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THE IMPERFECT PRICE-REVERSIBILITY OF NON-TRANSPORTATION OIL DEMAND IN THE OECD

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Abstract:

This paper examines the price-reversibility of OECD non-transportation oil demand and its largest components: residual (heavy) fuel oil, and non-transportation distillates. Our purpose is to determine the extent to which the reductions in demand following the oil price increases of the 1970's have been -- and will be -- reversed by the price cuts of the 1980's. The analysis is based on an econometric model which utilizes price-decomposition methods to measure separately the effects of price increases and price decreases. These methods allow empirical testing of irreversibility and hysteresis, and should be applicable in other areas of economics where asymmetry of response or persistence of effect are evident.

Based on the statistical evidence, we reject the conventional specification of demand being perfectly price-reversible. We conclude that the response to the price cuts of the 1980's has been significantly smaller than to the price increases of the 1970's. Demand has followed a ratchet process: price increases reduced demand substantially when demanders conserved and switched away from oil, but price cuts did not reverse this process completely, if at all. This has important implications for projections of oil demand, especially under low-price assumptions: the OECD's dependency on oil will not increase as much as some analysts may have feared. There is, however, another aspect of imperfect price-reversibility: the possibilities of adjusting to future price rises may not be as great as they had been in the past. The easiest and least costly demand savings have already been made, and oil has been replaced by other energy sources in many uses: what's done is done.

Keywords: oil demand; price reversibility; asymmetry; hysteresis
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1. Introduction

An important issue in the analysis of world oil demand is whether the reductions in demand following the oil price increases of the 1970's will be reversed by the price cuts of the 1980's. Now that we have returned to the low oil prices of the early 1970's, can we expect a resurgence of rapid growth in oil demand and oil imports? Fortunately, the answer is no.

A second important issue is whether -- in the event of an oil price increase, either by OPEC or by increased domestic oil taxes -- we can expect as great a demand reduction as we experienced the last time. Unfortunately, the answer to this question is also no.

With traditional demand modelling, the answer to both of these questions would have to be yes -- but by assumption rather than by statistical analysis and testing. This is because traditional models are based on the assumption of a stable long-run demand function, which, *ceteris paribus*, implies the existence of a unique equilibrium demand for any given price level. Thus, by assumption, the effects of any price change will be totally reversed as price returns to its initial level. Up until recently, the majority of energy demand studies[1] have been based on such "reversible" models, so that questions such as the two posed above could not be analyzed empirically. Despite the inability of these traditional models to explain the sluggish growth in demand following the oil price collapse in 1986, some analysts, most notably Hogan (1993), have been reluctant to abandon the conventional demand specification. However, as we shall show below, for non-transportation oil demand, the assumption of perfect price-reversibility must be rejected.

The notion of irreversibility in economic relationships is not a new one. The question seems first to have been raised in the agricultural economics literature, and the first empirical work was done on the price-reversibility of agricultural supply, by Wolffram (1971), and Traill, Colman and Young (1978). Irreversibility is also closely linked with the concept of hysteresis, which refers to an effect which persists long after its cause has been removed. Hysteresis has been employed in the analysis of travel demand by Goodwin (1977) and Blaise (1980), and more recently used to explain the persistence of high unemployment (Blanchard and Summers 1987), and the US trade deficit (Baldwin 1988, Baldwin and Krugman 1989). Much of this work is based on the irreversible, sunk-cost nature of investment; see the survey by Pindyck (1991), which provides numerous examples of irreversibility and asymmetry in economic behavior. The literature, however, is mainly of a

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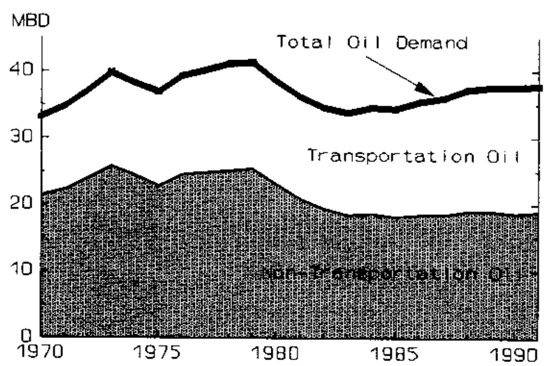
[1] For good examples of earlier work on energy and oil demand, see Griffin(1979), Pindyck(1979), and Hogan(1986).

theoretical nature and the empirical work is still rather sparse, and based largely on tests for structural change.

In this paper, we analyze the price-reversibility of oil demand, using the approach developed in the agricultural supply literature. The models employ price-decomposition techniques to distinguish between the response to different types of price changes, thus explicitly allowing empirical testing of asymmetry and some forms of irreversibility and hysteresis. These methods should be applicable to other economic issues mentioned above, where the cause of irreversibility or hysteresis can be linked to specific variables.

These methods have been applied in a number of recent empirical studies of energy and oil demand.[2] In the majority of instances examined, the perfectly reversible models are rejected in favor of the more general, imperfectly reversible specifications. For example, in our studies of the demand for highway fuels in France, Germany and the UK (Dargay 1992a) and the US and Japan (Gately 1992, 1993a), we concluded for all countries that the price decreases of the 1980's w/ill reverse only a fraction of the demand reductions caused by the price increases of the 1970's. This result is due primarily to the irreversibility of fuel-efficiency improvements, caused both by irreversible improvements in technology and also by the non-reversal of government policies such as automobile fuel-efficiency standards.

Figure 1 Total OECD Oil Demand



There is good reason to believe that oil use for non-transportation purposes may also exhibit such irreversibilities. This is clearly suggested in Figure 1, which shows total oil demand (in million barrels per day, MBD) within the industrialized (OECD) countries, split between transportation and non-transportation uses. As a whole, oil demand has been relatively flat since the first oil shock, the 1973-74 price increase. Not only has growth been retarded, but demand is lower today than it was, on average, during the 1970's. It is clear from

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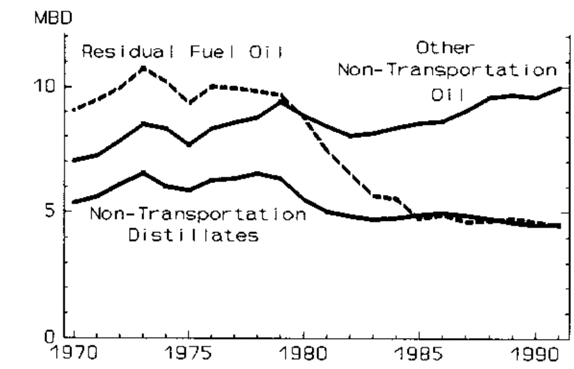
[2] We have analyzed the price-reversibility of *aggregate* oil and energy demand: see Dargay (1990), (1992b) and Gately (1993a), (1993b) and the demand for automotive fuels: see Dargay (1992a) and Gately (1992).

