic tests the hypothesis that the autocorrelations are zero; see Box and Pierce (1970). In all cases reported, the Q–statistic for the residuals from the regression (using 4 autocorrelations) was not significant at the 5% level, indicating non–rejection of the hypothesis that the underlying errors were serially uncorrelated.

In some cases, the autoregressive coefficients suggest the presence of a unit root in the case of complete asymmetry, to be discussed below.

For the unconstrained case, the estimated coefficients for income α_1 and lagged–prices β_0, β_1, and β_9 have the correct sign and are statistically significant. 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.

For the cubic PDL case, the results are similar. The GNP coefficient is positive and significant. Each of the four δ coefficients in the cubic PDL are significant, as are 6 of the 11 lagged–price coefficients β_i. All of the lagged–price coefficients have the correct sign and several are statistically significant.

The values of the lagged–price coefficients β_i for these two cases are compared in Figure 2. For individual years, the lagged–price coefficients differ slightly, but the overall structure can be seen to be similar in shape. In addition, using an F–test for the PDL suggested in Dhrymes(1971, section 8.2), we found that the cubic PDL specification did not place significant restriction on the form of the lag distribution[10].

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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.

[10] The test of the null hypothesis of the cubic PDL against the alternative of an unconstrained lag distribution yields an F–statistic of 0.87. This has (8,22) degrees of freedom, for which the 10% critical value is 2.01. Hence the cubic PDL model is not rejected. In Appendix A we test the cubic against the quadratic PDL specification.

