Short- and Long-Run Adjustments in U.S. Petroleum Consumption

By

Hillard G. Huntington*

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Energy Modeling Forum
Stanford University
Stanford, CA 94305-4026

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Abstract:

Long-run adjustments in petroleum consumption are not only larger than short-run adjustments. They may also be motivated by entirely different price events. This analysis shows that new price peaks have both short-run and long-run consumption responses, a result that is starkly different than price changes that track previous price paths. It also establishes significant trend effects where gasoline and residual fuel oil consumption decline over time. The analysis explores these adjustments by establishing long-run cointegrating relationships for different petroleum product groupings. An important implication is that price increases above historical levels may be providing substantially greater incentives for significant long-run demand adjustments than would be the case otherwise.

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1. Introduction

Until September 2008, the oil challenge had been one of unbridled and unprecedented demand growth. Expressed in inflation-adjusted dollar terms, crude oil prices responded to these market conditions and exceeded their peaks of the early 1980s before collapsing. At the same time, these demand expansions absorbed virtually all the available excess capacity in major oil-producing regions, leaving the world market more vulnerable to possible future supply disruptions. Both high prices and increased vulnerability sparked considerable interest in policies that might reduce oil dependence, including ethanol subsidies, vehicle efficiency standards, and possibly gasoline and congestion fees. If the world returns to its high economic growth path, policymakers will return to the issue of how to manage petroleum product demand growth.

These policy concerns arise at a time when uncertainty exists about the factors shaping future oil demand trends. A critical issue is the nature of oil-demand adjustments to price changes, particularly those that incorporate the turnover of new oil-using equipment. This issue is as much about what type of price changes produces these long-run responses as well as to the magnitude of the effect. Long-run adjustments in petroleum consumption will be lacking unless the price increase provides new motivations for choosing a more energy-efficient capital stock.

This paper evaluates this issue by estimating the U.S. oil consumption experience over the 1950-2005 period. The next section provides the motivation for investigating these issues, while section 3 develops the estimation equation. Section 4 evaluates the properties of the data set with particular reference to whether the individual variables are stationary or whether the variables are cointegrated with each other. Sections 5 through 8 present the results for total oil and each of three major product groupings and discuss their relevance to the long-run price elasticity of oil demand and rate of technical progress. After section 9 compares the demand responses by product, concluding comments are summarized in section 10.

2. Motivation for the Study

The principal petroleum product is gasoline for private vehicles. Popular accounts (Krauss, 2007) and recent studies (Hughes, Knittel, and Sperling, 2008) suggest that the short-run demand response to price in 2002 is considerably smaller than its counterpart during previous decades. These findings suggest that the long-run response may be similarly muted compared to previous periods, perhaps indicative of oil's declining share in a richer economy or some other lifestyle changes or adjustments. On the other hand, there is also anecdotal evidence on the other side. A prominent engineer who has long advocated the potential for energy efficiency foresees a major revolution in transportation technology at essentially today's prices (Lovins, 2004). In his view, this transition will improve vehicle fuel efficiency by offering consumers smaller, lighter, and more energy-efficient vehicles made from less weighty and more malleable materials. Recent surveys of past econometric research (Goodwin, Dargay, and Hanly, 2004, Graham and Glaister, 2004, and Dahl, 2007) suggest a response that lies between these two opposing views.

Evaluating the short- and long-run adjustments to energy price changes requires careful consideration of the energy consumption decisions. Past research[1] has emphasized that the nature of the oil price change may be as important as its magnitude. Prices that shift households and firms into new regions of their consumption or production frontiers may have dramatically

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[1] As examples, see Dargay and Gately (1994, 1995), Dargay, Gately and Huntington (2007), Gately and Huntington (2002), Plourde and Ryan (2002), and Walker and Wirl (1993).

different effects than prices that allow them to revisit price levels that they have already experienced previously. Recent price increases since 2001 have largely been the latter; inflation-adjusted oil prices in the United States did not exceed their 1980 peak until 2007.[2] If the capital stock has already adjusted to previous oil price shocks, there is little reason to expect that consumers would undertake additional energy efficiency improvements in these decisions.

For similar reasons, consumers who experience a price decline after a price peak may not immediately opt for a less-efficient vehicle. Not only are there adjustment costs associated with changing vehicle types in an era of unknown and fluctuating oil price paths, but technical progress in the energy-using equipment industry may not make that option viable any longer. In addition, vehicle fuel efficiency standards may prevent these firms from making less fuel-efficient vehicles.[3]

A popular approach for incorporating these considerations has been to decompose price changes into several different components. Price maximum components refer to price changes that force the consumers or energy-using firms into a new part of their consumption or production frontiers. Price recovery components are price increases that track previous price paths already experienced by consumers. Finally, price cut components also track previous price paths, although these price adjustments are declines rather than increases.

When applied to energy demand, this approach usually assumes that the relationship between short- and long-run adjustments are the same for maximum price components as they are for price-recovery or price-cut components. Griffin and Schulman (2005) note one problem with such a specification. If price increases reduce long-run consumption more than price

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[2] Inflation-adjusted imported oil prices for the United States in 2007 averaged $67 per barrel (2000 dollars), equal to its 1980 peak price. See US Energy Information Administration (2008).

[3] Offsetting this effect, however, will be shifts to less-efficient vehicles that fall under different restrictions, such as the light-duty trucks in the U.S. market.

decreases augment its use, continual price volatility can cause a spiraling downward trend in oil consumption. Moreover, it seems unrealistic to assume that price recoveries and price cuts will produce the same type of long-run demand adjustments as maximum price increases, because the capital-stock turnover effect is the primary reason to expect a different price response across these different price components. Agricultural economists, who first studied the asymmetric responses of different price components, have discovered recently that the short- and long-run response to price may vary by the nature of the price change (Vande Kamp and Kaiser, 1999).

This first issue leads to a second closely related issue, the nature of technical progress in estimates of the long-run path for oil consumption (Adeyemi and Hunt, 2007; Griffin and Schulman, 2005; and Huntington, 2006). Part of the response to maximum price increases should incorporate some technical progress, because the economy removes old, less-efficient capital stock and replaces it with more-efficient equipment. This replacement is time dependent, operates in one direction and is often impossible or very costly to reverse, a characteristic shared with technical progress (Nordhaus, 2002, p. 190). Once maximum price changes are included as a separate variable in the equation, it becomes interesting to observe whether time-related technical progress contributes an independent and separate effect.