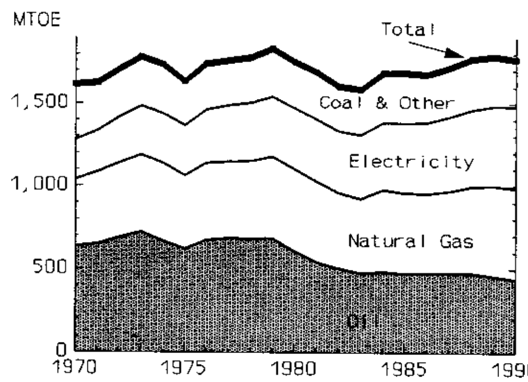
the figure that the reduction in oil consumption has been the result of an absolute decline in non-transportation oil demand. Transportation oil demand has continued to grow, almost as fast as income growth. It is also apparent that the price collapse of the mid-1980's has had, as yet, no discernable impact on non-transportation oil use. The graphical evidence for the price-irreversibility of non-transportation oil demand is clearly very strong.

Figure 2 OECD Non-Transportation Oil Product Demand



Besides *total* non-transportation oil demand, in this paper we focus on the two most important non-transportation oil products: non-transportation distillates and residual (heavy) fuel oil, each of which account for about a quarter of non-transportation oil use. The share of distillates used for non-transportation purposes -- for space heating and hot water -- is now less than half of all distillates, with the remainder being diesel fuel used for highway and rail transportation. We analyze only non-transportation distillates demand. Residual Fuel is used almost exclusively for non-transportation purposes: about 55 per cent for electricity generation over the past two decades, and most of the remainder in industry. These two products have experienced the greatest demand reductions of any oil products since the price increases of the 1970's.

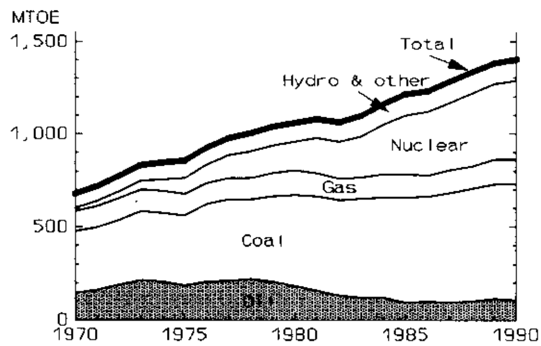
Figure 3 OECD Final Use of Energy, 1970-90: Residential + Commercial + Industrial Sectors



Unlike in transportation where there are virtually no substitutes for oil, in non-transportation uses of oil (in the residential, commercial, and industrial sectors) there are substitutes available. Figure 3 shows the final use of energy (in million tons of oil equivalent, MTOE) in these three sectors combined, for the entire OECD for 1970-90, disaggregated into oil, natural gas, electricity, and "coal and other". Oil use in these three sectors declined after the price increases in 1973-74 and especially after 1979-80. This is due both to overall energy conservation and also to fuel-switching to other energy sources such as natural gas and electricity.

Within electricity generation, the OECD has also switched away from oil, back to coal. In addition, there has been expanded use of nuclear power, throughout the OECD and especially in France and Japan. Figure 4 depicts this, showing both the growing total of all fuels used in electricity generation, as well as oil's decline (especially in the early 1980's), both relatively and absolutely.

Figure 4 OECD: Fuels Used in Electricity Generation, 1970-90



2. The Analysis of Imperfectly Price-Reversible Demand:

If demand were perfectly price-reversible, then the demand reductions caused by a price increase would be reversed when price returns to its previous level. A conventional demand curve illustrates this "reversibility": movement up the demand curve (price increases and demand falls) is reversed by movement down the demand curve (price decreases and demand rises). Similarly, if price were to recover subsequently to its previous high level, the demand reduction would be the same as when price increased initially. Even with a lagged or delayed adjustment to price changes, this reversal ought to be evident.

But if demand were not perfectly price-reversible, then the demand-reducing effects of a price increase would not be fully reversed when price falls. The graph at right shows this possibility, in greatly simplified form: the demand reductions caused by the price increases of the 1974-81 period are only partially reversed by the price declines of the mid-1980's. This contrasts with the perfectly price-reversible case, in which demand would return to what it was in 1973.

Figure 5 Imperfectly Price-Reversible Demand

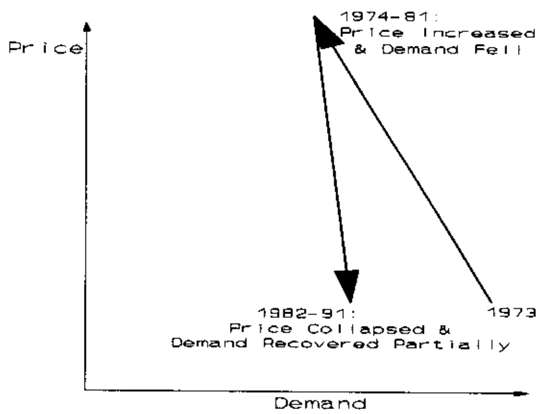
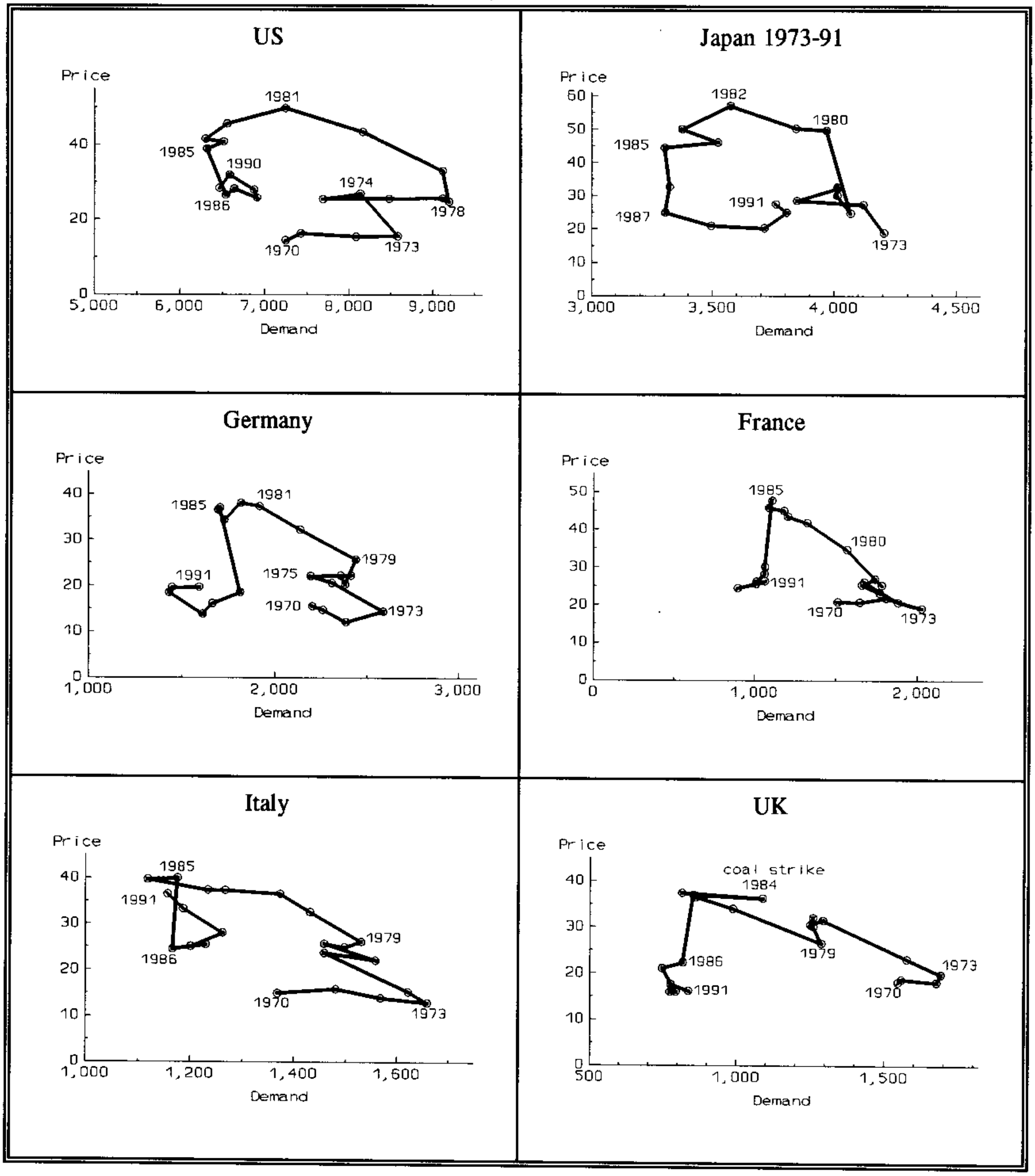