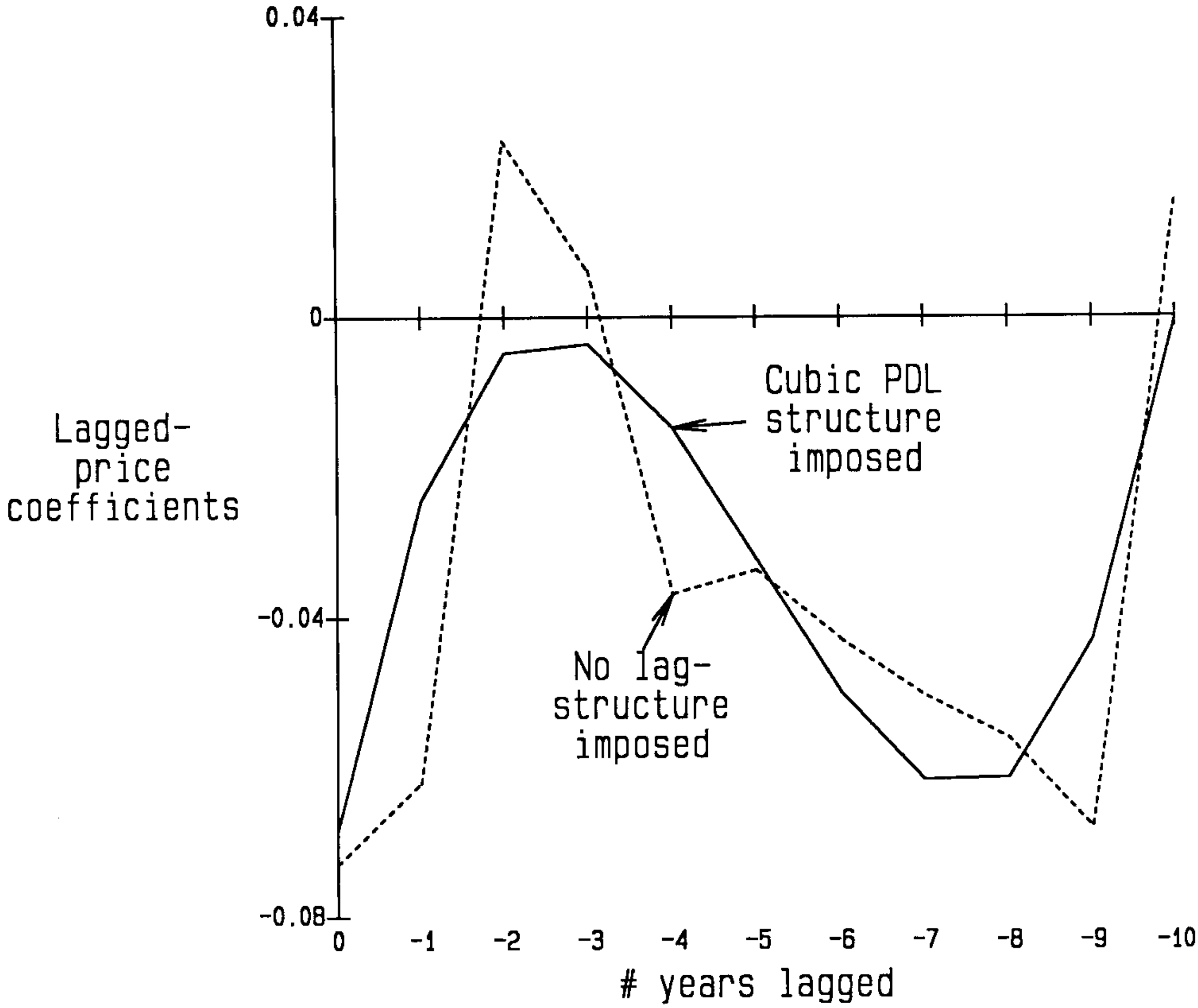
Table 1

Results for Log-linear Demand Function with 10-year lag-length:

	Variable	No Long-run Asymmetry; Unconstrained Coefficients		No Long-run Asymmetry; Cubic Polynomial Distributed Lag		Complete Long-run Asymmetry; Unconstrained Coefficients	
		Coeff.	*t-stat.*	*Coeff.*	*t-stat.*	*Coeff.*	*t-stat.*
α_0	constant	−0.683	−0.54	−1.474	−1.52	−0.74	−0.57
α_1	log GNP_t	0.597	4.09	0.689	5.73	0.60	4.06
β_0	log P_t	−0.073	−2.79	−0.068	−3.25	−0.076	−2.79
β_1	log P_{t-1}	−0.062	−2.32	−0.024	−1.84	−0.06	−2.24
β_2	log P_{t-2}	0.023	0.97	−0.005	−0.35	0.02	0.99
β_3	log P_{t-3}	0.006	0.25	−0.004	−0.27	0.01	0.36
β_4	log P_{t-4}	−0.037	−1.51	−0.015	−1.26	−0.034	−1.41
β_5	log P_{t-5}	−0.034	−1.39	−0.032	−2.96	−0.03	−1.26
β_6	log P_{t-6}	−0.043	−1.71	−0.050	−4.00	−0.04	−1.54
β_7	log P_{t-7}	−0.050	−1.83	−0.062	−4.20	−0.05	−1.84
β_8	log P_{t-8}	−0.056	−1.88	−0.061	−4.00	−0.05	−1.60
β_9	log P_{t-9}	−0.068	−2.46	−0.043	−2.79	−0.05	−1.86
β_{10}	log P_{t-10}	0.015	0.58	−0.0003	−0.01	0.02	0.71
$\Sigma\ \beta_i$		−0.377		−0.364		−0.34	
δ_0				−0.068	−3.25		
δ_1				0.058	2.90		
δ_2				−0.015	−3.10		
δ_3				0.001	3.15		
AR(1)		1.315	6.41	1.200	6.61	1.31	6.42
AR(2)		−0.348	−1.80	−0.250	−1.47	−0.34	−1.75
Price elasticity		−0.377		−0.364		−0.34	
Income elasticity		0.597		0.689		0.60	
Adjusted R^2		0.997		0.998		0.997	
Standard Error of regression		0.0177		0.0174		0.0177	

Data Period 1949 – 1985: 37 Observations

Figure 2
Lagged-price coefficients:
Cubic PDL structure vs.
No lag-structure imposed



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. As noted above, this result is similar to that of Brown(1983), who used a shorter lag–length and data through 1979.

It should be noted, however, that the apparent termination of lagged–price effects after 10 years is misleading, primarily because of the decreasing reliability of coefficients for years lagged so long. In the unconstrained case, the coefficient β_{10} is positive but not statistically significant. Because our last year of data is 1985, price lagged 10 years contains only two years of high prices, 1974 and 1975; price lagged 12 years contains *no* years of high prices. If a lag–length longer than 10 years is assumed, the lagged–price coefficients for those additional years are unreliable and the coefficients fluctuate sharply from year to year[11]. Similarly, successively dropping the most recent years from the data–sample period causes sharp fluctuations in the coefficients for prices lagged 9 years, 8 years, and so forth[12].

