ECONOMIC RESEARCH REPORTS

OIL DEMANDS IN THE US AND JAPAN: WHY THE DEMAND REDUCTIONS CAUSED BY THE PRICE INCREASES OF THE 1970'S WON'T BE REVERSED BY THE PRICE DECLINES OF THE 1980'S

BY

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RR # 92-09 February, 1992

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Abstract:

This paper analyzes the imperfect price-reversibility ("hysteresis") of oil demand in the US and Japan. We test econometrically oil demand data, disaggregated into transportation oil and non-transportation oil uses.

The oil demand reductions following the oil price increases of the 1970's will not be completely reversed by the price cuts of the 1980's. The response to price cuts in the 1980's is perhaps only one-fifth that for price increases in the 1970's. This has dramatic implications for projections of oil demand, especially under low-price assumptions.

We also consider the demand effects of a price recovery in the 1990's, specifically whether the effects would be as large as for the price increases of the 1970's or only as large as the smaller demand reversals of the 1980's. On this the results are inconclusive.

Keywords: price reversibility; hysteresis; oil demand
Journal of Economic Literature classification number: Q41

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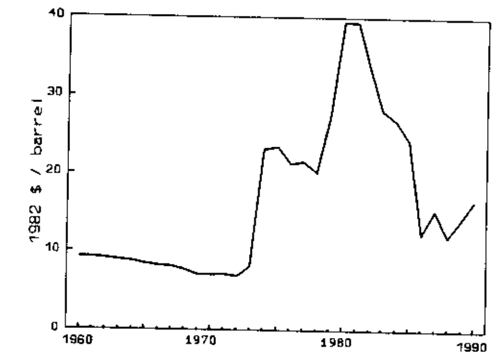
The author is grateful for research support from the C. V. Starr Center for Applied Economics and from the Center for Japan-U.S. Business and Economic Studies, both at New York University. He is also grateful to Ken Rogoza for technical support and Wei Zheng for excellent research assistance. He would also like to thank Hill Huntington for helpful comments on a previous draft. Of course, none of the above are responsible for any remaining errors.

1. Introduction

Two developments in the last decade have posed important questions for analysts of world oil demand. One is the decline of oil prices since the early 1980's, especially in 1986. These declines reversed most of the price increases achieved by OPEC in the 1970's. A continuation of relatively low prices seems possible for much of the 1990's, given the willingness of Saudi Arabia to increase its capacity and its production, and given the resumption of production from Kuwait and Iraq. With low prices in the 1990's, the key question is whether low prices would reverse the demand reductions caused by the price increases of the 1970's. Would oil demand surge: is demand perfectly price-reversible? However, many energy-efficiency improvements are irreversible. Attic insulation will not be ripped out. Improved aerodynamic design of vehicles will not be abandoned. Hence, the demand reductions will be (at most) only partially reversed.

Figure 1. International Price of Crude Oil 1960-90 (1982 $ / barrel)



The second development is the growing concern about global warming, caused by greenhouse gas emissions, especially carbon dioxide from fossil fuels (oil, gas, and coal). This concern is manifested in proposed limits on carbon dioxide emissions. A lively debate has ensued. Some economists have argued that it would be too costly to limit such emissions, and instead far more cost-effective to mitigate the effects of global warming. Others have disagreed, arguing that emissions could be reduced at relatively low cost. In effect, this is a second reversibility question. Will the demand response to a tax increase in price be comparable to what was the response to the price cut -- will the partial demand reversal itself be reversed? Or will it be much larger, perhaps as large as it would be to another increase in the maximum historical price?

These issues can be reduced to a pair of simple questions. First, if oil prices remain low, how rapidly will oil demand grow? Second, if oil prices are increased (perhaps by taxes, in order to reduce carbon dioxide emissions), what will be the effect on oil demand?

The outline of the paper is as follows. Section 2 summarizes the growth of energy and oil demand for the US and Japan, relative to growth in income and changes in price. Section 3 presents a framework within which to analyze whether oil demand is imperfectly price-reversible. It distinguishes between the demand response to three different types of price changes: increases in the maximum historical price, decreases in price, and price recoveries (sub-maximum increases).

We then examine econometrically, for evidence of imperfect price-reversibility, oil demand in the US and Japan, disaggregated into oil used for transportation and oil used for other purposes. This is done in Sections 4 and 5, for the US and Japan respectively. The econometric results allow us to reject the hypothesis of perfect price-reversibility. The demand response to price increases is perhaps five times greater than the response to price cuts.

Finally in Section 6, we discuss the implications of different types of price-reversibility for oil demand in the 1990's, and for the likely response to either continued low prices or price increases.

2. Energy and Oil Consumption in the US and Japan

2.1 Energy Consumption: Oil, Coal, Natural Gas, Hydro, and Nuclear

Figure 2. US Energy Consumption, by Fuel: 1960-89.
MTOE: million tons oil equivalent

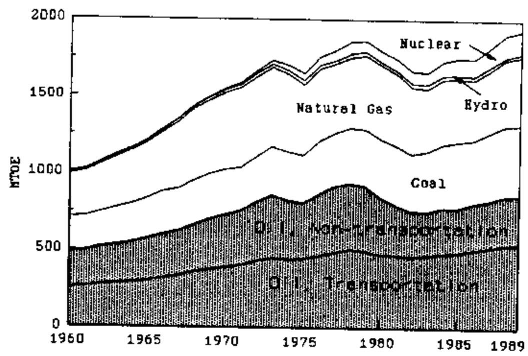
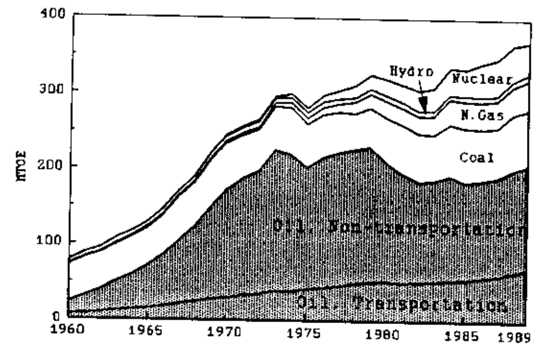


Figure 3. Japan Energy Consumption, by Fuel: 1960-89.
MTOE: million tons oil equivalent



In both the US and Japan during the decade prior to the 1973-74 oil price shock, energy demand grew steadily: about as rapidly as did GNP (shown below). Since then, however, energy demand has virtually flattened out. This has resulted from energy conservation following the price increases, and from slower GNP growth.

Prior to 1973-74, oil demand also grew steadily: as rapidly as income in the US, and even faster than income growth in Japan, especially for non-transportation uses such as electricity generation. But since then, although transportation oil use has continued to grow in both countries, oil used for non-transportation purposes has been greatly reduced, due both to fuel-switching and efficiency improvements. With increases in transportation oil outweighing the declines in non-transportation oil, total oil demand has grown slowly in both countries since the mid-1980's, although it remains below its previous peak of 1978.