Table 1 shows the actual historical data of real price vs. demand, for total non-transportation oil in 1970-91, in each of the six largest OECD countries; price is measured in 1985 $ per barrel, and demand is in Thousand Barrels per Day. Although this actual data is not as neat as the simple diagram of Figure 5 -- due to lagged adjustment or changes in income and other exogenous factors -- there is clear evidence of imperfect price-reversibility: an inverted V or U shape describing the period 1973-91. The price increases, in 1973-74 and again in 1979-81, cause demand reductions that are barely reversed at all when price falls during the mid-1980's. There is little evidence of demand increasing after the 1986 price collapse: only in Japan in 1987-90.

There are a number of explanations for this irreversibility. One is the technological development in energy efficiency, which has been induced by the price rises of the 1970's and which remains economically optimal despite a return to lower prices. Examples of this can be found in the improvements in fuel efficiency in heating systems, industrial processes and household appliances, which have been developed largely in response to the oil price rises of the seventies. Another relates to the sunk-cost nature of much capital investment: building insulation that will not be removed when energy prices fall, nuclear power plants with high fixed costs but low variable costs.

Table 1: Total Non-Transportation Oil: Price ($/barrel) vs. Demand (Th.B/D), 1970-91 for US, Japan, Germany, France, Italy, & UK



2.1. Specification of an Irreversible Model

In order to distinguish between the responses to different types of price change, let us decompose the price P_t into three component series, each of which is monotonic: maximum historical price $P_{max,t}$ (positive and non-decreasing), the cumulating series of price cuts $P_{cut,t}$ (non-positive and non-increasing), and the cumulating series of price recoveries $P_{rec,t}$ (non-negative and non-decreasing):

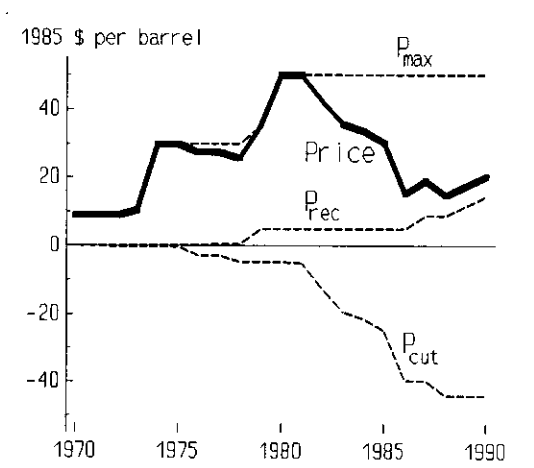
(1) $P_t = P_{max,t} + P_{cut,t} + P_{rec,t}$

(1a) $P_{max,t} \equiv \max (P_0,\ldots,P_t)$

(1b) $P_{cut,t} \equiv \Sigma^t_{i=0} \min \{0, (P_{max,i-1}-P_{i-1})-(P_{max,i}-P_i)\}$

(1c) $P_{rec,t} \equiv \Sigma^t_{i=0} \max \{0, (P_{max,i-1}-P_{i-1})-(P_{max,i}-P_i)\}$

Figure 6 Decomposing Price into 3 Series



The graph at right shows the real price of crude oil, together with its three-way decomposition[3]. We see the jump in P_{max} in 1973-74 and 1979-80; it is always positive and non-decreasing. The cumulating series of price cuts, P_{cut}, is negative and non-increasing; it shows the dramatic price declines of the 1980's. Also shown is the cumulating series of price recoveries, P_{rec}, which is positive and non-decreasing; but such price increases have been relatively few, and small.

[3] In the econometric work below, we use the real price of distillates and residual fuel oil, respectively, in each of the OECD countries.

3. Econometric Results

We examine the results for two alternative demand specifications: one in which demand is assumed to be perfectly price-reversible, and one which allows for irreversibility by using the price decomposition method presented above. The model is a relatively simple, reduced-form equation: long-run demand is assumed to be determined solely by real prices and income (GDP), using a constant-elasticity (log-linear) specification . The dynamic adjustment process is represented by a simple partial adjustment mechanism, in which lagged demand is included among the independent variables. The two models estimated are as follows:

(2.1) Perfectly Price-Reversible:

$$\log D_{it} = \alpha_i + \gamma \log GDP_{it} + \beta \log P_{it} + \phi \log D_{it-1}$$

(2.2) Imperfectly Price-Reversible:

$$\log D_{it} = \alpha_i + \gamma \log GDP_{it} + \beta_m \log P_{max,it} + \beta_c \log P_{cut,it} + \beta_r \log P_{rec,it} + \phi \log D_{it-1}.$$

A description of the data sources is contained in the Appendix A. In all cases we used pooled time-series/cross-section data for the OECD: annual data for 1970-91, and 11 OECD country/regions[4]. The model incorporates separate intercepts for the 11 different regions, but assumes common slope coefficients for all regions. The model was estimated by a two-stage procedure that corrects for heteroscedasticity across regions[5].