The third issue, oil product aggregation, arises when this equation is estimated for total U.S. oil consumption over the 1950-2005 period. Estimates reported in section 5 below reveal a weak dynamic response where a critical parameter is insignificant. Furthermore, tests for whether the variables move together in the long run are not robust. The analysis overcomes this problem in section 5 by disaggregating total oil consumption into gasoline, other non-residual products and residual fuel oil. Dargay, Gately and Huntington (2007) have recently emphasized this point in their multi-country analysis of oil consumption trends. This separation of products appears logical given the very different uses for petroleum. Although gasoline is closely aligned with the automobile stock and has had few close energy substitutes, residual fuel oil can be replaced quickly by natural gas without requiring major installation costs. It would be indeed surprising if the same function and similar parameters could be applied to both types of uses, and yet, that approach is often used.

3. Framework

The regression analysis uses a general dynamic framework, whose flexibility allows a number of different specifications (Hendry, 1995, Chapter 7). Both current and lagged values of petroleum product demand (*D*) and independent variables (*X*) are included in the following specification:

$$D_t = \beta_0 + \beta_1 X_t + \beta_2 X_{t-1} + \beta_3 D_{t-1} + \mu_t \quad (1)$$

Subtracting D_{t-1} from both sides and adding $\beta_1 X_{t-1}$ - $\beta_1 X_{t-1}$ to the right side yields the equation estimated in this analysis:

$$dD_t = \beta_0 + \beta_1(dX_t) + (\beta_1 + \beta_2)X_{t-1} - (1-\beta_3)D_{t-1} + \mu_t \quad (2)$$

where $dD_t = D_t - D_{t-1}$ *and* $dX_t = X_t - X_{t-1}$. Short-run demand adjustments to current changes in *X* are represented by the coefficient β_1.

This autoregressive distributed lag (ADL) specification contains an equilibrium-corrections mechanism, where petroleum consumption adjusts to disequilibrium conditions in the previous year. This formulation can be represented by arranging the terms as:

$$dD_t = \beta_0 + \beta_1(dX_t) - \lambda[D_{t-1} - \phi X_{t-1}] + \mu_t$$

where $\lambda = (1-\beta_3)$ and $\phi = (\beta_1 + \beta_2)/(1-\beta_3)$. One can estimate this equation in one step, as in equation (2) above, or in the two-step Engle-Granger (1987) approach. After first estimating ϕ

above, this second approach computes the previous period's error represented in the bracketed term and adds this additional variable for explaining the change in oil demand. Although the two approaches are similar in principle, the estimates may not be the same. For transparency, the paper will report the direct estimates based upon the ADL specification in equation (2).[4]

In long-run equilibrium, $D^*=D_t=D_{t-1}$ and $X^*=X_t=X_{t-1}$, so that $dD_t=dX_t=0$. Rearranging terms provides the long-run relationship between D^* and X^*

$$D^* = [\beta_0 /(1-\beta_3)] + [(\beta_1+\beta_2)/(1-\beta_3)]X^* + \mu_t \qquad (3)$$

The long-run response of D with respect to a change in X is based upon the estimated coefficients from Equation (2). It equals the estimated coefficient for X_{t-1} divided by the estimated coefficient for D_{t-1} (multiplied by –1).

Oil consumption (D) within a particular economy can be represented conceptually as the conditional input demand function related to the following explanatory factors (X):

$$X = f(W, S, Z)\,, \qquad (4)$$

where W represents a vector of oil and substitute fuel prices, S is a vector of energy service demands including refineries, steel factories, vehicles, floorspace, and other activity variables, and Z incorporates a vector of policy and socioeconomic variables. It is difficult to retain the latter set of variables (Z) in any meaningful fashion, once the analysis aggregates across a number of different petroleum uses. It is frequently difficult to measure these variables in terms of prices or real income unless they are taxes or some similar instrument.

The vector of service activities incorporates multiple specific investments that must recoup their costs over an extended period. They will change as the economy grows and its structure shifts (vehicles replacing steel firms or oil-burning powerplants) but also as the vector

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[4] Johnston and DiNardo (1997, pp. 215-228) provide a clear exposition of this approach.

of energy prices changes. The effect of energy prices on investment and long-run energy demand will depend upon whether they encourage the purchase of new energy-using equipment that was previously uneconomic or whether they simply fluctuate over ranges experienced in previous periods.[5] Previously experienced prices should have smaller effects, because the existing capital stock has already been optimized in previous periods. Moreover, some asymmetry in the response of investment to oil price increases and decreases may result from the uncertainty about oil prices, if manufacturers and consumers of energy-using equipment encounter important irreversibilities in investment expenditures.[6] These possibilities mean that the price component vectors (*W*) that directly influence demand in the above equation may not be the same price component vectors (*W**) that shape the economy's future capital stock. Thus, the service activities respond to income (*Y*) as well as to this different set of energy price events:

$$S = g\,(W^*, Y) \tag{5}$$

After replacing S in equation (4) with its counterpart in equation (5), the contingent oil demand level can be expressed as a function of these variables:

$$X = f^*(W, W^*, Y) \tag{6}$$

Note that W should have a more contemporaneous effect during the year in which energy prices change, while W^* should have a longer-run impact over a number of periods as the economy's capital stock and service activities adjust. This analysis makes no *a priori* judgments about which price components will influence oil consumption directly through W in the short run and which components will also affect demand through W^* and the capital stock in the long run. Initially, each price component is allowed to have both a short- and long-run effect. The

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[5] The vector *S* can be considered as the stock choice decision in the Fischer-Kaysen (1962) stock-utilization analysis.

[6] See Pindyck (1991) for an overview of the literature, and Pindyck (1988) and Dixit (1992) for models evaluating the impact of irreversibilities. Lam (1989) extends the analysis to consumer durable expenditures, where resale market imperfections may be an important impediment.

empirical results will determine which price components have both short- and long-run significant effects.

4. Properties of the Data

The data set includes oil consumption by product category, petroleum product prices, and gross domestic product, where the latter two variables have been converted to real 2002 US dollars.[7] Per-capita estimates were used for oil consumption and GDP. All variables were converted to logarithms.