Figure 4. US Energy Consumption, Fuel Shares: 1960-89 (% of total)

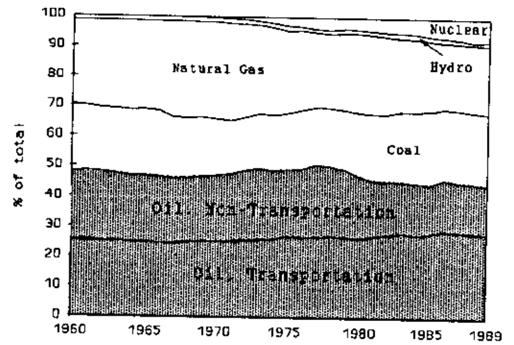
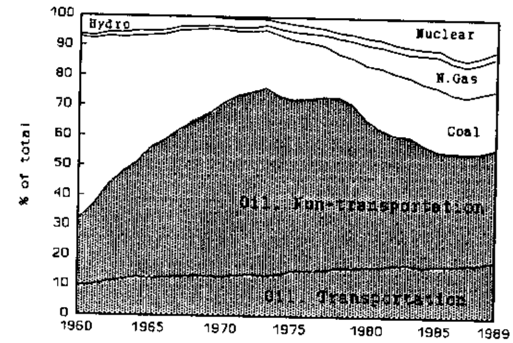


Figure 5. Japan Energy Consumption, Fuel Shares: 1960-89 (% of total)



With respect to fuel shares, US energy consumption is more diversified than Japan's. Although oil constitutes more than 40% of total US energy consumption, substantial amounts of both coal and natural gas are also used; their combined share exceeds that of oil.

Japan, in contrast, is much more dependent upon oil than the US. During the 1960-73 period, Japan had shifted rapidly toward oil, especially for non-transportation purposes: oil's share grew from about one-third to nearly three-fourths. This shift toward oil has been reversed since 1973, but Japan still gets about 60% of its energy from oil, which is about twice the combined share of coal and natural gas.

Since 1973 both countries have reduced their dependence on oil for non-transportation purposes. The US has shifted toward coal and nuclear. Japan has shifted even more dramatically, toward natural gas, nuclear and coal.

The energy share of oil used for transportation has continued to increase slowly, in both countries. Transportation oil constitutes a higher percentage of total energy in the US than in Japan, even though the energy share of total oil is considerably lower in the US than in Japan.

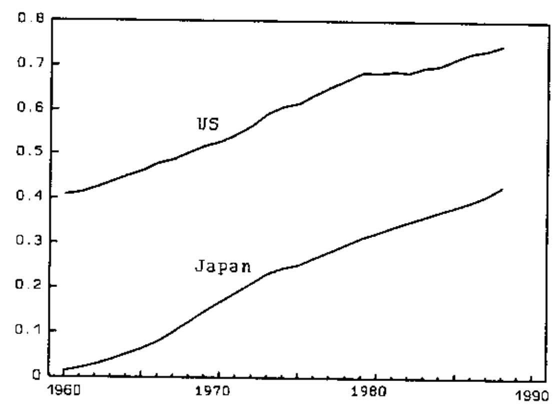
2.2 Oil Consumption: Transportation & Non-Transportation

Oil use in the US is far more concentrated in transportation than is the case for Japan. In 1990 nearly two-thirds of total US oil is used for transportation, compared with about one-third in Japan. The non-transportation percentage of total oil use is declining in both countries, due to the greater possibilities for fuel-substitution in non-transportation uses of oil (space and water heating, industrial uses, and as a fuel for generating electric power).

Since 1973, US transportation oil use has grown much more slowly than in Japan, for two main reasons. One is greater improvements in US automobile fuel-efficiency, which had started from a much lower level than in Japan. The second reason is the post-1978 slowdown in growth in the number of registered drivers in the US. During the period 1960-78, the number of drivers grew more than twice as fast as population: a combination of baby-boomers getting drivers' licenses and a rapid increase in the percentage of adults holding licenses.

Japan, on the other hand, used more than twice as much transportation oil in 1990 as in 1973. In part, this resulted from continuing growth in vehicle availability during 1973-90: the vehicle/population ratio has continued to rise. It is now at a level where the US was in 1960: about 40 vehicles for every 100 people. Despite a slowdown from the breathtaking rates of 1960-73 (during which the number of cars registered grew at an annual rate exceeding 30%), the number of vehicles in Japan has doubled since 1973.

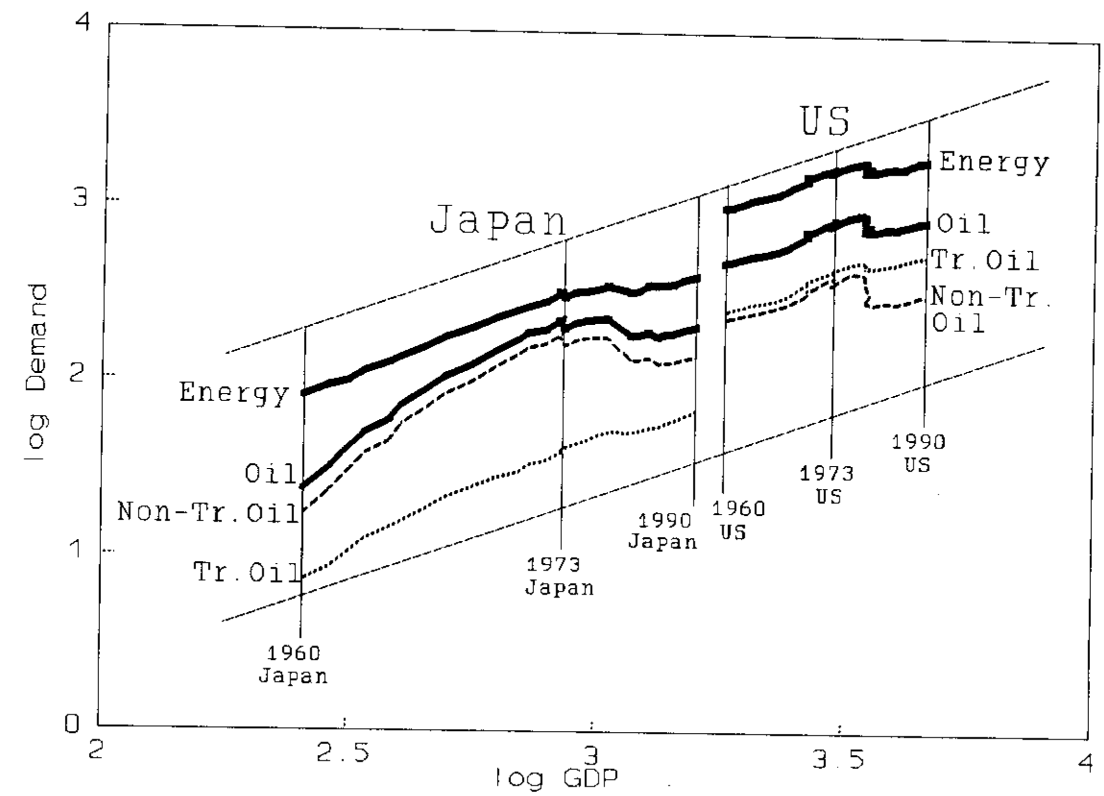
Figure 6. Vehicle/Population Ratios, US & Japan: 1960-88



The US, on the other hand, is effectively saturated with vehicles: every American adult can sit in a driver's seat. The vehicle/population ratio has been about 70% for nearly a decade.