In separate sections below, we discuss the econometric results for the following: total non-transportation oil, distillates (non-transportation), and residual fuel oil. For each equation we display results of the following statistical tests: a Ramsey RESET test[6] of specification error, and a Chow test of the stability of the coefficients before and after the 1986 price collapse.

Given the identity $P_t = P_{max,t} + P_{cut,t} + P_{rec,t}$, the Perfectly Reversible model (2.1) is a special case of the Imperfectly Reversible model (2.2), i.e. when $\beta_m = \beta_c = \beta_r$. Thus the hypothesis of Perfect Price-

[4] These eleven consisted of the 8 largest OECD countries -- US, Japan, Germany (West), France, Italy, UK, Canada, Netherlands -- and 3 aggregated regional groups: Europe North (Norway, Sweden, Finland, Denmark, Belgium, Luxembourg, Iceland, Ireland, Austria, Switzerland); Europe South (Spain, Portugal, Greece, Turkey); and Australia - New Zealand.

[5] The model was first estimated by Ordinary Least Squares and the White Test used to test for homoscedasticity. Heteroscedasticity was then corrected for by dividing the variables by region-specific standard deviations, which were estimated from the OLS residuals. The model was then re-estimated using the transformed data, again with OLS. See Kmenta (1986, pp. 616-635).

[6] The results shown for the Ramsey RESET test are those which used the square of the predicted values of the dependent variable. Similar results were obtained when the 3rd and 4th power were added.

Reversibility can be tested using a Wald test of imposing these equality restrictions on the coefficients of equation (2.2). These results are presented below.

The Imperfectly Reversible model (2.2) also encompasses two other specifications as special cases. We have the Wolffram model when $\beta_m=\beta_r$: the response is the same to all price rises, but different, and presumably smaller, for price cuts. The Traill model results when $\beta_c=\beta_r$: price cuts and price recoveries affect demand equivalently, but the response is different, and presumably greater, when price rises above its historical maximum level. These two special types of irreversibility are also evaluated by Wald tests below.

3.1 Econometric Results: Demand for Non-Transportation Oil

First we examine the demand for total non-transportation oil. This includes not only those products to be examined separately below (residual fuel and non-transportation distillates) but it includes many other products, such as kerosene and LPG (liquified petroleum gas). We exclude only gasoline, jet fuel, and distillates used in transportation.

The estimated coefficients and related statistics are shown in Table 2 for the two alternative specifications. The Perfectly Reversible case, although it has a high Adjusted R^2 and it passes the Ramsey specification tests, has the wrong sign for the Income coefficient (-.027): it is negative, although not statistically significant. Moreover, the equations fails the Chow test: we can reject the hypothesis that the coefficients are stable, before and after the 1986 price collapse; in particular, the income coefficient changes dramatically, as we discuss below.

Superior results are obtained from the Imperfectly Reversible case. All the coefficients have the expected signs. The income coefficient has the correct (positive) sign, and it is statistically significant. The price coefficients for P_{max} and P_{rec} have the correct (negative) sign and are statistically significant, but the coefficient for P_{cut} has the wrong (positive) sign although it is not statistically significant. In addition, the Imperfectly Reversible specification passes not only the Ramsey RESET test, but also the Chow test of coefficient stability before and after 1986 -- in contrast to the Perfectly Reversible specification, which does not.

This conclusion favoring the Imperfectly Reversible specification is supported by the Wald test results for the Perfectly Reversible hypothesis $\beta_m=\beta_c=\beta_r$; with an F-statistic probability of .00, it can be clearly rejected. Among the special cases of irreversible specifications, the Traill hypothesis can be rejected, but the Wolffram hypothesis cannot. The interpretation of this is that demanders respond more strongly to price rises than to price cuts, and equally strongly between increases in the maximum historical price and price recoveries.

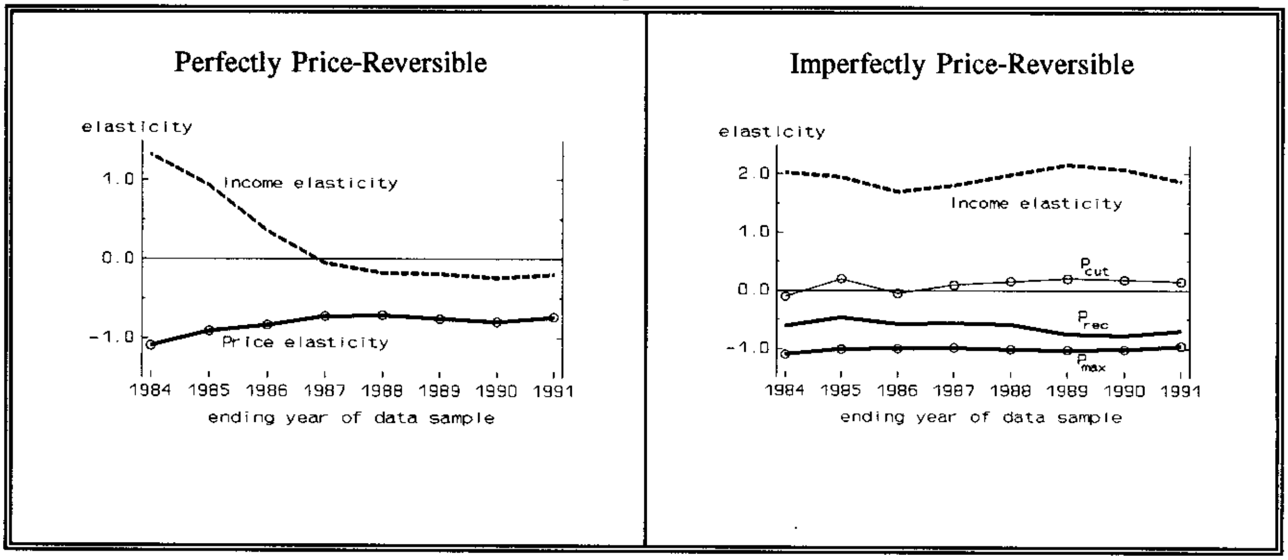
Table 2. Demand for Non-Transportation Oil: Estimated Coefficients and Specification Tests Pooled 11-region OECD, Data Sample 1970-91.

where η = long-run elasticity = coefficient/(1-ϕ)