The single oil price variable (P_t) can also be decomposed into separate series that are mutually exclusive[8] but that equal the original oil price series when aggregated. Beginning with an initial-year price (P_0=1949), we define separate components for maximum prices (P_{max}), submaximum prices (P_{sub}), price recoveries (P_{rec}) and price cuts (P_{cut}) in logarithms as follows:

$$\begin{aligned}
P_{\max,t} &= \max(P_t, \ldots, P_0) \\
P_{sub,t} &= P_t - P_{\max,t} \leq 0 \\
P_{rec,t} &= P_{sub,t} \quad if\ P_{sub,t} \geq P_{sub.t-1} \\
P_{cut,t} &= P_{sub,t} \quad if\ P_{sub,t} < P_{sub.t-1} \\
P_t &= P_{sub,t} + P_{\max,t} = P_{rec,t} + P_{cut,t} + P_{\max,t}
\end{aligned} \tag{7}$$

These price components are similar to those developed by Gately and Huntington (2002) except that the price recoveries and cuts are expressed in terms of current prices rather than as

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[7] The Producer Price Index was extracted from the U.S. Bureau of Labor Statistics website, http://www.bls.gov/ppi/, for the following commodities grouping: refined petroleum products, gasoline, residual fuel oil and industrial natural gas. Each price was deflated by the economywide producer price index and calibrated to the 2002 level in real 2002 US dollars per million British Thermal Units (BTUs) as provided by the US Energy Information Administration, Annual Energy Review 2005, Report No. DOE/EIA-0384 (2005), July 27, 2006, Table 3.4, http://www.eia.doe.gov/emeu/aer/finan.html. This same volume of the Annual Energy Review also provided total, gasoline and residual fuel oil consumption (Table 5.11), US population and real gross domestic product (Table 16.1) and industrial natural gas prices after 1966 (Table 6.8). American Gas Association (1975, Table 72, p. 125) provided comparable natural gas prices for 1950-66.

[8] Although the price series or components are mutually exclusive of each other, more than one price component may change in any one year. For example, an upward price increase can begin as a price recovery until the price level reaches its old price maximum. If it continues upward after that point, it would also be establishing a new price maximum in that same year.

cumulative price changes over all periods. This construction allows hypothesis testing with respect to current rather than cumulative prices and also seems more realistic from the consumer's perspective. Representing price recoveries and cuts as current rather than cumulative price changes principally affects the time trend in the gasoline and residual fuel oil consumption equations, which otherwise would not be significant.

Both price cuts and price recoveries can be considered sub-maximum prices, while any prices that exceed the previous historical peak can be considered maximum prices. As levels rather than logarithms, sub-maximum prices are ratios of the maximum price. Summation of the different price components continues to result in the original price series, as in the original Gately-Huntington approach.

Figure 1 shows the maximum and sub-maximum price components in *levels* (logarithms) for total refined product prices in real 2002 dollars. The maximum price component is very similar to the comparable trend reported in earlier studies, such as Gately and Huntington (2002: p.33). New price maximums are reached primarily in the 1970s and early 1980s. Since that period and until 2006, real petroleum prices have remained below these peaks.

The *change* in each price component in Figure 2 is the (logarithmic) change in petroleum prices if prices satisfy the above criteria for being a maximum, recovery or cut.[9] It will be zero if that component does not change; otherwise, it will be a positive or negative number. The price maximum change is very similar in spirit to the oil price change variable used very elegantly by Hamilton (2003) in his macroeconomic estimates of oil price shocks. Note that it is possible to have both a price recovery back to the previous maximum as well as a new maximum in the same year, as happened in 1974, 1979 and 2006.

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[9] These estimates are available from the author upon request.

The direct estimate of these variables in levels requires that all dependent and independent variables are stationary and that their means and variances do not increase as more recent data is included. If the variables are not stationary in levels but are in first differences, an equation like (2) may be appropriate if a significant cointegrating relationship can be found between the variables. Analysts apply unit root and cointegration tests to determine these data properties. They are not always clear cut and depend upon the technique and their specification. For example, Bentzen and Engsted (1996) criticize the estimates of U.S. price elasticities offered by Jones (1993) because they find that the levels of the original data are not stationary or cointegrated using the two most common procedures. They advocated using first differences rather than a dynamic long-run-adjustment model, a specification that resulted in higher long-run price elasticities than Jones originally found.[10]

Table 1 shows that adjusted Dickey-Fuller tests applied to the current data base indicate that the logarithms of the variables are not stationary when expressed as levels but are stationary as first differences. This pattern applies to all variables, where a significant (asterisked) test coefficient rejects non-stationarity (unit roots) for a variable. At the far right side of this table, the tests indicate that the first differences are stationary across all variables at the 1 percent significance level.

Table 2 reports the Engle-Granger tests for cointegration between per-capita consumption, real oil prices and per-capita GDP in the top row. These results indicate that these three non-stationary variables are not cointegrated for any of the product groupings in the different columns. The Engle-Granger tests, however, impose restrictions that make them less powerful for relationships between more than two variables, as discussed by Kremers *et al*

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[10] See Jones (1993: p. 691) and Bentzen and Engsted (1996: p. 785) for their estimates. Jones (1996) countered that his original data was cointegrated using a different testing procedure.

(1991). Johansen trace and maximum eigenvalue tests for cointegration in the rows immediately below find cointegration for total and residual fuel oil but not for gasoline and other products (where the latter excludes gasoline and residual fuel oil). Thus, there remains some question whether cointegration applies for all major categories of petroleum products when prices are specified as one variable with a symmetric response on oil consumption.

The single price variable may be the wrong series to include in the cointegration tests because consumers may respond differently to maximum and sub-maximum prices and because sub-maximum prices may not provide the right incentive for long-term investment in oil-using equipment. Table 2 also reports different cointegration tests on the same three variables, where the maximum and sub-maximum prices replace the single price variable in the middle section. The Engle-Granger tests continue to find no cointegrating relationship between the variables, but analysts frequently prefer the Johansen tests for more than two variables, as discussed above. With this substitution, the Johansen tests for gasoline now indicate a significant cointegrating relationship between oil consumption, real oil prices defined as maximums and sub-maximums, and real GDP in levels. Cointegration for the same relationship also holds for total oil, as it does in the symmetric price case. Cointegration also applies between other petroleum product consumption, maximum prices and real GDP, reported in the bottom set of estimates in this table. When oil consumption is disaggregated into major product groupings, cointegration between key variables becomes more compelling when oil prices are decomposed than when they are not. The gasoline and residual fuel oil tests include a time trend, which will enter the ADL equations in the next several sections.