2.3 Energy & Oil Demand, relative to Real Income

Figure 7. US & Japan, Energy & Oil Consumption vs. GDP: 1960-90 (logarithmic scales) with (dashed) unitary income-elasticity lines



The graph above shows the growth of energy and oil demand, relative to growth in real income, from 1960 through 1990. Because the axes are measured logarithmically, horizontal [vertical] distances measure *percentage* changes in income [energy or oil], rather than absolute changes. The diagonal (dashed) lines show unitary income-elasticity: movement parallel to these lines indicates the same percentage change in energy or oil consumption as in income. Vertical lines are used to mark 1960, 1973, and 1990 in the two countries respectively.

We see that real income grew much more rapidly in Japan than in the US, especially prior to 1973. Since then, income growth in both countries has slowed dramatically. Japan's energy consumption grew slightly faster than income before 1973, but slower than income after 1973. Japan's oil consumption grew much faster than income prior to 1973, due to the rapid growth in non-transportation oil use. But oil demand has flattened out since then, despite the fact that income has continued growing (although at a much slower rate than before 1973). The declines in non-transportation oil have outweighed the increases in transportation demand.

In the US, energy and oil demand grew about as rapidly as income until 1978. After significant reductions in oil consumption during 1978-82, especially in non-transportation uses, energy and oil demand have grown about half as fast as income since then.

2.4 Energy/Income and Oil/Income Ratios

Figure 8. US Energy/GDP and Oil/GDP Ratios, 1960-90

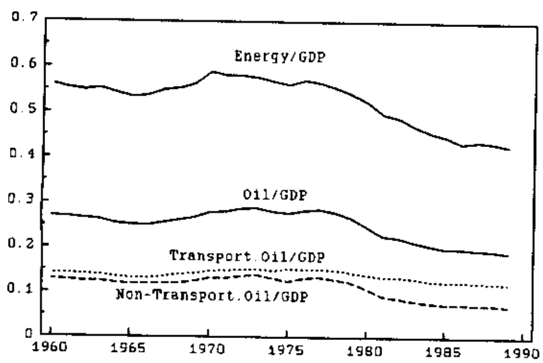
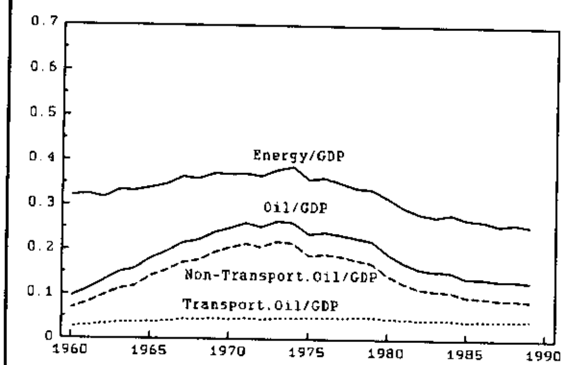


Figure 9. Japan Energy/GDP and Oil/GDP Ratios: 1960-90



Prior to 1973, the US energy/GDP and oil/GDP ratios were relatively flat, while Japan's were increasing -- due to its rapid shift toward oil for non-transportation purposes. Since 1973 the ratios have declined in both countries. The greatest reductions have been in non-transportation oil: Japan reduced to 40% of its 1973 level; US to 49% of its 1973 level. Smaller reductions occurred in transportation: the US ratio has declined by about 20%, three times as large a decline as in Japan.

Despite significant improvements in the US since 1973, the oil/GDP ratio has declined more in Japan. This follows from Japan's far greater share of non-transportation oil in total oil, and the dramatic reductions in non-transportation uses of oil in both countries.

Cross-country comparisons of absolute levels of energy/GDP and oil/GDP ratios should be made cautiously, for reasons discussed most recently in Shin(1991). He examines the detailed structural differences on a sectoral level: residential, transportation, and manufacturing (disaggregated into ten industries). For example, the fact that US residential energy consumption per capita is nearly four times greater than Japan's does not imply US energy inefficiency. The difference is almost completely explained by inter-country differences in living space per person.

3. The Analysis of Imperfectly Price-Reversible Demand

If oil demand were perfectly price-reversible, then demand would respond to all types of price change in similar ways. A demand reduction caused by a price increase would be exactly reversed if price were to decline to its original level: demand also would return to its original level. Moreover, if price were to recover subsequently to its previous maximum level, the demand reduction would be the same as when price increased initially.

However, if demand were not perfectly price-reversible, then the oil demand reduction following a price increase would not be completely reversed when price fell. For example, if oil price increases resulted in better insulated attics and reduced oil demand, we would not expect that an oil price decline would cause insulation to be removed and oil demand to increase. Nor would it necessarily be true that the demand response to a price recovery would be the same as to the original price increase. Attic insulation would not be re-done because it had not been un-done.

Previous work on irreversibility in economic relationships has proceeded along several lines. The first work was done on the price-reversibility of agricultural supply, by Wolffram(1971) and by Traill, Colman, and Young(1978). Analysis of the price-reversibility of energy and oil demand has utilized this approach[1], which is used below.

Subsequent work has been done in other areas of economics, adopting the physics term *hysteresis*: an effect that persists even after the factor that caused it has been removed. Much of this work is based upon the irreversible, sunk-cost nature of investment[2]. Applications have appeared in international economics and in macroeconomics[3]. But this literature made no reference to the

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[1] The initial studies estimated demand-elasticities with respect to price and income, and the dynamics of the long-run adjustment; see Pindyck(1979) and Hogan(1986), among others. But after the oil price collapse of 1986, economists began to address the question of whether the demand reductions might be reversed: see Gately & Rappoport(1988), Brown & Phillips(1991), Shealy(1990), and Dargay(1990a,1990b).

[2] See the survey by Pindyck(1991), which describes work by Dixit, Baldwin and Krugman, Pindyck, and others.

[3] In international economics, the persistence of the US trade deficit in the late 1980's has been explained as the result of hysteresis in the trade-balance relationship and in the import-price pass-through equation. The rising value of the dollar in the early 1980's led to an increase in the trade deficit and lower real import prices. However, the subsequent decline in the dollar after 1985 brought about only small increases in real import prices and very slow improvement in the trade balance. Baldwin(1988) and Baldwin-Krugman(1989) propose an industrial organization model of entry and exit decisions to (continued...)

previous work on the price-reversibility of agricultural supply. Nor did it utilize the econometric techniques which were proposed there; equations were only examined for structural breaks at the time of the price decline.