	Perfectly Price-Reversible	Imperfectly Price-Reversible		
Income (GDP): γ	-.027 (t=-1.2) η=-.19	.42 (t=5.6) η=1.88		
lagged demand: ϕ	.86 (t=33.)	.78 (t=27.)		
	P: β	P_{max}: β_m	P_{cut}: β_c	P_{rec}: β_r
Price	-.10 (t=-8.7) η=-.71	-.21 (t=-8.9) η=-.94	.032 (t=1.3) η=.14	-.16 (t=-3.6) η=-.71
Adjusted R^2	.9997	.9997		
F-statistic	53779.	59051.		
Sum of Squared Residuals	186.	165.		
Ramsey RESET test hypothesis: no specification error	F-stat.prob.=.91 cannot reject	F-stat.prob.=.95 cannot reject		
Chow test: pre-'85, post-'86 hypothesis: same coefs. pre/post	F-stat.prob.=.00 reject	F-stat.prob.=.64 cannot reject		
Wald tests, of restrictions on price coefficients: hypothesis: Reversible $\beta_m=\beta_c=\beta_r$		F-stat.prob.=.00 reject		
specific types of irreversibility: hypothesis: Wolffram $\beta_m=\beta_r$ hypothesis: Traill $\beta_c=\beta_r$		F-stat.prob.=.27 cannot reject F-stat.prob.=.00 reject		

Notes: The following statistical tests were done for each of the equations, and no problems were indicated: Lagrange Multiplier (Breusch-Godfrey) tests for autocorrelation, White test for heteroscedasticity, and ARCH tests.

Table 3. Sensitivity of Non-Transportation Oil Demand elasticities to different ending years of the data sample, 1984-91



Supporting the Chow test results of coefficient stability is a comparison in Table 3 of the effects upon each equation's elasticities of changing the ending year of the data sample, successively including the additional years 1985 through 1991. These years following the 1986 price collapse were years of low prices and moderate income growth, but very sluggish demand growth. Under the Perfectly Price-Reversible case, we would expect the inclusion of this additional data to reduce the estimated responsiveness to price and/or income, because the expected stimulus of low prices on demand did not have much effect: demand growth was sluggish. In contrast, for the Imperfectly Price-Reversible case, the inclusion of these additional years would be expected to provide a better estimate of the effect of price cuts, without necessarily affecting the estimated responsiveness to price rises or to income.

Under the Perfectly Price-Reversible specification, the inclusion of these years causes the income elasticity to decline dramatically. When the last year of the data sample is 1984 or 1985, the income elasticity is positive (and statistically significant); but when 1987 or beyond is included the income elasticity becomes negative (but not statistically significant). Thus, the effect of including these years of *sluggish* demand growth combined with low prices and moderate income growth, both of which ought to have stimulated demand, is to switch the estimated income elasticity from positive to negative! At the same time, the price elasticity is reduced from -1.1 to -.7. Not surprisingly, the Perfectly Reversible specification failed the Chow test of coefficient stability.

In contrast, the Imperfectly Reversible case is not so affected. The elasticities for income and for P_{max} and also for P_{rec} are relatively stable; both always have the expected signs and are significant.

The elasticity for P_{cut} hovers around zero, and often has the wrong sign, but it is never statistically significant.

3.2 Econometric Results: Non-Transportation Distillates

The estimated coefficients and related statistics are shown in Table 4 for the two alternative specifications. In general, the results are similar to those for total non-transportation oil demand. Both specifications have a high Adjusted R^2 and pass the Ramsey specification test. The Perfectly Reversible specification, again, has the wrong sign for the income coefficient: it is negative, and statistically significant as well. Moreover, it fails the Chow test, indicating a significant difference in parameters before and after the 1986 price collapse.

The Imperfectly Reversible case presents a substantial improvement. All the coefficients have the expected signs, and the equation passes the Chow test as well as the Ramsey RESET test. The income coefficient is positive, although small and not statistically significant. The price coefficients are all negative, although only the coefficient for P_{max} is statistically significant. The coefficients for P_{cut} and P_{rec} are much smaller in absolute value, but are not statistically significant. That is, demand responds more strongly to increases in the maximum historical price than it does to either price cuts or price recoveries.

This conclusion is supported by the Wald test results. The Perfectly Reversible hypothesis $\beta_m=\beta_c=\beta_r$ is rejected with an F-statistic probability of .00. Among the special cases of irreversible specifications, the Wolffram hypothesis can also be rejected, but the Traill hypothesis cannot.

Table 4. Non-Transportation Distillates Demand:
Estimated Coefficients, t-values and Specification Tests:
Pooled 11-region OECD, Data Sample 1970-91.

where η = long-run elasticity = coefficient/(1-ϕ)

	Perfectly Price-Reversible	Imperfectly Price-Reversible		
Income (GDP): γ	-.15 (t=-5.3) η=-1.1	.023 (t=.3) η=.14		
lagged demand: ϕ	.86 (t=36.)	.84 (t=32.)		
	P: β	P_{max}: β_m	P_{cut}: β_c	P_{rec}: β_r
Price	-.087 (t=-5.7) η=-.61	-.16 (t=-5.5) η=-.97	-.022 (t=-.8) η=-.13	-.005 (t=-.09) η=-.03
Adjusted R^2	.9996	.9995		
F-statistic	44571.	29306.		
Sum of Squared Residuals	185.	162.		
Ramsey RESET test hypothesis: no specification error	F-stat.prob.=.87 cannot reject	F-stat.prob.=.94 cannot reject		
Chow test: pre-'85, post-'86 hypothesis: same coefs. pre/post	F-stat.prob.=.01 reject	F-stat.prob.=.13 cannot reject		
Wald tests, of restrictions on price coefficients: hypothesis: Reversible $\beta_m=\beta_c=\beta_r$		F-stat.prob.=.00 reject		
specific types of irreversibility: hypothesis: Wolffram $\beta_m=\beta_r$		F-stat.prob.=.03 reject		
hypothesis: Traill $\beta_c=\beta_r$		F-stat.prob.=.74 cannot reject		

Notes: The following statistical tests were done for each of the equations, and no problems were indicated: Lagrange Multiplier (Breusch-Godfrey) tests for autocorrelation, White test for heteroscedasticity, and ARCH tests.