IV.2 Econometric Results: Complete Long–run Asymmetry

Suppose we now consider the opposite assumption about asymmetry, that the long–run asymmetry is complete: there is *zero* demand–response to price declines. In

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[11] Extending the lag length has virtually no effect on coefficients for price lagged less than 10 years, but longer–lagged coefficients fluctuate sharply and are not significant. With a cubic PDL structure, extending the lag length has no effect on the shape of the coefficients' distribution, although it does change their values for given years as it "stretches out" the cubic shape over a longer interval. See Gately and Rappoport(1986).

[12] However, with the cubic PDL structure, dropping these years has virtually no effect on any of the coefficients. This illustrates the strong effect of the cubic PDL specification. See Gately and Rappoport(1986).

effect this is like assuming that price has not declined since 1981, but that all the other variables retained their historical values. Such an implausible assumption is being examined so as to determine its implications for demand projections.

If there were perfect sysmmetry then we would get the correct price–elasticity by regressing against actual prices. But if there were complete *asymmetry* then the correct elasticity would be better approximated by a regression in which we assumed that price had not declined since 1981. These two estimates will bracket the true elasticity.

When we re–estimate the equation, using actual prices prior to 1981 and the 1981 price for 1981–85, we get a slightly smaller price–elasticity than when we used actual prices for 1981–85. The results are shown in the last two columns of Table 1: the sum of the lagged–price coefficients (–0.34) is about 10% smaller than for the original case (–0.377). Otherwise the results are fairly close.

Hence our conclusions about long–run price elasticity are not very sensitive to assumptions about the degree of asymmetry.

V Implications for U. S. Oil Demand

The real importance of the preceding econometric work lies in its implications for future demand. In particular, we are interested in whether the demand–increasing effects of GNP growth (and perhaps of lower prices since 1981) would outweigh the demand–reducing effects of any continuing lagged–price response to the price increases of the 1970's.

In an attempt to bracket the plausible range of demand projections, or at least provide a lower bound, we did the following. Assuming 3% annual GNP growth, and using a log–linear demand function with a cubic PDL structure on lagged–prices, with a lag–length of either 10 or 15 years, we made projections under each of the two assumptions about long–run asymmetry. These are depicted in Figures 3 and 4, respectively, for the case of no long–run asymmetry (with price assumed to be at its 1985 level for 1986–2000) and for the case of complete long–run asymmetry (with price at its much higher 1981 level for 1986–2000).

In the first case (assuming 1985 price levels) we see in Figure 3 that demand will grow to 21 MMBD by year 2000 with a 10–year lag–length, and about 17 MMBD with a 15–year lag–length. The underlying long–run price–elasticities are –.36 and –.59 respectively.

In the second case (assuming complete asymmetry and 1981 price levels: Figure 4), the lower underlying price–elasticities (–.33 and –0.47) are more than offset by a price that is much higher. Hence, demand by the year 2000 would be about 10% less than in Figure 3, for the two lag–lengths respectively.

Thus, even with a 15–year lag–length and with zero responsiveness to post–1981 price declines, demand by the year 2000 will be at or above its 1985 level by the year 2000. Assuming a lag–length of 10 years, demand will even exceed its previous maximum from 1978.

To the degree that demand *is* responsive to recent price declines, demand will grow even more rapidly, perhaps exceeding its previous maximum within ten years.