5. Results for Total Oil

Estimation of equation (2) for total oil included no lagged change variables (dX_{t-i} *and* dY_{t-i}), because the optimal lag based upon the Akaike Information Criteria excluded all lagged values in the Johansen tests. Independent variables included real GDP and real prices for refined petroleum products.

The first column of coefficients in Table 3 reveals that the symmetric price series (Δprice) and GDP (Δincome) have significant short-term effects. The equation explains 70% of the annual variation in total U.S. oil consumption *growth rates* over the 1950-2005 period. The errors appear to be serially correlated at the 5 percent level as revealed by the Breusch-Godfrey test but they display normality conditions as revealed by the Jarque-Bera test.

Rather disappointing is the coefficient on the lagged consumption level in the row labeled "Demand(-1)". It is not significant at even the 15% level and its relatively weak response implies a long adjustment period. The implied long-run price elasticity with respect to prices is –1.92 (= -0.054/0.028), which is substantially higher than the long-run elasticity for any of the individual product groups that will be discussed below.

The price variable is decomposed into maximum prices, price recoveries and price cuts in the second column. As shown at the bottom of the table, F-tests for symmetry between price recoveries and cuts could not be rejected for either the short or long run. The third column reports results when price recoveries and cuts are aggregated into a single component for sub-maximum prices. F-tests reject the hypothesis that maximum and sub-maximum prices have similar impacts on total oil consumption in either the short or long run. The size of the response to new price maximums is particularly striking. A one percent increase in this variable produces more than 4 times the reduction in oil consumption as a one percent increase in sub-maximum prices in either the short or long run. These results confirm that the major effect of price components is to differentiate the effect of prices that reach new peaks from other price changes rather than to differentiate price recoveries from price cuts.

Even the preferred results for total oil in the third column have a relatively low adjustment coefficient on the demand(-1) variable. Long-run adjustments to the maximum price variable remain relatively high, at -1.54 (=- 0.074/0.048). The relatively low and insignificant adjustment term for total oil suggest the possibility that aggregate petroleum consumption may be mixing together a range of oil products, some (residual fuel oil) with very rapid adjustment and others (gasoline) with a distinctly delayed adjustment.

6. Results for Other Petroleum Products

Table 4 reports similar results for other petroleum products, which exclude gasoline and residual fuel oil. The summary regression equation statistics are very similar to those for total oil, except that indicators of fitness like the squared error of the regression or the adjusted R-squared coefficient are lower. The coefficient for the lagged demand level is now significant in the symmetric-response equation (column 1).

Short- and long-run symmetry between price recovery and price cut responses cannot be rejected in the second-column results. There is more evidence that new price maximums and sub-maximum prices have significantly different effects on other product consumption, but these differences are not significant at the standard 5% level. The long-run effect for price recoveries and cuts, however, is very weak with low t-statistics, while the long-run maximum price effect is significant. The estimates in the third column eliminate the sub-maximum prices from the long-run effect but include its short-run response (Δsubmax).

7. Results for Gasoline

Similar results for gasoline consumption, which represents slightly less than half of all U.S. oil consumption, appear in Table 5. From the cointegration tests (Table 2), the equation also includes a time trend. Although demand and prices have significant long-term coefficients in the symmetric specification (first column), the magnitude and significance of these coefficients increase when prices are decomposed (second and third columns). Ordinary-least-squares estimates of the last equation (column 3) produced a Breusch-Godfrey statistic that was significant at the 5% level. To adjust for this potential problem, the coefficients reported in column 3 have been corrected for first-order autocorrelation. Due to the presence of the lagged dependent variable, the Cochrane-Orcutt procedure was used.

Price recoveries and cuts do not have significantly different responses from each other in either the short or long run. In contrast, prices reaching new peaks have significantly different effects on gasoline consumption than sub-maximum prices in either the short or long run. Sub-maximum prices appear to have no effect on gasoline consumption in the long run, because the t-statistics on the lagged price recovery and cut levels are very close to zero. These terms have been dropped from the equation in the last column.

8. Results for Residual Fuel Oil

Cointegration tests for residual fuel oil (Table 2) supported the use of a single petroleum price and a time trend without any lagged changes. Table 6 reports results for this product estimated over the 1954-2005 period because it includes the cross-price effect from the substitute fuel, natural gas, whose price was not available prior to 1953. The first column shows coefficients when residual fuel oil and industrial natural gas prices are entered as separate variables.

A dummy variable for the 1970-79 period has been inserted in the regression to adjust for the effect of natural gas shortages in stimulating residual fuel oil consumption. Although natural gas curtailments in the 1974-76 period captured much of the publicity, the natural gas industry was significantly influenced before that period, when pipelines stopped adding new industrial and powerplant customers. Constraints on new customers continued in later years, as well. The simple dummy variable worked better as a shortage variable than the difference between intrastate and interstate natural gas prices during this period as implemented by Huntington (2005).

Changes in the residual fuel oil price, the natural gas price and real GDP all had significant immediate impacts on residual fuel oil consumption. Among the lagged level variables, only income had a significant effect. F-tests could not reject a similar but opposite effect between the previous year's residual fuel oil and natural gas price levels. Since both variables were insignificant with very low t-statistics, they were eliminated in the second-column results. Here both lagged consumption and income levels were significant. Further F-tests also failed to reject a similar but opposite effect in the short-run response to oil and natural gas prices. Therefore, these variables were entered as an oil-gas price ratio in the equation in the third column. All coefficients are significant. A doubling of the oil-gas price ratio will immediately reduce residual fuel oil consumption by 13 percent.

The main conclusion is that residual fuel oil adjusts much more quickly to price changes than the other petroleum products. Unlike other petroleum uses, buyers of residual fuel oil may be highly sensitive to the price of natural gas, which competes often without major installation changes. Econometric estimates that combine residual fuel oil with other products will be misspecified for this reason.