Table 5. Sensitivity of Non-Transportation Distillates Demand elasticities to different ending years of the data sample, 1984-91

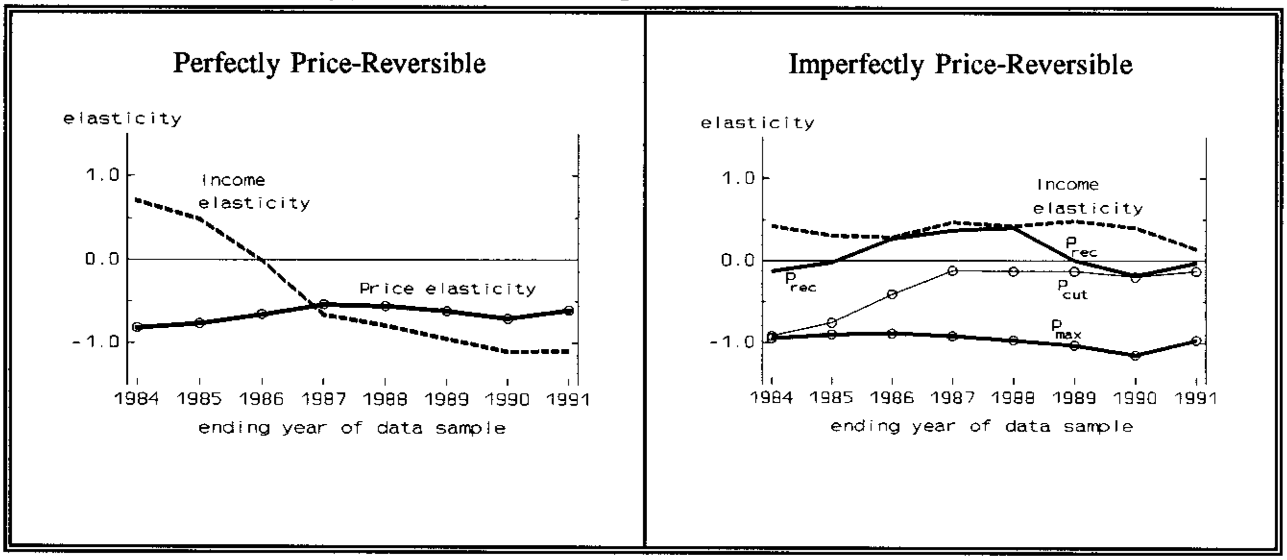


Table 5 displays the sensitivity of each specification's elasticities to the ending year of the data sample. Again, in the Perfectly Reversible case, the successive inclusion of the years 1985-91 causes the estimated income elasticity to switch from positive (and statistically significant) before 1986 is included, to negative (and significant) when 1987 and later are included. The price elasticity also declines, but only slightly.

In contrast, for the Imperfectly Price-Reversible case, the inclusion of these additional years has relatively little effect, especially on the estimated elasticity for either income or P_{max}. It does affect, however, the estimated elasticities for P_{cut} and P_{rec}, but the coefficients are not statistically significant.

Taking all these results into account, from both Table 4 and 5, we reject the Perfectly Reversible specification in favor of the Imperfectly Reversible one.

3.3 Econometric Results: Demand for Residual Fuel

Using the standard demand equations (2.1) and (2.2) for residual fuel oil, we get the results shown in Table 6 -- with income (GDP) either included or excluded from those equations, for reasons discussed below.

When GDP is included in the equations, the results are problematic. In the Perfectly Reversible case, the GDP coefficient (-.18) has the wrong sign -- and it is statistically significant. In the Imperfectly Reversible specification it also has the wrong sign (-.05), but it is not statistically significant.

When GDP is dropped from these equations, the results are affected differently for the two cases. With the Imperfectly Price-Reversible case, dropping the Income variable has little effect on the equation's results, which is not surprising because Income had not been statistically insignificant. However, with the Perfectly Reversible case, dropping the Income variable has dramatic effects: the coefficient for lagged demand increases sharply from .92 to .98 (i.e. the speed of adjustment falls from .08 to .02), so that the long-run price-elasticity increases quintuples, from 1.4 to 7.4.

Because we would not expect income growth to affect oil usage negatively, we performed statistical tests only for these latter equations, which exclude the income variable. As was the case with the distillates demand equations, the results allow us to reject the Perfectly Price-Reversible specification, in favor of the Imperfectly Price-Reversible case. In particular, the Chow test is failed by the Perfectly Reversible case, but not by the Imperfectly Reversible case. Moreover, the Wald test on the Perfectly Reversible hypothesis is clearly rejected.

The tests for the two special cases of irreversible specifications are less clear than those for non-transportation distillates or for total non-transportation oil. The Traill hypothesis can be rejected at the 10 per cent level but not at the 5 per cent level, while the Wolffram hypotheses cannot be rejected at either. The evidence thus leans toward the Wolffram specification, suggesting an equal response to all price increases, whether above the historical maximum or not.

Table 6. Residual Fuel Oil Demand: Pooled 11-region OECD, data sample 1970-91; data in logarithms.

	Perfectly Price-Reversible		Imperfectly Price-Reversible					
	with GDP	without GDP	with GDP			without GDP		
Income (GDP): γ	-.18 (t=-3.3) η=-2.2		-.05 (t=-.5) η=-.5					
lagged demand: ϕ	.92 (t=34.)	.98 (t=58.)	.90 (t=31.)			.90 (t=32.)		
	P: β	P: β	P_{max}: β_m	P_{cut}: β_c	P_{rec}: β_r	P_{max}: β_m	P_{cut}: β_c	P_{rec}: β_r
Price	-.11 (t=-7.7) η=-1.4	-.13 (t=-8.9) η=-7.4	-.13 (t=-4.3) η=-1.34	-.08 (t=-3.3) η=-.9	-.16 (t=-3.2) η=-1.34	-.145 (t=-6.2) η=-1.45	-.08 (t=-3.7) η=-.8	-.158 (t=-3.2) η=-1.58
Adjusted R^2	.9986	.9985	.9985			.9985		
F-statistic	12937.	12991.	10514.			11206.		
Sum of Squared Residuals	185.	186.	162.			162.		
Ramsey RESET test hypothesis: no specification error		F-stat.prob.=.16 cannot reject				F-stat.prob.=.33 cannot reject		
Chow test: pre'85,post'86 hypothesis: same coefs. pre/post		F-stat.prob.=.01 reject				F-stat.prob.=.61 cannot reject		
Wald tests, of restrictions on price coefficients: hypothesis: Reversible $\beta_m=\beta_c=\beta_r$						F-stat.prob.=.00 reject		
specific types of irreversibility: hypothesis: Wolffram $\beta_m=\beta_r$						F-stat.prob.=.83 cannot reject		
hypothesis: Traill $\beta_c=\beta_r$						F-stat.prob.=.06 cannot reject		

Notes: The following statistical tests were done for each of the equations, and no problems were indicated: Lagrange Multiplier (Breusch-Godfrey) tests for autocorrelation, White test for heteroscedasticity, and ARCH tests.