Figure 3
US Oil Consumption, 1970-85
& Projections, 1986-2000:
No Long-run Asymmetry,
Price at 1985 level

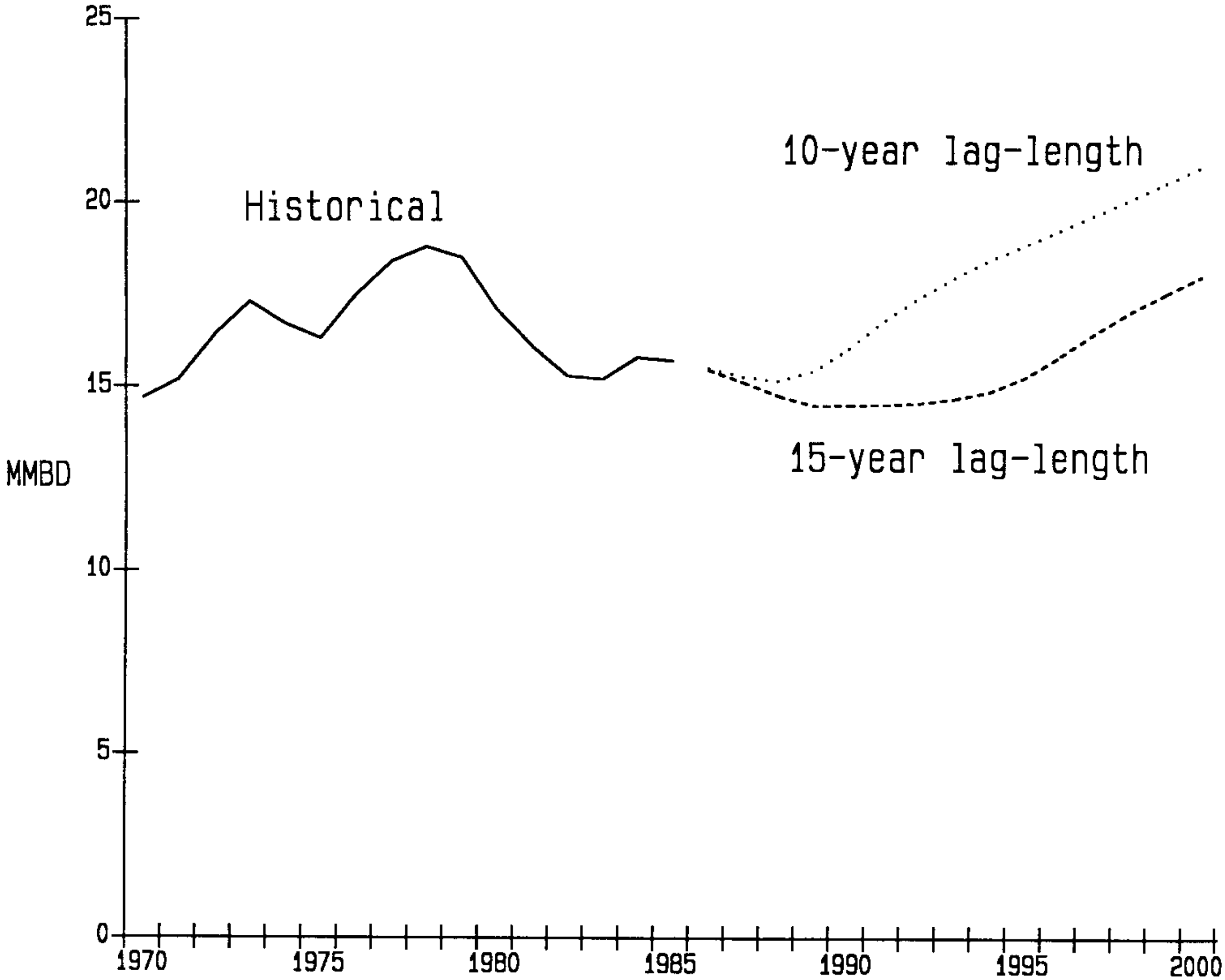
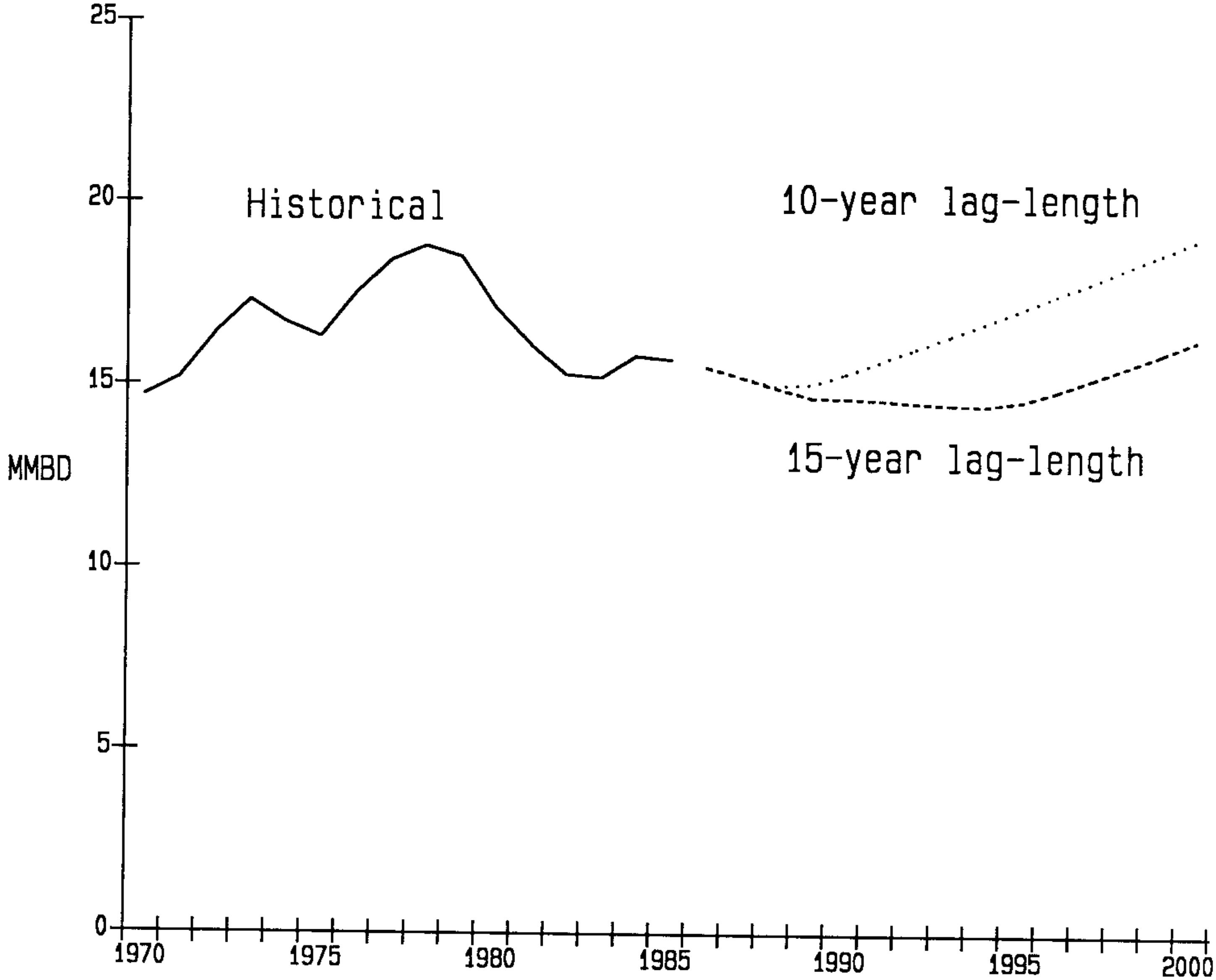