9. Short- and Long-Run Responses

Short- and long-run responses can be obtained from the coefficients in the last column of Tables 3-6, using the expressions developed in section 3. In the first three columns, Table 7 shows that short-run responses to income are dramatically higher than for either of the price variables. Among prices, new maximums have larger impacts than their sub-maximum counterparts. The long-run responses in the last three columns are unrealistically higher for total oil than for the different consumption components, reflecting the low and weak adjustment coefficient for lagged total consumption. For gasoline and other, nonresidual oil, the long-run elasticity for maximum prices lies in the -0.6 to -0.7 range. The long-run income elasticity for other oil is 0.74, nearly identical to its short-run response.

Long-run income elasticities for gasoline and residual fuel oil are not directly comparable because the estimates for these products include a strong trend effect. The last column of this table, however, reports an estimate for the trend-adjusted income effect that summarizes how rapidly product consumption increases with economic growth. It first computes the consumption growth attributable to an economic growth rate of 2.2 percent per year, which is the mean growth rate for the 1950-2005 period. Then it adds the time trend effect. Finally, it expresses that oil consumption growth as a ratio of the 2.2 percent economic growth. Gasoline consumption grows about as rapidly as economic growth in the long run, while residual fuel oil declines by an amount approximately equal to the economic growth rate.

10. Conclusion

The long-run relationship between consumption, prices and income may be hidden or disguised if dissimilar products are aggregated together into a single demand for petroleum products. Residual fuel oil demand can be replaced immediately by substitute fuels with minor installation costs. These choices happen much more quickly than purchases of automobiles with internal combustion engines that must use gasoline. A key finding of this analysis is that product disaggregation provides a much richer understanding of the long-run properties of oil consumption. There is unequivocal evidence of more pronounced long-run adjustments in product consumption that cannot be detected from aggregate oil consumption patterns. Moreover, these variables do not move together in long-run equilibrium, unless maximum prices are separated from other types of price movement. These findings support efforts to apply the price-components approach to different petroleum products, like the pooled OECD and world analysis by Dargay, Gately and Huntington (2007).

The long-run response of oil consumption is closely aligned with the turnover in the nation's capital stock. This situation not only results in a much larger long-run than short-run effect in the response to oil price changes. It also raises the possibility that investors will refrain from long-term investments with certain types of price changes and will accelerate these investments with other types of price changes. Since oil is a relatively minor share of total expenditures, firms and households will not change their costly capital equipment unless they are convinced that oil prices have entered, and will remain within, new regions. Other price changes are likely to have a much more modest impact. Hughes, Knittel, and Sperling (2008) provide valuable evidence that the short-run gasoline demand response may be smaller now than during the 1970s, but one should remember that these are price adjustments that track inflation-adjusted oil prices well below levels experienced during previous decades. If inflation-adjusted oil prices should return to their levels in the middle of 2008, about five times their 2002 levels and well above their previous peaks, the long-run adjustments might be considerably greater than implied by these estimates.

This study offers empirical evidence that contrasts with previous findings that all price changes have long-run effects several times their short-run effects. It shows that the response is stronger and more permanent when oil prices reach beyond levels that were previously experienced. Such price events push consumers and equipment-producing firms into new market environments, where oil-saving investments are more profitable.

Fluctuating prices below previous peaks, on the other hand, are essentially a short-run story. Their major effects were experienced immediately rather than in the long run. The study produced limited evidence that increases and decreases in sub-maximum price changes had dissimilar (asymmetric) effects on the response of oil consumption to price. This finding means that cyclical prices are unlikely to cause oil demand to spiral downward, unless price recoveries consistently reach beyond previous price maximums and establish new higher prices with each cycle. An important refinement in the specification of demand has been representing price recoveries and cuts as current price levels and changes rather than as cumulative changes over time. By removing the trend from these price variables, this approach allows for significant exogenous trend effects in gasoline and residual fuel oil consumption that coexist with the price-induced technology shifts caused by maximum prices.

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Table 1. Dickey-Fuller Test Results for Unit Roots

	Logarithmic Levels DF Test	Lags	Logarithmic Changes DF Test	
Per Capita Consumption				
Total	-1.01	3	-3.35	**
Other	-1.69	3	-3.67	**
Gasoline	-1.25	3	-2.93	**
Residual Oil	0.88	3	-2.62	**
Per Capita GDP#	-2.60	3	-5.10	**
Real Prices				
Refined Product	0.76	2	-3.29	**
Crude Oil	0.94	3	-2.84	**
Gasoline	0.65	2	-3.49	**
Residual Oil	0.63	2	-3.38	**

Constant and time trend included as deterministic regressors.
Significant at 5%(*) and 1%(**) levels.

Table 2. Cointegration Tests

	Total		Other		Gasoline		Residual Fuel Oil	
Single Price								
Engle-Granger	1.49		1.46		2.32		2.27	
Lags	3		3		3		2	
Johansen Trace	42.71	**	25.98		25.86		42.06	**
Johansen Maximum	35.36	**	20.71		15.31		27.09	**
Lags	0		1		1		0	
Price Maximum-Price Submaximum								
Engle-Granger	0.019		0.147		1.57			
Lags	2		2		2			
Johansen Trace	68.09	**	44.27		55.99	*		
Johansen Maximum	40.99	**	23.68		27.04	*		
Lags	0		1		2			
Price Maximum								
Engle-Granger			0.834					
Lags			3					
Johansen Trace			31.94	*				
Johansen Maximum			23.91	*				
Lags			1					

Notes:

Determistic regressors are constant (all equations) and trend (gasoline and residual fuel oil only).

Residual fuel oil-natural gas price ratio is used for residual fuel oil demand.

Sources for critical values: MacKinnon (1991) and Osterwald-Lenum (1992).