Table 7. Sensitivity of Residual Fuel Demand elasticities to different ending years of the data sample, 1984-91

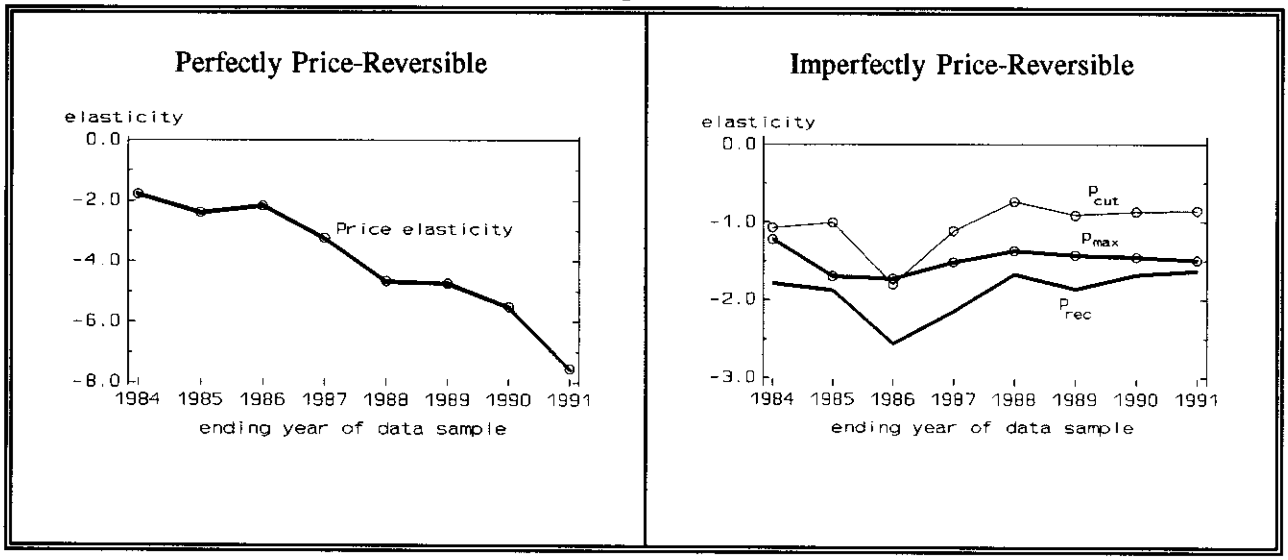
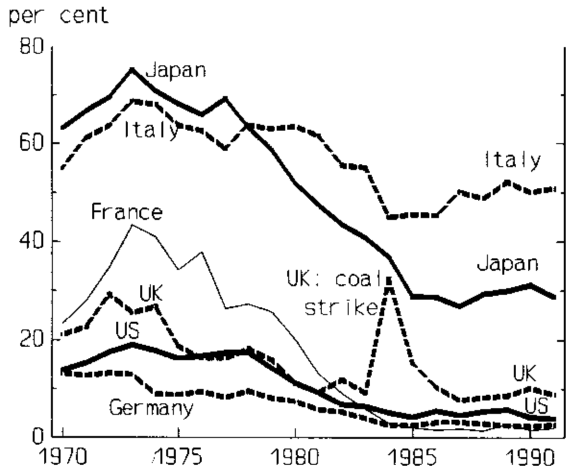


Table 7 displays the sensitivity of the results to extending the data sample from 1984 through 1991 -- years of low prices, moderate income growth, but virtually no demand growth. In the Perfectly Reversible case, the effect is not so much to change the price coefficient as to reduce the estimated speed of adjustment $(1-\phi)$ -- from .10 in 1984 to .02 in 1991. The result is that the estimated long-run price elasticity becomes much greater, because the period of adjustment is estimated to be much longer. With the Imperfectly Reversible specification, on the other hand, there is relatively little effect on the estimated elasticities.

3.4 Econometric Results: Share of Residual Fuel in Electricity Generation

Of course, it is not completely satisfactory simply to exclude income from the residual fuel demand equations. Thus we also examine, as an alternative dependent variable, residual-fuel's share of all fuels used in electricity generation. The graph at right shows how these shares have varied over the past two decades, for the six largest countries. In each of these countries, the share declined after the oil price increases of 1973-74 and 1979-80. However, although that decline has been stopped by the price cuts of the mid-1980's, it has not been reversed -- with the minor exception of the UK during the coal strike in 1984-85.

Figure 7 Residual Fuel Oil's Fuel Share of Electricity Generation



Using not residual fuel demand, but rather the share of residual fuel of in total fuel used in Electricity Generation, we estimate the following (semi-log) equations:

(3.1) Perfectly Price-Reversible:

$$\text{Resid. Share}_{it} = \alpha_i + \beta \log P_{it} + \phi \text{ Share}_{it-1}$$

(3.2) Imperfectly Price-Reversible:

$$\text{Resid. Share}_{it} = \alpha_i + \beta_m \log P_{max,it} + \beta_c \log P_{cut,it} + \beta_r \log P_{rec,it} + \phi \text{ Share}_{it-1}$$

The estimation results are shown in Table 8, and the sensitivity of the elasticities to the ending year of the data sample are shown in Table 9.

We see that the results in Table 8 differ somewhat from those of Table 6. Now the Chow test is passed not only by the Imperfectly Reversible specification, but also by the Perfectly Reversible case. However, for both cases, the Ramsey RESET test now suggests specification error, which would undermine confidence in either. In addition, the coefficient for P_{rec} has a relatively low t-statistic, so neither the Traill nor Wolffram specification can be preferred at any normal confidence level. However, the Wald test clearly rejects the Perfectly Reversible specification.

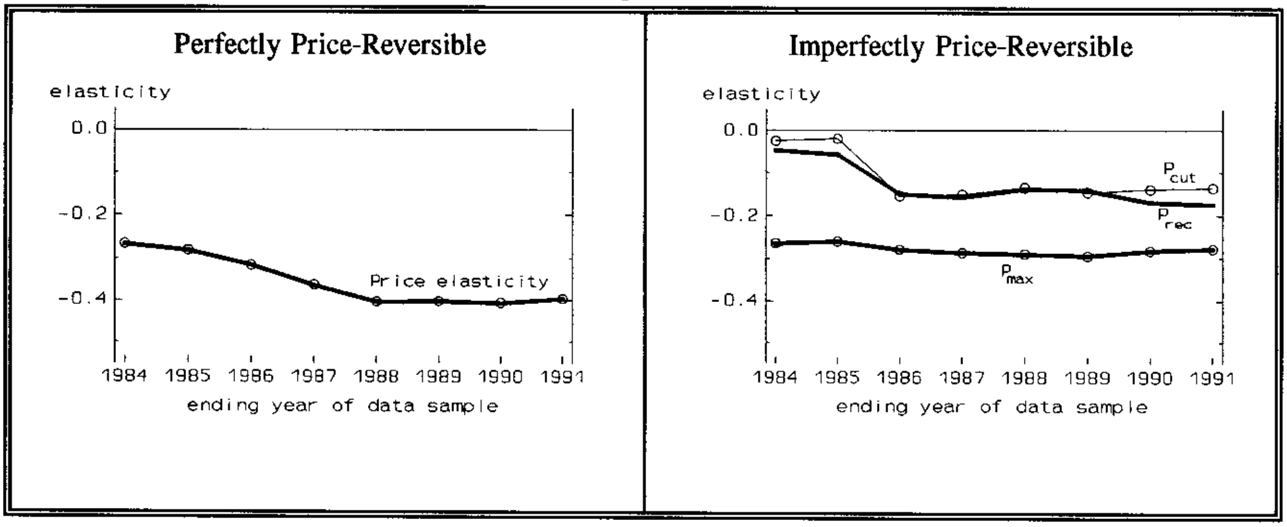
Table 8. Residual Fuel's Fuel-Share in Electricity Generation, Estimated Coefficients, t-values and Specification Tests: Pooled 11-region OECD, Data Sample 1970-91.