3.1 Decomposing Price into 3 Monotonic Series

In order to distinguish between the three possibly different responses to the three different types of price change, let us decompose the Price P_t into its 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):

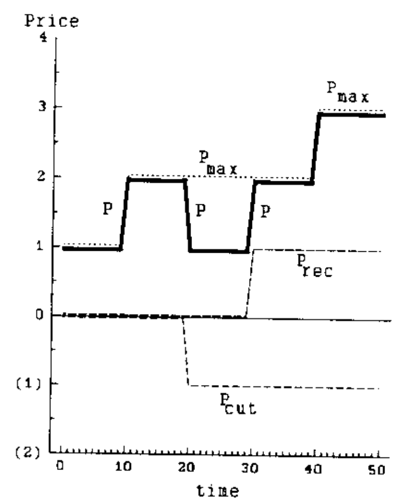
(1) $P_t = P_{max,t} + P_{cut,t} + P_{rec,t}$

(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 10. Decomposing Price into 3 Series



The decomposition of an illustrative price-path is presented in the graph. Price doubles in time period t=10, returns to its original level in t=20, recovers to its previous maximum in t=30, then increases to a new maximum in t=40.

The maximum historical price series P_{max} is non-decreasing; it increases in times t=10 and t=40.

The price cut series P_{cut} is non-positive and non-increasing. It shows the price cut in time t=20, and remains at that level. By definition non-increasing, it would decrease if any further price cuts were made.

[3](...continued)
explain the hysteresis. The increase in the value of the dollar caused foreign firms to invest in the US, incurring sunk costs to expand their marketing and distribution networks. These sunk costs cannot be recouped if the firms were to exit; the firms will remain profitable even at a lower exchange rate.

In macroeconomics, Blanchard and Summers(1987) provide a hysteresis explanation for the persistence of high unemployment in Europe in the 1980's, despite the reversal of the oil price increases and the absence of other obvious macroeconomic shocks. Their explanation of high wages persisting in the face of high unemployment is based upon wage-setting being dominated by firms' incumbent workers, with the unemployed exerting little or no downward pressure on wages.

Conversely, the price recovery series P_{rec} is non-negative and non-decreasing. It shows the cumulation of all price recoveries (increases below historical maxima). It remains at zero until the price recovery in time t=30, and it remains at that level subsequently because there are no further price recoveries assumed. By definition non-decreasing, it would increase if further price recoveries were to occur.

3.2 Demand, with or without Perfect Reversibility

Given this decomposition of price, we can now deal explicitly with different types of price-irreversibility. Suppose we have a simple linear demand equation, with no lagged adjustment to changes in price, and no other explanatory variables. If demand were perfectly price-reversible, then we would have the equation:

(2) $D_t = k_0 - k_1 P_t$

To allow for imperfect price-reversibility, we substitute the price decomposition (1) into (2):

(3) $D_t = k_0 - aP_{max,t} - bP_{cut,t} - cP_{rec,t}$

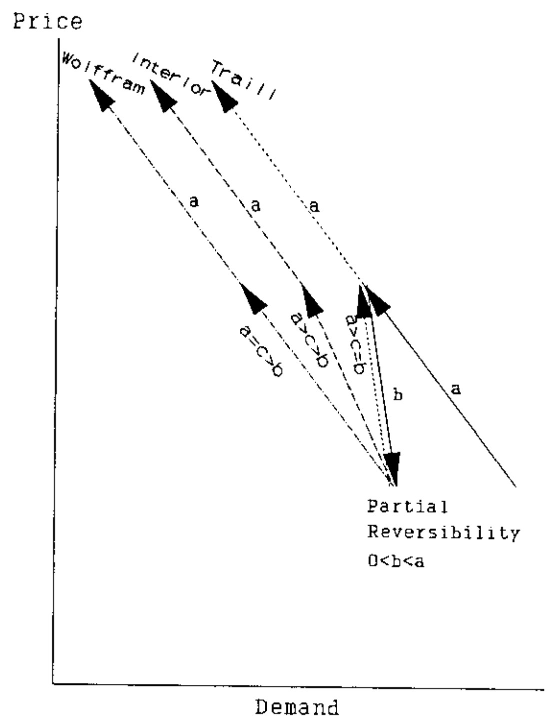
We expect that the response to a price cut would be smaller than to an increase in P_{max}: $a > b$. We also expect that the response to an increase in P_{max} ought to exceed the response to a price recovery: $a > c$. Finally, we expect that the response to a price recovery ought to be no smaller than to a price cut: $c > b$; that is, the net effect of letting price collapse and then recover cannot be to *raise* demand -- demand would either decrease or be unchanged. Thus, in the most general case, we expect the size of these coefficients to be as follows: $a \geq c \geq b \geq 0$.

This approach has its origins in the literature on irreversible agricultural supply, in which the irreversibility results from asset fixity and the divergence between the acquisition cost of an input and its salvage value. Wolffram(1971) first proposed a specification in which irreversibility was possible. Using our notation, he assumed $a = c > b$. That is, he assumed that the response to an increase in P_{max} would be greater than to a price cut ($a > b$). But he also assumed that the response to a price recovery would be as large as it would be to an increase in P_{max} ($c = a$).

Traill *et al.*(1978) modified Wolffram's approach. They assumed that the response to an increase in P_{max} would exceed that of a price recovery ($a > c$). But they also assumed that the response to a price recovery would be equal to the response to a price cut ($c = b$), which precludes the possibility of ratchets.

Our approach in this paper allows for all of these as special cases, since we can provide estimates for all three coefficients of the price-decomposed series. In particular, we allow for the intermediate case in which a > c > b. In the graph, this case lies between those of Wolffram and of Traill. Unlike Wolffram, we do not necessarily assume the same response to all price increases. Unlike Traill, we do not necessarily assume that the response to a price cut will match the response to a price recovery.

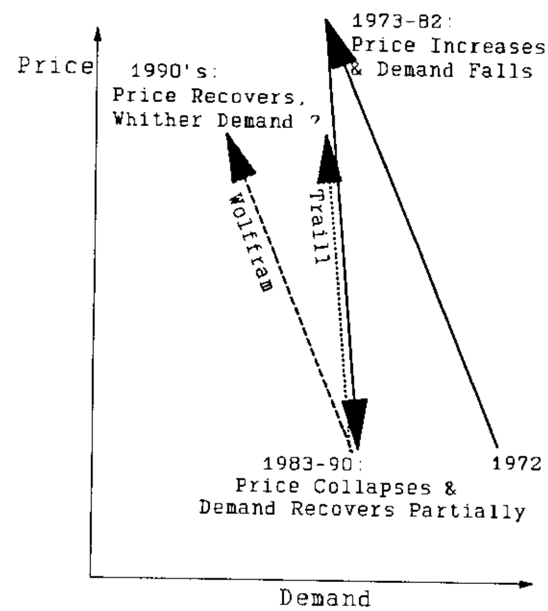
Figure 11. Coefficients $a \geq c \geq b \geq 0$ & types of price-irreversibility



A full taxonomy of all the possible types of imperfect price-reversibility is provided in Gately(1991), and this approach is used there to analyze US gasoline demand. Previous work in energy demand has used various of these specifications. A specification equivalent to Wolffram's was used in Gately & Rappoport(1988), and in Brown & Phillips(1991); used as regressors were both P_t and $(P_{max,t}+P_{rec,t})$. A Traill-equivalent specification has been used in Gately(1990) and in Shealy(1990); the regressors include both P_t and $P_{max,t}$. Dargay(1990a), which had an especially clear discussion of the issues involved, examined several of the specifications.