Figure 4
US Oil Consumption, 1970-85
& Projections, 1986-2000:
Complete Long-run Asymmetry,
Price at 1981 level



VI Conclusions

Let us summarize the econometric results about the lagged–price effects, as well as present the main implications for US demand.

The length of the lagged–price adjustment is 10 years, or more. The ultimate length remains uncertain, as does the cumulative, long–run response to the price increases of the 1970's. There might be much more adjustment still to come, especially if one believes that the price increases stimulated much research and development whose oil–saving benefits are yet to be seen.

The distribution of the lagged–price coefficients appears to be fairly well characterized by a cubic PDL structure, in which the coefficients decline after the first few years, then increase as the capital–stock adjustment has its effect. Other structures are possible, but this would not have a significant effect upon the ultimate price–responsiveness of demand.

The long–run price elasticities estimated here (about –0.4), using a 10–year lag–length, are lower than some others in the literature. However, if a longer lag–length were assumed, the elasticity would increase.

Finally, the implications for US demand. Unless one assumes that there substantial adjustment to the price increases of the 1970's is still to come, it seems quite likely that US oil consumption will resume its growth and could well be at historically high levels by the mid–1990's. At the same time, virtually all observers agree that U.S. domestic oil production will be declining for the next 15 years, perhaps by 3% annually. 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 the 1970's, again vulnerable to oil supply interruptions, either intended or accidental.

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Appendix A

Results of Alternative Demand Specifications

In Table A1 we summarize the results of two alternative specifications of the demand equation: a log–linear function with a quadratic PDL structure[13], and a linear demand function with unconstrained lagged–price coefficients. In both cases we assume no long–run asymmetries.

A.1 Log–linear demand, with quadratic PDL

Compared with the *cubic* PDL results of Table 1, the *quadratic* PDL results of Table A1 have a slightly lower price–elasticity and a higher income–elasticity, both of which would imply higher demand growth. Although a few of the lagged–price coefficients β_i have higher t–statistics, this is misleading because none of the δ coefficients in the underlying quadratic PDL equation are statistically significant. In contrast, for the cubic PDL specification in Table 1, all of these δ coefficients were significant. In addition, using a test from Dhrymes(1971, section 8.2) for discriminating among PDL models of different orders, the quadratic PDL can be seen to be inferior to the cubic PDL. The F–statistic for the null hypothesis of the quadratic model against the alternative of the cubic model is 9.1. This is significant at the 1% level, indicating that the quadratic model constrains the data unduly. Hence we prefer to use the more general cubic model.

A.3 Linear demand, with no lag–structure imposed

With no lag–structure, the *linear* demand results in Table A2 are similar to the *log–linear* results of Table 1, especially the shape of the lagged–price coefficients. Both

[13] Johnson and Lascar(1984) used a quadratic PDL to estimate the lagged effect of price upon the U.S. energy/GDP ratio.

have the same coefficients being significant and with the correct sign (for GNP_t, P_{t-0}, P_{t-1}, and P_{t-9}); also significant in the linear case is the coefficient for P_{t-8}.

There are no strong grounds on which to prefer the log–linear over the linear specification. A log–linear demand function can be derived from a Cobb–Douglas utility function, while a linear demand function implies a much more complicated utility function. But the use of a linear demand function would not change the basic conclusions of this paper.

Table A1
Results for alternative specifications

	Variable	Log–linear, Quadratic PDL Coeff.	t–stat.	Linear, Unconstrained Coefficients Coeff.	t–stat.
α_0	constant	−3.029	−3.93	13.63	1.21
α_1	log GNP	0.886	8.28	0.009	5.07
β_0	log P_t	−0.036	−1.67	−0.187	−4.35
β_1	log P_{t-1}	−0.035	−2.65	−0.136	−2.53
β_2	log P_{t-2}	−0.035	−3.60	0.050	0.99
β_3	log P_{t-3}	−0.034	−3.37	−0.022	−0.41
β_4	log P_{t-4}	−0.033	−2.86	−0.111	−1.87
β_5	log P_{t-5}	−0.031	−2.61	−0.093	−1.69
β_6	log P_{t-6}	−0.029	−2.61	−0.038	−0.70
β_7	log P_{t-7}	−0.027	−2.67	−0.092	−1.20
β_8	log P_{t-8}	−0.025	−2.21	−0.184	−2.15
β_9	log P_{t-9}	−0.022	−1.34	−0.251	−3.09
β_{10}	log P_{t-10}	−0.019	−0.75	0.074	1.01
$\Sigma\ \beta_i$		−0.327		−0.99	
δ_0		−0.036		−1.67	
δ_1		0.00013		0.01	
δ_2		0.00015		0.13	
	AR(1)	1.195	6.45	1.550	8.06
	AR(2)	−0.295	−1.77	−0.567	−2.96

	Log–linear, Quadratic PDL	Linear, Unconstrained Coefficients
Price elasticity	−0.327	−0.723 (at 1985 price) −0.266 (at half of 1985 price)
Income elasticity	0.886	0.882 (at 1985 income level)
Adjusted R^2	0.997	0.998
Standard Error of regression	0.0196	0.019

Data Period 1949 – 1985: 37 Observations