Table 3. Per-capita Total Oil Consumption (Logarithms), 1950-2005

Sum of squared residuals	0.018		0.012		0.014	
Std. error of regression	0.019		0.017		0.017	
Adjusted R-squared	0.703		0.744		0.752	
Breusch/Godfrey	5.20	*	0.53		0.87	
Jarque-Bera	0.87		0.85		0.72	
F (zero slopes)	27.06	**	18.41	**	24.85	**
Schwarz B.I.C.	-134.17		-132.86		-136.34	
Akaike Information Crit.	-140.25		-142.90		-144.45	
Log likelihood	146.25		152.90		152.45	

Variable	Coefficient		Variable	Coefficient		Variable	Coefficient	
constant	-0.032		constant	-0.182		constant	-0.191	
	(0.083)			(0.150)			(0.143)	
Δprice	-0.071	**	Δmax price	-0.211	**	Δmax price	-0.196	**
	(0.021)			(0.056)			(0.055)	
Δincome	0.841	**	Δincome	0.736	**	Δincome	0.800	**
	(0.115)			(0.109)			(0.109)	
demand(-1)	-0.028		demand(-1)	-0.039		demand(-1)	-0.048	
	(0.021)			(0.031)			(0.030)	
price(-1)	-0.054	**	max price(-1)	-0.080	**	max price(-1)	-0.074	**
	(0.011)			(0.016)			(0.016)	
income(-1)	0.008		income(-1)	0.067	*	income(-1)	0.058	*
	(0.011)			(0.030)			(0.029)	
			Δrecovery	-0.094	*	Δsubmax	-0.049	*
				(0.045)			(0.024)	
			Δcut	-0.073	*	submax(-1)	-0.018	
				(0.031)			(0.015)	
			recovery(-1)	-0.008				
				(0.018)				
			cut(-1)	-0.033				
				(0.023)				
			F Tests (Prices)			F Tests (Prices)		
			Asym-SR	1.356		Peak-SR	5.050	*
			Asym-LR	0.914		Peak-LR	5.965	*

Standard errors are reported in parentheses.
Significant at 5%(*) and 1%(**) levels.

Table 4. Per-capita Other Oil Consumption (Logarithms), 1950-2005

Sum of squared residuals	0.029			0.021			0.023	
Std. error of regression	0.025			0.023			0.023	
Adjusted R-squared	0.604			0.635			0.661	
Breusch/Godfrey	0.054			0.280			0.106	
Jarque-Bera	0.480			2.126			1.405	
F (zero slopes)	11.28	**		7.60	**		11.55	**
Schwarz B.I.C.	-111.85			-106.12			-113.40	
Akaike Information Crit.	-120.88			-121.04			-124.44	
Log likelihood	129.88			136.04			135.44	
Variable	Coefficient		Variable	Coefficient		Variable	Coefficient	
constant	-0.280		constant	-0.480		constant	-0.428	
	(0.152)			(0.297)			(0.248)	
Δprice	-0.042		Δmax price	-0.092		Δmax price	-0.081	
	(0.029)			(0.081)			(0.077)	
Δincome	0.841	**	Δincome	0.691	**	Δincome	0.805	**
	(0.178)			(0.181)			(0.171)	
demand(-1)	-0.078	**	demand(-1)	-0.091		demand(-1)	-0.092	*
	(0.029)			(0.047)			(0.041)	
price(-1)	-0.043	**	max price(-1)	-0.068	*	max price(-1)	-0.057	*
	(0.016)			(0.029)			(0.026)	
income(-1)	0.022		income(-1)	0.095		income(-1)	0.068	
	(0.020)			(0.060)			(0.049)	
Δdemand(-1)	-0.067		Δrecovery	-0.106		Δsubmax	-0.023	
	(0.142)			(0.068)			(0.032)	
Δprice(-1)	-0.044		Δcut	-0.074		Δdemand(-1)	-0.147	
	(0.031)			(0.047)			(0.135)	
Δincome(-1)	0.113		recovery(-1)	0.001		Δmax price(-1)	-0.214	*
	(0.205)			(0.038)			(0.083)	
			cut(-1)	0.020		Δsubmax(-1)	-0.041	
				(0.028)			(0.034)	
			Δdemand(-1)	-0.099		Δincome(-1)	0.102	
				(0.147)			(0.188)	
			Δmax price(-1)	-0.234	*			
				(0.090)				
			Δrecovery(-1)	-0.067				
				(0.058)				
			Δcut(-1)	-0.039				
				(0.061)				
			Δincome(-1)	-0.032				
				(0.201)				
			F Tests			F Tests		
			(Prices)			(Prices)		
			Asym-SR	1.609		Peak-SR	2.125	#
			Asym-LR	0.175		Peak-LR	2.823	##

Standard errors are reported in parentheses. Significant at 5%(*) and 1%(**) levels.
Significant at 15%(#) and 10%(##).

Table 5. Per-capita Gasoline Consumption (Logarithms), 1950-2005

Sum of squared residuals	0.009			0.005			0.005	
Std. error of regression	0.014			0.012			0.011	
Adjusted R-squared	0.666			0.784			0.794	
Breusch/Godfrey	1.68			2.76			- -	
Jarque-Bera	5.71			0.09			- -	
F (zero slopes)	12.99	**		14.08	**		- -	
Schwarz B.I.C.	-140.57			-144.46			-148.85	
Akaike Information Crit.	-150.61			-160.51			-161.78	
Log likelihood	160.61			176.51			174.78	
Variable	Coefficient		Variable	Coefficient				
constant	-0.493		constant	-1.020	**	constant	-0.699	**
	(0.273)			(0.269)			(0.150)	
Δprice	-0.077	**	Δmax price	-0.298	**	Δmax price	-0.277	**
	(0.018)			(0.048)			(0.034)	
Δincome	0.554	**	Δincome	0.530	**	Δincome	0.505	**
	(0.106)			(0.091)			(0.077)	
demand(-1)	-0.053	*	demand(-1)	-0.100	**	demand(-1)	-0.072	**
	(0.025)			(0.029)			(0.016)	
price(-1)	-0.023	*	max price(-1)	-0.068	**	max price(-1)	-0.055	**
	(0.011)			(0.017)			(0.010)	
income(-1)	0.135		income(-1)	0.301	**	income(-1)	0.205	**
	(0.087)			(0.084)			(0.048)	
time	-0.003		time	-0.004	**	time	-0.003	**
	(0.002)			(0.002)			(0.001)	
Δdemand(-1)	0.393	**	Δrecovery	-0.067		Δsubmax	-0.063	**
	(0.128)			(0.032)			(0.013)	
Δprice(-1)	0.038		Δcut	-0.067	**	Δdemand(-1)	0.369	**
	(0.019)			(0.023)			(0.118)	
Δincome(-1)	-0.369	**	recovery(-1)	0.035		Δmax price(-1)	0.160	**
	(0.114)			(0.022)			(0.037)	
			cut(-1)	-0.003		Δsubmax(-1)	-0.006	
				(0.015)			(0.015)	
			Δdemand(-1)	0.070		Δincome(-1)	-0.368	**
				(0.144)			(0.079)	
			Δmax price(-1)	0.087		rho	-0.434	**
				(0.053)			(0.145)	
			Δrecovery(-1)	-0.008				
				(0.029)				
			Δcut(-1)	0.014				
				(0.030)				
			Δincome(-1)	-0.234	*			
				(0.097)				
			F Tests (Prices)			F Tests (Prices)		
			Asym-SR	2.23		Peak-SR	10.41	**
			Asym-LR	2.25		Peak-LR	9.75	**

Standard errors are reported in parentheses. Significant at 5%(*) and 1%(**) levels.
Third-column coefficients have been corrected for first-order autocorrelation.