At the risk of getting ahead of our story, let us present graphically -- in a greatly simplified form -- what has happened since the price increases of the 1970's, and what we might expect in the 1990's if price were to be increased. With respect to our first question, of whether the price collapse of the 1980's would reverse the demand reductions that followed price increases of the 1970's, the answer is no. The demand response to the price cuts has been much smaller than for the price increases: only about one-fifth of the demand reductions will be reversed.

Figure 12. Oil Demand Responses to Price Increase, Decrease, & Recovery: 1972-2000



Our section question, which amounts to a choice between the Wolffram and the Traill specification of irreversibility, is whether a price recovery in the 1990's would reduce demand by as much as the price increases of the 1970's (Wolffram), or only by as much as the partial demand reversal when price collapsed (Traill). On this question, unfortunately, the evidence is inconclusive.

Wolfframm-irreversibility yields the best of both worlds for consumers, and the worst for OPEC. Demand falls when price rises to new historical levels. But when price falls, the demand reductions are not fully reversed; demand does not recover completely. Yet when price recovers, demand falls again, by as much as it did originally. Thus, demand is ratcheted down: reduced when price increases, but not increased when price falls, and reduced again when price recovers.

For Traill-irreversibility, the message is mixed. Demand fell when price jumped in the 1970's, and did not recover completely when price fell in the 1980's. However, a price recovery in the 1990's will not reduce demand by much at all: it will exactly reverse the small reversal of demand caused by the price cuts of the 1980's. Demand did not surge when price collapsed, so neither can it fall by much when price recovers.

4. US Oil Demand

Figure 13. US: Real Prices, Oil Products

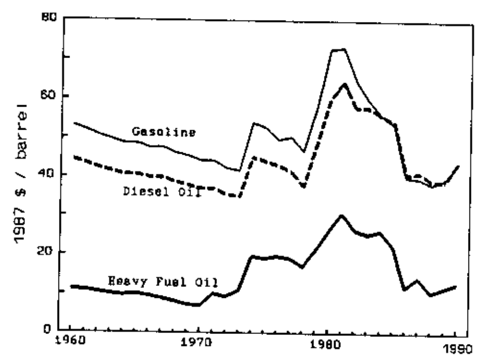
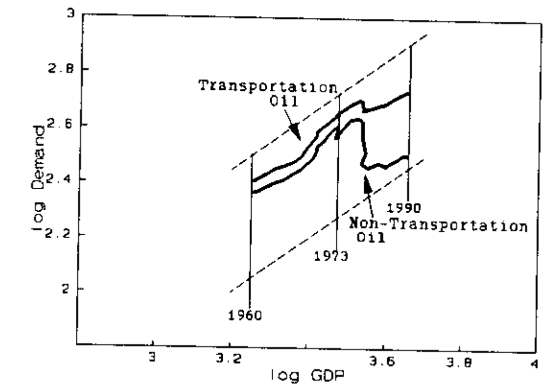


Figure 14. US Oil Demand vs. Income, 1960-90 (logarithmic scales)



As we see in the graph of the US prices of oil products above, product prices had declined substantially in the decade prior to the 1973-74 price shock, by much more than had the world price of oil (Figure 1). The decline is even more dramatic in Japan, which is discussed in the following section. As a result, the 1973-74 price increase did not represent much of an increase in the maximum historical price, but was instead more a price recovery. Hence -- despite the dramatic 1973-74 increases in world oil prices to historically high levels, as shown in Figure 1 -- we do not have an unambiguous test of the effect the 1973-74 price shock. This will influence the results that follow, and especially our choice of the Wolffram specification, which assumes the same response to all price increases, both increases in maximum historical price and price recoveries.

4.1 US Oil Demand, Transportation

Oil used in transportation consists primarily of highway fuel (gasoline and diesel) for personal transportation in cars and light trucks, and for freight transport in large trucks. Jet fuel is also important, comprising more than 10% of all transportation uses. The demand for these fuels have been analyzed separately, in Gately(1988, 1990, 1991). Here we aggregate all transportation uses of oil, and estimate econometrically their historical determinants.

As was shown in Gately(1990), a previously omitted variable which is needed to explain the growth of highway travel and fuel demand is the number of drivers. Especially prior to 1978, this grew much more rapidly than did real income, for two reasons: the baby-boomer surge in licensed drivers, and an increase in the percentage of adults holding drivers' licenses (from 75% in 1960 to above 90% by 1990). But neither of these two phenomena will continue in the 1990's. Instead, there will be a continuing slowdown in the growth rate of the number of drivers, and thus the upward pressure on highway travel and fuel use.

Our specification of the demand equation for transportation oil thus includes both real income and the number of drivers, together with the price of oil. We assume that the structure of lagged response to past price changes is that of a quadratic polynomial distributed lag, over a ten-year period.[4] For price, we use the Refiners' Acquisition Cost of Crude Oil, rather than product prices; this allows us to use a consistent price series back to 1949.

We examine three alternative specifications of the demand equation: perfect price-reversibility, imperfect price-reversibility (the general case, with separate coefficients for all three components of price), and Wolffram imperfect price-reversibility (same coefficients for both types of price increase, P_{max} and P_{rec}).

The results are presented in Table 1. All three regressions appear to have good results, except for the Chow-forecast test probabilities of the perfectly-reversible case. All coefficients have the expected signs (except for the P_{cut} coefficients in (4.2)), and all are statistically significant (except for the P_{cut} coefficients in (4.2) and (4.3)). The regressions' Adjusted R^2 and F-statistics are very high.

In either of the imperfectly price-reversible specifications, the estimated effect of price cuts is very small, especially in comparison with the response to price increases. Similarly, the estimated coefficients for GNP and drivers in either of the two imperfectly price-reversible specifications are higher than in the perfectly price-reversible specification. Thus, for the two imperfectly price-reversible specifications, the demand growth in the 1980's is explained more by the growth of GNP and drivers than by the price reductions. The opposite is true for the perfectly price-reversible case: demand growth in the 1980's results more from the price reductions than by the growth of GNP and drivers.

[4] Other lag-lengths were examined, as were cubic polynomial distributed lags, but the basic results were similar. Ideally, of course, it would be better to impose less structure on the form of the lagged coefficients. Our approach was necessitated by the long lags involved in demand adjustment, and the need to examine the lagged effects of two or three price series.

Table 1. US Oil Demand: Transportation; data sample 1949-90; data in logarithms.