where η = long-run elasticity = coefficient/(1-ϕ)

	Perfectly Price-Reversible	Imperfectly Price-Reversible		
lagged Share: ϕ	.95 (t=51.)	.89 (t=34.)		
	P: β	P_{max}: β_m	$P_{cut:}$: β_c	P_{rec}: β_r
Price	-.02 (t=-6.4) η=-.4	-.031 (t=-5.9) η=-.28	-.015 (t=-3.3) η=-.14	-.019 (t=-1.7) η=-.17
Adjusted R^2	.9748	.9783		
F-statistic	742.	742.		
Sum of Squared Residuals	176.	149.		
Ramsey RESET test hypothesis: no specification error	F-stat.prob.=.02 reject	F-stat.prob.=.01 reject		
Chow test: pre-'85, post-'86 hypothesis: same coefs. pre/post	F-stat.prob.=.45 cannot reject	F-stat.prob.=.76 cannot reject		
Wald tests, of restrictions on price coefficients: hypothesis: Reversible $\beta_m=\beta_c=\beta_r$		F-stat.prob.=.00 reject		
specific types of irreversibility: hypothesis: Wolffram $\beta_m=\beta_r$		F-stat.prob.=.42 cannot reject		
hypothesis: Traill $\beta_c=\beta_r$		F-stat.prob.=.63 cannot reject		

Notes: The following statistical tests were done for each of the equations, and no problems were indicated: Lagrange Multiplier (Breusch-Godfrey) tests for autocorrelation, White test for heteroscedasticity, and ARCH tests.

Table 9. Sensitivity of price-elasticities of Residual-Fuel-Share of Electricity Generation to different ending years of the data sample, 1984-91



The sensitivity of the elasticities to the ending year of the data sample is shown in Table 9. For the Perfectly Reversible case, extending the data sample period through 1991 causes the price elasticity to increase (in absolute value). When additional years are included, the price coefficient diminishes, but the estimated speed of adjustment (1-ϕ) decreases even more, so that the long-run elasticity gets larger. For all ending years, the coefficients are always statistically significant.

For the Imperfectly Reversible case, the elasticities are relatively unaffected by extending the data sample, once 1986 or later is included. When 1984 or 1985 is the last year of the data sample, the elasticities for P_{rec} and P_{cut} are much smaller than those estimated using data including the 1986 price collapse or beyond. But the coefficient for P_{cut} is significant only after 1986 is included; the coefficient for P_{rec} is never statistically significant. The coefficient for P_{max}, however, is stable over the entire period, and always significant.

Taking into account all these results -- both for residual fuel demand and for its share of electricity generation -- we conclude that the Imperfectly Reversible specification is again superior to that of the Perfectly Reversible case.

4. Conclusions

In the early 1980's we were told by some analysts that oil prices would ratchet up: increasing when oil demand rose, but not retreating when oil demand was sluggish. Price would change in only one direction: up when the demand for OPEC oil rose, but not down when the demand for OPEC oil fell.

What actually happened in the 1980's is that we did see a ratchet process, but of a different type. It was not oil prices ratcheting up. Instead it was oil demand ratcheting down, and particularly oil in non-transportation uses. Price increases reduced demand when oil users switched away from oil, but price cuts did not reverse the process.

The phenomenon of imperfectly price-reversible oil demand is thus more widespread than may have been thought. As was shown elsewhere, the irreversibility of gasoline demand resulted primarily from automobile fuel-efficiency improvements not being reversed by the price cuts; these were due both to irreversible improvements in technology and to the non-reversal of government policies such as fuel-efficiency standards. But for non-transportation oil and for its two main products considered here -- non-transportation distillates and residual fuel -- the irreversibility is better explained by fuel-switching not being reversed by the price cuts.

Also in contrast to transportation oil demand, the dramatic response of non-transportation oil demand to the price increases of the 1970's has outweighed the positive effect of income growth since 1973. Non-transportation oil demand remains well below its 1973 level, while transportation oil demand has grown modestly.

For the OECD countries, this result is a mixed blessing. On the one hand, they may be comforted by now having both low oil prices and lessened oil-import dependence; they need not fear a full reversal of the demand reductions achieved in the past two decades. On the other hand, in the event of an oil price recovery (due either to OPEC or to domestic tax increases) they may not be able to rely upon the same demand reductions in the future as they experienced in the past. Fuel-switching or conservation measures, which had been done in response to the price increases of the 1970's but not un-done by the price declines of the 1980's, cannot be re-done if price recovers in the 1990's. The possibilities for demand reduction are smaller than in the 1970's, because the uses of oil which remain significant today are probably those less amenable to switching to other energy sources, and for which further efficiency improvements are more costly. The only cases in which non-transportation oil demand might be sharply reduced by a price recovery would be those where there is still a substantial amount of demand, and where fuel-switching is relatively easy.

Appendix A:
Data Sources

Real Income (GDP): *Energy Balances for OECD Countries* (Paris: International Energy Agency); taken originally from *OECD Main Economic Indicators*.

Oil Consumption: *Energy Statistics of OECD Countries* (Paris: International Energy Agency).

Real Price of Oil Products: *Energy Prices and Taxes* (Paris: International Energy Agency); *Annual Energy Review* (Washington: US Department of Energy);

We used the following prices:

for distillates:	Price of Light Fuel Oil, Industry
for residual fuel:	Price of Heavy Fuel Oil, Industry
for non-transportation oil:	volume-weighted average using the above two prices and -- for kerosene and all other non-transportation oil products -- the Price of Light Fuel Oil, Households.

All nominal prices were converted to real 1985 prices using domestic deflators, and then converted to 1985 US $, using 1985 exchange rates.

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