Table 6. Per-capita Residual Fuel Oil Consumption (Logarithms), 1950-2005

Sum of squared residuals	0.197		0.216		0.228	
Std. error of regression	0.066		0.068		0.069	
Adjusted R-squared	0.458		0.432		0.411	
Breusch/Godfrey	0.022		0.531		0.249	
Jarque-Bera	2.64		1.55		0.776	
F (zero slopes)	6.07	**	6.87	**	7.29	**
Schwarz B.I.C.	-56.80		-58.32		-58.76	
Akaike Information Crit.	-66.83		-66.35		-65.78	
Log likelihood	76.83		74.35		72.78	

Variable	Coefficient		Variable	Coefficient		Variable	Coefficient	
constant	-2.506	*	constant	-3.820	**	constant	-3.559	**
	(1.181)			(1.002)			(1.008)	
Δprice	-0.185	**	Δprice	-0.122	*	Δoil-gas	-0.134	*
	(0.071)			(0.055)			(0.055)	
Δcross	0.327	*	Δcross	0.270	**	Δincome	1.723	**
	(0.131)			(0.098)			(0.465)	
Δincome	1.786	**	Δincome	1.921	**	demand(-1)	-0.202	**
	(0.512)			(0.472)			(0.049)	
demand(-1)	-0.116		demand(-1)	-0.205	**	income(-1)	1.092	**
	(0.064)			(0.048)			(0.375)	
price(-1)	-0.081		income(-1)	1.194	**	time	-0.029	**
	(0.097)			(0.373)			(0.009)	
cross(-1)	-0.003		time	-0.031	**	1970s	0.132	**
	(0.101)			(0.008)			(0.038)	
income(-1)	0.835	*	1970s	0.115	**			
	(0.408)			(0.039)				
time	-0.020	*						
	(0.010)							
1970s	0.090							
	(0.052)							

F Tests (Prices)		F Tests (Prices)	
Sub-LR	0.162	Sub-SR	2.751

Standard errors are reported in parentheses. Significant at 5%(*) and 1%(**) levels.

Table 7. Summary of Short- and Long-Run Responses

	Short-Run			Long-Run		
	Maximum Price	Sub-maximum Price	Income	Maximum Price	Income	Trend-adjusted Income
Total	**-0.196**	**-0.049**	**0.800**	**-1.537**	**1.204**	
Other	**-0.081**	**-0.023**	**0.805**	**-0.621**	0.740	
Gasoline	**-0.277**	**-0.063**	**0.505**	**-0.760**		**1.027**
Residual Oil	**-0.134**	0	**1.723**	0		**-1.038**

Long-run responses for total oil are highly uncertain due to weak adjustment rates.

Bold estimates are significant at least at 5% level.

Trend-adjusted income response combines energy-saving trend with income effect where the latter assumes 2.2% economic growth rate.