(4.1) Perfectly Price-Reversible:

$$D_t = k_0 + k_1 GNP_t + k_2 Drivers_t + \Sigma_{i=0..10}\, \alpha_i P_{t-i} + AR(1)$$

(4.2) Imperfectly Price-Reversible:

$$D_t = k_0 + k_1 GNP_t + k_2 Drivers_t + \Sigma_{i=0..10}\, \alpha_i P_{max,t-i} + \Sigma_{i=0..10}\, \beta_i\, P_{cut,t-i} + \Sigma_{i=0..10}\, \tau_i P_{rec,t-i} + AR(1)$$

(4.3) Wolffram: Imperfectly Price-Reversible:

$$D_t = k_0 + k_1 GNP_t + k_2 Drivers_t + \Sigma_{i=0..10}\, \alpha_i (P_{max,t-i} + P_{rec,t-i}) + \Sigma_{i=0..10}\, \beta_i\, P_{cut,t-i} + AR(1)$$

	Perfectly Price-Reversible	Imperfectly Price-Reversible			Wolffram: Imperfectly Price-Reversible	
constant	-4.85	-7.29			-6.64	
GNP	0.63	0.70			0.78	
# Drivers	0.49	0.87			0.67	
AR(1)	.86	0.69			0.75	
	P	P_{max}	P_{cut}	P_{rec}	P_{max} & P_{rec}	P_{cut}
Price t=0	-.007	-.003	.00001	-.022	-.008	-.001
t-1	-.012	-.005	.0002	-.040	-.015	-.002
t-2	-.017	-.006	.0002	-.054	-.020	-.003
t-3	-.020	-.007	.0003	-.064	-.024	-.004
t-4	-.022	-.008	.0003	-.070	-.026	-.004
t-5	-.022	-.008	.0003	-.072	-.027	-.004
t-6	-.022	-.008	.0003	-.070	-.026	-.004
t-7	-.020	-.007	.0003	-.064	-.024	-.004
t-8	-.017	-.006	.0002	-.054	-.020	-.003
t-9	-.012	-.005	.0002	-.040	-.015	-.002
t-10	-.007	-.003	.00001	-.022	-.008	-.001
sum	Σ=-.176	Σ=-.066 (t=-1.)	Σ=.0024 (t=.04)	Σ=-.571	Σ=-.213	Σ=-.035 (t=-.5)
Adjusted R^2	.9945	.9966			.9959	
F-statistic	1358	1454			1474	
Probabilities, Chow Forecast Test 1984	.099	.99			.71	
1985	.058	.99			.58	
1986	.029	.96			.44	
1987	.016	.93			.30	

Note: t-statistic is shown only when coefficient is not statistically significant.

The probability estimates from the Chow forecast tests clearly indicate the inferiority of the perfectly price-reversible specification. For any of the break-point years (1984 through 1987), it is highly improbable that the post-break-point data would be consistent with projections based on pre-break-point econometric estimates. In contrast, this is not true for either of the two imperfectly price-reversible specifications.

In the results for equation (4.2), the relative size of the two price-increase components is surprising: the response to price recoveries is almost ten times larger than for increases in maximum historical price. However, this is merely a result of our previous observation that the 1973-74 price increase was a price recovery rather than an increase in maximum historical price. More reasonable are the results of the Wolffram specification (4.3), which assumes the same response to all price increases. However, it should be noted that this does not tell us much about the response to post-1973 price recoveries, because there have been almost none.

4.2 US Oil Demand, Non-Transportation

A similar approach was used for non-transportation oil demand, as a log-linear function of real income and the real price of oil. However, because greater possibilities for fuel-switching possibilities allow more rapid adjustment to price changes, we assumed a partial-adjustment (Koyck) lag mechanism. The results for three price-reversibility specifications are shown in Table 2: the perfectly price-reversible case, imperfect price-reversibility (the general case, with separate coefficients for all three components of price), and Wolffram imperfect price-reversibility.

For the perfectly reversible case (5.1), the statistical results are reasonably good. All coefficients have the expected signs; and all are significant, except for GNP. The Adjusted R^2 and F-statistic are good, as are the probabilities for the Chow forecast test. However, the estimated speed of adjustment to a price change is surprisingly slow: it takes more than 15 years for half of the total price-adjustment to occur.

For the general form of imperfect price-reversibility (5.2), the statistical results are reasonable: high Adjusted R^2 and F-statistic, with coefficients having the expected sign and significant (except for P_{cut} and P_{rec}, which have the wrong sign but are not significant). However, the Chow forecast test probabilities are low enough to allow us to reject that specification. For each of the break-point years, it is highly improbable that the post-break-point data would be consistent with projections based on pre-break-point econometric estimates.

Finally, for the Wolffram case, the results are the best of the three. All coefficients have the expected sign, and all are significant except for P_{cut}. The Adjusted R^2 and F-statistic are high, and the probabilities for the Chow forecast test are twice as high as for the reversible case (5.1). The speed of adjustment to a price change is also more reasonable than for the reversible case: it takes about four years for half of the adjustment to occur.

Table 2. US Oil Demand: Non-Transportation; data sample 1949-90; data in logarithms.
(5.1) Perfectly Price-Reversible:
$D_t = k_0 + k_1 GNP_t + \alpha P_t + k_2 D_{t-1}$
(5.2) Imperfectly Price-Reversible:
$D_t = k_0 + k_1 GNP_t + \alpha P_{max,t} + ß P_{cut,t} + \tau P_{rec,t} + k_2 D_{t-1}$
(5.3) Wolffram: Imperfectly Price-Reversible:
$D_t = k_0 + k_1 GNP_t + \alpha (P_{max,t} + P_{rec,t}) + ß P_{cut,t-i} + k_2 D_{t-1}$

	Perfectly Price-Reversible	Imperfectly Price-Reversible			Wolffram: Imperfectly Price-Reversible	
constant	.076 (t=.6)	-1.87			-1.11 (t=-1.6)	
GNP	.033 (t=1.0)	.38			.22	
lagged demand	.96	.72			.85	
	P	P_{max}	P_{cut}	P_{rec}	P_{max} & P_{rec}	P_{cut}
Price	-.094	-.19	.027 (t=.9)	.017 (t=.5)	-.116	-.034 (t=-.7)
Adjusted R^2	.9819	.9847			.9833	
F-statistic	707	502			576	
Probabilities, Chow Forecast Test 1984	.44	.05			.84	
1985	.49	.03			.93	
1986	.45	.03			.94	
1987	.41	.01			.86	

Note: t-statistic is shown only when coefficient is not statistically significant.

5.0 Japan Oil Demand, 1960-90

Figure 15. Japan: Oil Products, Real Prices

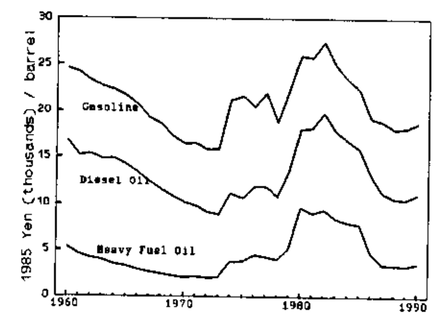
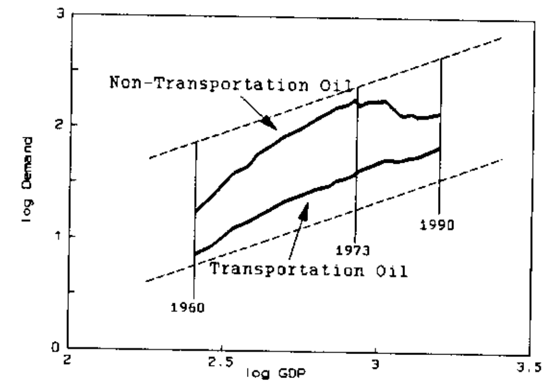


Figure 16. Japan Oil Demand vs. Income, 1960-90 (logarithmic scales)



Even more than in the US, oil product prices in Japan had declined substantially in the decade prior to the 1973-74 price shock, by much more than the world price of oil (Figure 1). As a result, the 1973-74 price increase was a price recovery rather than an increase in the maximum historical price. This determines our choice of the Wolffram specification, which assumes the same response to all price increases, both increases in maximum historical price and price recoveries.

5.1 Japan Oil Demand: Transportation

The specification of the equation is similar to that used for the US, except that the number of vehicles is used instead of the number of licensed drivers. Demand is a log-linear function of real income, the number of vehicles, and real fuel price[5] (with a quadratic polynomial-distributed lag on price, with a 10-year lag length).

The results are presented in Table 3, for both a perfectly price-reversible case and for a Wolffram imperfectly price-reversible case. The results of the two cases are quite similar. All coefficients have the expected signs and are significant, and both cases have high Adjusted-R^2 and F-statistics.

In the Wolffram case (6.2), the coefficients for price cuts are only slightly lower than for price increases. This result suggests something close to perfect price-reversibility. In addition, the Chow forecast-test probabilities for the perfectly price-reversible case are quite high, which further supports the case of perfect price-reversibility.

[5] A share-weighted average of gasoline and diesel fuel prices was used.

Table 3. Japan Oil Demand: Transportation **data sample 1960-88; data in logarithms.**

(6.1) Perfectly Price-Reversible:

$$D_t = k_0 + k_1 GNP_t + k_2\, Vehicles_t + \Sigma_{i=0..10}\, \alpha_i P_{t-i}$$

(6.2) Wolffram: Imperfectly Price-Reversible:

$$D_t = k_0 + k_1 GNP_t + k_2\, Vehicles_t + \Sigma_{i=0..10}\, \alpha_i (P_{max,t-i} + P_{rec,t-i}) + \Sigma_{i=0..10}\, \beta_i\, P_{cut,t-i}$$

	Perfectly Price-Reversible	Wolffram: Imperfectly Price-Reversible	
constant	-4.37	-3.93	
GNP	.93	.82	
Vehicles	.08 (t=.5)	.08 (t=.5)	
	P	P_{max} & P_{rec}	P_{cut}
Price t=0	-.018	-.017	-.022
t-1	-.032	-.031	-.040
t-2	-.044	-.042	-.054
t-3	-.052	-.050	-.065
t-4	-.057	-.055	-.071
t-5	-.058	-.056	-.073
t-6	-.057	-.055	-.071
t-7	-.052	-.050	-.065
t-8	-.044	-.042	-.054
t-9	-.032	-.031	-.040
t-10	-.018	-.017	-.022
sum	Σ=-.46	Σ=-.45	Σ=-.58
Adjusted R^2	.9925	.9921	
F-statistic	796	568	
Probabilities, Chow Forecast Test 1983	.99	.96	
1984	.99	.91	
1985	.99	.81	

Note: t-statistic is shown only when coefficient is not statistically significant.

However, it could be that the dramatically declining prices pre-1973 are complicating the analysis. That is, the apparently large response to price cuts could be attributable more to the pre-1973 data than to the price declines of the 1980's. In order to determine whether the demand response since 1973 has been the same for price increases and price cuts, we estimated a version of the demand equation using data starting in 1972 rather than 1960. Because of limitations in the number of years available, we were forced to assume a partial-adjustment (Koyck) lagged specification. Demand is a log-linear function of GNP, # Vehicles, price, and lagged demand.

These results are shown in Table 4, using the data sample 1972-90, for both a price-reversible specification (7.1) and a Wolffram price-irreversible specification (7.2). Because the inclusion of GNP in either equation -- (7.1a) or (7.2a) -- does not yield a statistically significant coefficient for GNP, we also show regression results when GNP is not included: (7.1b) and (7.2b).

Although the price-reversible specification (7.1b) appears to yield satisfactory results, those of the Wolffram case (7.2b) are superior. The latter has much higher probabilities for the Chow Forecast Test, and the Vehicles coefficient is statistically significant, unlike that in the price-reversible case (7.1b).

Table 4. Japan Oil Demand: Transportation; data sample 1972-88; data in logarithms.

(7.1) Perfectly Price-Reversible:

$$D_t = k_0 + k_1 GNP_t + k_2 \text{ Vehicles}_t + \alpha P_t + k_3 D_{t-1}$$

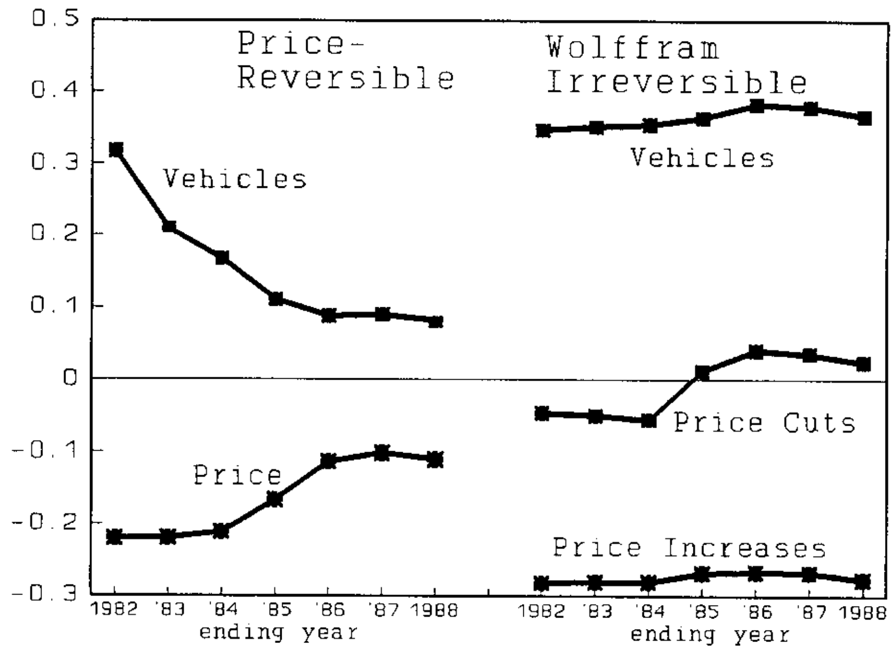
(7.2) Wolffram: Imperfectly Price-Reversible:

$$D_t = k_0 + k_1 GNP_t + k_2 \text{ Vehicles}_t + \alpha (P_{max,t-i} + P_{rec,t-i}) + \beta P_{cut,t-i} + k_3 D_{t-1}$$

	Perfectly Price-Reversible		Wolffram: Imperfectly Price-Reversible			
eq. #	(7.1a) with GNP	(7.1b) without GNP	(7.2a) with GNP		(7.2b) without GNP	
constant	-4.70 (t=-1.4)	-.87 (t=-.4)	-4.76 (t=-1.7)		-4.99	
GNP	-.36 (t=-1.5)		.036 (t=.1)			
Vehicles	.43 (t=1.6)	.08 (t=.7)	.34 (t=1.6)		.37	
lagged demand	.78	.87	.88		.87	
	P	P	P_{max} & P_{rec}	P_{cut}	P_{max} & P_{rec}	P_{cut}
Price	-.15	-.11	-.28	.034 (t=.4)	-.28	.025 (t=.5)
Adjusted R^2	.9877	.9865	.9913		.9920	
F-statistic	322	391	365		497	
Probabilities, Chow Forecast Test 1983	.61	.45	.92		.90	
1984	.52	.36	.83		.79	
1985	.36	.25	.68		.63	

Note: t-statistic is shown only when coefficient is not statistically significant.