Figure 1. Levels (Logs) of Price Components for Refined Petroleum Products

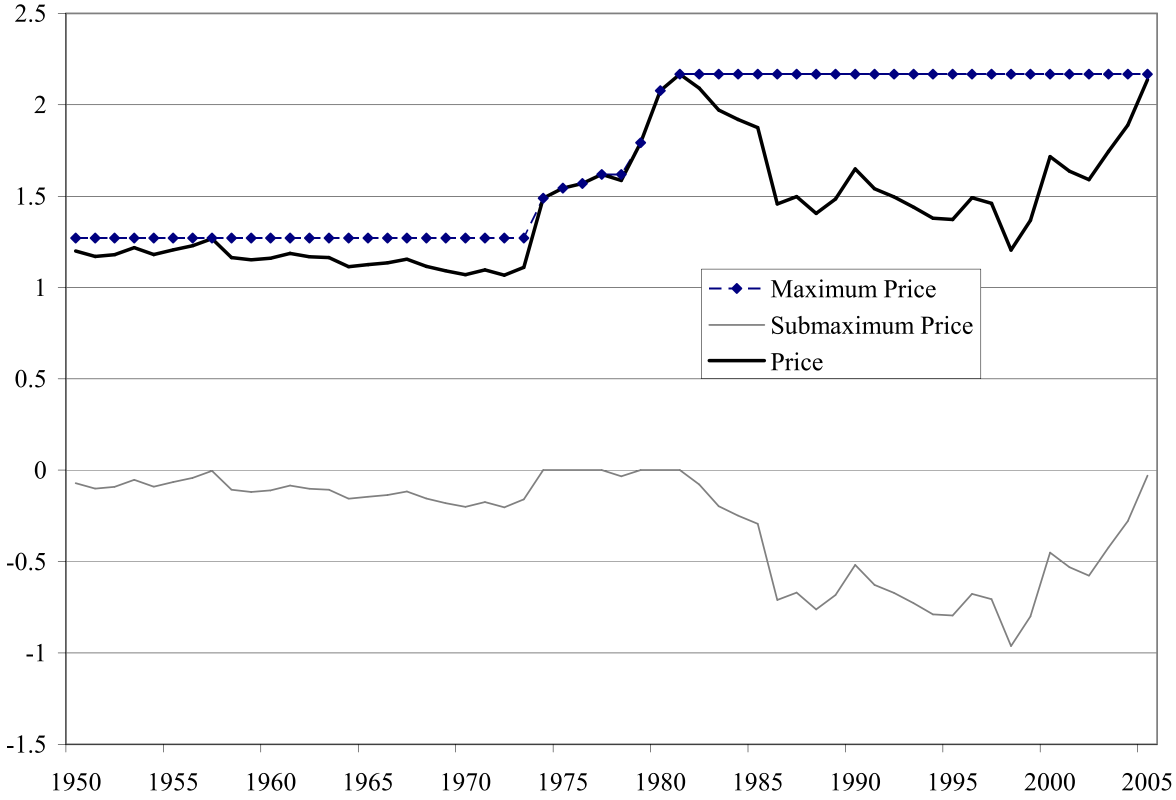
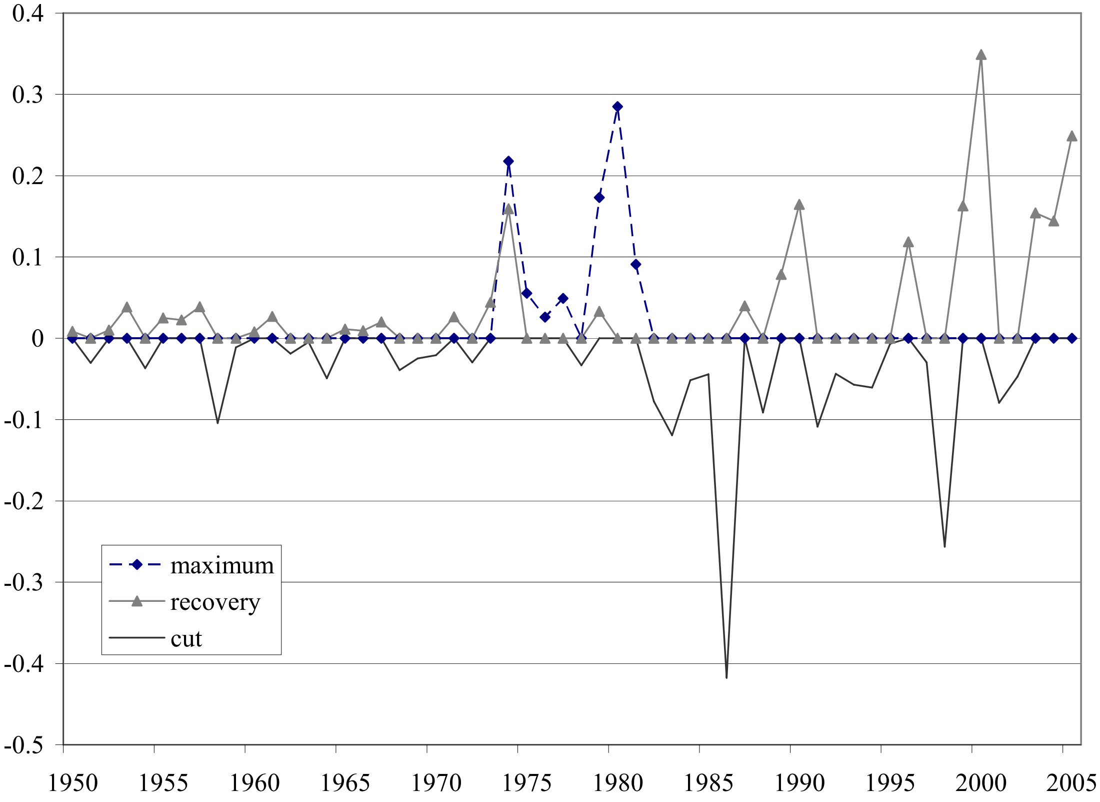


Figure 2. First Differences (Logs) of Price Components for Refined Petroleum Products



Appendix: First Differences of Price Components for Refined Petroleum Products (to be made available upon request)

	PMAX	PREC	PCUT
1950	1.27039	-0.070976	0.00000
1951	1.27039	0.00000	-0.10124
1952	1.27039	-0.091239	0.00000
1953	1.27039	-0.052736	0.00000
1954	1.27039	0.00000	-0.089491
1955	1.27039	-0.064386	0.00000
1956	1.27039	-0.041706	0.00000
1957	1.27039	-0.0030258	0.00000
1958	1.27039	0.00000	-0.10743
1959	1.27039	0.00000	-0.11862
1960	1.27039	-0.11059	0.00000
1961	1.27039	-0.083715	0.00000
1962	1.27039	0.00000	-0.10262
1963	1.27039	0.00000	-0.10743
1964	1.27039	0.00000	-0.15662
1965	1.27039	-0.14547	0.00000
1966	1.27039	-0.13612	0.00000
1967	1.27039	-0.11595	0.00000
1968	1.27039	0.00000	-0.15500
1969	1.27039	0.00000	-0.17974
1970	1.27039	0.00000	-0.20045
1971	1.27039	-0.17404	0.00000
1972	1.27039	0.00000	-0.20361
1973	1.27039	-0.15935	0.00000
1974	1.48829	0.00000	0.00000
1975	1.54353	0.00000	0.00000
1976	1.56969	0.00000	0.00000
1977	1.61884	0.00000	0.00000
1978	1.61884	0.00000	-0.033100
1979	1.79206	0.00000	0.00000
1980	2.07693	0.00000	0.00000
1981	2.16792	0.00000	0.00000
1982	2.16792	0.00000	-0.077528
1983	2.16792	0.00000	-0.19692
1984	2.16792	0.00000	-0.24853
1985	2.16792	0.00000	-0.29295
1986	2.16792	0.00000	-0.71064
1987	2.16792	-0.67078	0.00000
1988	2.16792	0.00000	-0.76229
1989	2.16792	-0.68366	0.00000
1990	2.16792	-0.51888	0.00000
1991	2.16792	0.00000	-0.62775

1992	2.16792	0.00000	-0.67165
1993	2.16792	0.00000	-0.72868
1994	2.16792	0.00000	-0.78912
1995	2.16792	0.00000	-0.79585
1996	2.16792	-0.67729	0.00000
1997	2.16792	0.00000	-0.70692
1998	2.16792	0.00000	-0.96334
1999	2.16792	-0.80060	0.00000
2000	2.16792	-0.45147	0.00000
2001	2.16792	0.00000	-0.53068
2002	2.16792	0.00000	-0.57773
2003	2.16792	-0.42360	0.00000
2004	2.16792	-0.27926	0.00000
2005	2.16792	-0.030373	0.00000