Figure 17. Sensitivity of Coefficients to Ending Year of Data Sample: Price-Reversible & Wolffram-Irreversible Specifications, (4.1b) & (4.2b)



In addition to a comparison of results in Table 4, it is useful to examine how sensitive are each equation's coefficients (for both the reversible and the Wolffram case) to changes in the ending year of the data sample. Any changes in the coefficients will reveal the effects of successively including the lower-price years of the 1980's. Starting with the period 1972-82, we extend the data sample by one year at a time and re-estimate the coefficients: for 1972-83, 1972-84, and so forth, through 1972-88. The coefficient sensitivity is shown in the graph above, for the equations (7.1b) and (7.2b).

In the reversible case, we see that including the price-cut years of the 1980's reduces the price coefficient, especially when the 1984-86 price declines are added to the data sample. This also reduces the coefficient for vehicles, in order to compensate for the lower coefficient for price.

In contrast, the coefficients in the Wolffram-irreversible specification are much more robust to changes in the ending year of the data sample. The coefficients for vehicles and price-increases are virtually unchanged as the low-price years of the 1980's are successively included. However, the price-cut coefficient is affected. It changes from being small and negative (the correct sign) to being small and positive; but it is always insignificant: statistically indistinguishable from zero.

5.2 Japan Oil Demand, Non-Transportation

We assume that non-transportation oil demand is a log-linear function of real income and the real price of heavy fuel oil, with a partial-adjustment (Koyck) lag mechanism. The results are shown in Table 5, with a perfectly price-reversible case and a Wolffram imperfectly price-reversible case.

In the perfectly price-reversible case, the results are reasonably good, except that the income variable has the wrong sign, although it is not significant. However, the Chow forecast-test probabilities are quite low, especially in comparison with those for the Wolffram case.

In the Wolffram case, all coefficients have the expected sign and are significant, except for P_{cut} which has the wrong sign, but it is close to zero and is non-significant. From this comparison, we conclude that the Wolffram specification is preferable to the perfectly price-reversible case.

Table 5. Japan Oil Demand: Non-Transportation; data sample 1960-90; data in logarithms.

(8.1) Perfectly Price-Reversible:

$$D_t = k_0 + k_1 GNP_t + \alpha P_t + k_2 D_{t-1}$$

(8.2) Wolffram: Imperfectly Price-Reversible:

$$D_t = k_0 + k_1 GNP_t + \alpha (P_{max,t-i} + P_{rec,t-i}) + \beta P_{cut,t-i} + k_2 D_{t-1}$$

	Perfectly Price-Reversible	Wolffram: Imperfectly Price-Reversible	
constant	0.58	-.84 (t=-1.4)	
GNP	-.008 (t=-.3)	.37	
lagged demand	0.87	.75	
	P	P_{max} & P_{rec}	P_{cut}
Price	-.11	-.19	.02 (t=.3)
Adjusted R^2	.9937	.9947	
F-statistic	1529	1359	
Probabilities, Chow Forecast Test 1984	.13	.47	
1985	.07	.35	
1986	.26	.88	
1987	.45	.93	

Note: t-statistic is shown only when coefficient is not statistically significant.

6. Conclusions

In the Introduction, we posed two questions. First, whether the demand reductions following the price increases of the 1970's would be reversed by the price declines of the 1980's. And second, whether a price recovery in the 1990's would reduce demand by as much as did the price increases of the 1970's.

On the first question, we answer in the negative: the demand reductions will not be reversed, at least not completely. The response to price increases of the 1970's was (approximately) five times greater than the response to the price cuts of the 1980's. For US transportation oil, the response was about 7 times greater for price increases (Table 1); for non-transportation oil, it was about 3 times greater (Table 2). For Japan in both transportation and non-transportation uses of oil (Tables 4 and 5), the response to price declines of the 1980's was statistically indistinguishable from zero. Thus, at most a small fraction of the demand reductions will be reversed.

To appreciate the importance of this first question, consider the following. If oil demand were assumed (incorrectly) to be perfectly price-reversible, then using conventional-wisdom estimates of price elasticity would have greatly overestimated the effect of the price declines of the 1980's upon demand growth in the 1990's. For example, in the recently completed study of world oil models by the Energy Modeling Forum (1991), the three econometrically-based models that assumed perfect price-reversibility had dramatically higher demand projections under low-price assumptions than did other models. In effect, they assumed that the price collapse of the mid-1980's had reduced price well below a level to which demand had already adjusted. Thus, when demanders re-adjusted to these lower prices, if demand were perfectly price-reversible, then demand would surge. By the year 2000, they projected OECD demand to be anywhere from 15 to 30 million barrels per day higher than the average of the other models. This amounts to needing another OPEC by the year 2000 in order to satisfy world oil demand, if price were to remain low.

Similarly, if the data sample for econometric estimation included the low-price-and-low-demand years since the mid-1980's, then assuming the same demand response for price increases and price cuts would understate the former and overstate the latter. Since separate estimation yields a response to price increases that is (say) five times as great as the response to price cuts, then assuming equality would lower the estimated response to price increases, and magnify the response to price decreases.

For the second question -- the effect of a price recovery upon demand -- unfortunately, for neither the US nor Japan, does the data provide an answer. We remain uncertain whether the response to a price recovery in the 1990's could be as great as it had been to the price increases of the 1970's (Wolffram-irreversibility), or whether the response would be no greater than the small response to the price cuts of the 1980's (Traill-irreversibility). We have not had sufficient experience since 1973 with price recoveries to know whether the demand response would be as large as it was for the price increases of the 1970's. Certainly, some demand reductions will not be repeated: attic insulation installed in the 1970's will not be re-done, because it had not been un-done when oil prices fell in the 1980's. But other energy-saving technologies (such as compact florescent bulbs), whose development was spurred by the energy price increases of the 1970's but whose distribution has been depressed by price declines in the 1980's, could be quickly revived by a price recovery.

Data Sources:

Real 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).
Energy Consumption: *Energy Balances of OECD Countries* (Paris: International Energy Agency).
Population: *International Financial Statistics*, (Washington, International Monetary Fund); *UN Monthly Bulletin of Statistics*.
Vehicles: *World Motor Vehicle Data*, (Detroit: Motor Vehicle Manufacturers' Association)
Prices: *Energy Prices and Taxes* (Paris: International Energy Agency); *Annual Energy Review* (Washington: US Department of Energy).

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