# World oil demand's shift toward faster growing and less price-responsive products and regions

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**Abstract**

Using data for 1971-2008, we estimate the effects of changes in price and income on world oil demand, disaggregated by product – transport oil, fuel oil (residual and heating oil), and other oil – for six groups of countries. Most of the demand reductions since 1973-74 were due to fuel-switching away from fuel oil, especially in the OECD; in addition, the collapse of the Former Soviet Union (FSU) reduced their oil consumption substantially. Demand for transport and other oil was much less price-responsive, and has grown almost as rapidly as income, especially outside the OECD and FSU. World oil demand has shifted toward products and regions that are faster growing and less price-responsive. In contrast to projections to 2030 of declining per-capita demand for the world as a whole – by the U.S. Department of Energy (DOE), International Energy Agency (IEA) and OPEC – we project modest growth. Our projections for total world demand in 2030 are at least 20% higher than projections by those three institutions, using similar assumptions about income growth and oil prices, because we project rest-of-world growth that is consistent with historical patterns, in contrast to the dramatic slowdowns which they project.

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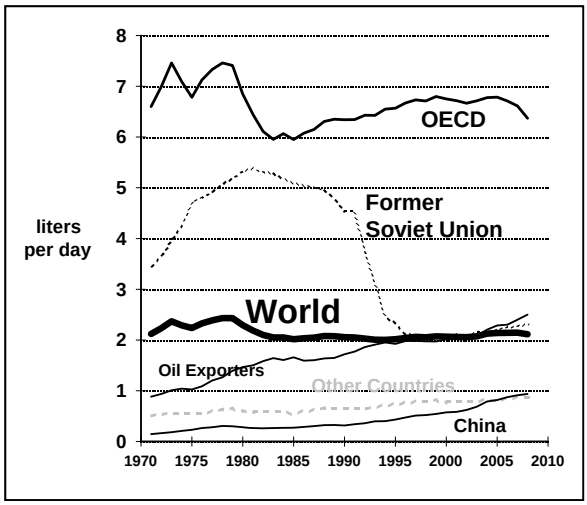
## 1. Introduction

Two liters a day – that's what per-capita world oil demand has been for forty years. Yet this constancy conceals dramatic changes. While per-capita demand in the OECD and the FSU have been reduced – primarily due to fuel-switching away from oil in electricity generation and space heating, and by economic collapse in the FSU – per-capita oil demand in the rest of the world has nearly tripled, to more than 1 liter/day. In addition, the rest of the world's population has grown much faster than in the OECD and FSU (1.85% v. 0.74% annually). As a result, the rest of the world's total oil consumption has grown *seven times faster* (4.4% annually, versus 0.6% in the OECD and FSU) – increasing from 14% of the world total in 1971, to 39% today. Strangely, however, recent projections by DOE, IEA, and OPEC project a sharp deceleration of per-capita oil demand growth through 2030 in the rest of the world – from 2.54% annually since 1971 to 0.6% annually (DOE) or 1% annually (IEA, OPEC).

Figure 1. Per-capita Oil Demand, 1971-2008 (liters/day)




The factors most responsible for reducing demand since 1971 cannot be repeated. Almost all the low-hanging fruit has now been picked; it cannot be picked again.

1. The OECD has already done the easy fuel-switching, away from oil used in electricity generation and space heating. This fuel substitution started after the two price jumps in the 1970's, continued in the 1980's and 1990's despite the oil price collapse, and accelerated after recent price increases. Fuel oil's share of total OECD oil has fallen from 44% in 1971 to 16% in 2008; OECD Fuel Oil's share of total world oil has fallen from 33% to 9%.
2. The economic collapse of the FSU reduced their oil consumption by 54% in the period 1990-1998: from 8.3 to 3.8 mbd. Residual oil use has been almost completely eliminated since 1990, declining steadily by about 7% annually; its product share went from 34% in 1990 to 13% by 2006.

If annual per-capita oil demand growth rates to 2030 were assumed to be held zero in the OECD, 1% in the FSU, and at its 1971-2008 historical rate (2.54% annually) in the rest of the world, total oil demand will be 138 mbd in 2030 – about 30 mbd greater than what is projected by DOE, IEA, and OPEC. By

2030 the rest of the world's per-capita demand would be almost 2 liters/day, and its share of total world demand would increase from 39% now to 58%.

Now that the OECD and FSU have almost exhausted their easy fuel-switching opportunities, it will be much more difficult to restrain oil demand growth in the future, while the rest of the world's economies and population continue to grow. To illustrate the difficulty of reducing demand, compare two decades in which the price of crude oil has quintupled: 1973-84 and 1998-2008. After the price increases of the 1970's, per-capita demand fell by 19% for the OECD and by 13% for the world as a whole. In the past decade, with oil price increases similar to those of the 1970's, per-capita demand fell only 3% in the OECD; worldwide it actually increased, by 4%.

The outline of this paper is as follows. We employ a model similar to that of Gately and Huntington (2002) to analyze oil demand disaggregated by product (transport oil, fuel oil, and other oil), for almost all countries of the world. In Section 2, we summarize how oil demand has changed over time and relative to income, by oil product and by country group. Section 3 describes the demand equations that we shall use, and Section 4 summarizes the econometric results, for each group of countries. We allow for the possibility that demand has responded asymmetrically to price increases and decreases, and find strong evidence for this in the OECD, especially for Fuel Oil. We also test for asymmetric demand response to *income* increases and decreases, and find evidence for this in the demand behavior of the Oil Exporters. Section 5 presents our demand projections and compares them with the short-term and long-term projections of IEA and DOE. Section 6 presents our conclusions. Appendix A describes the data sources.

## 2. Background

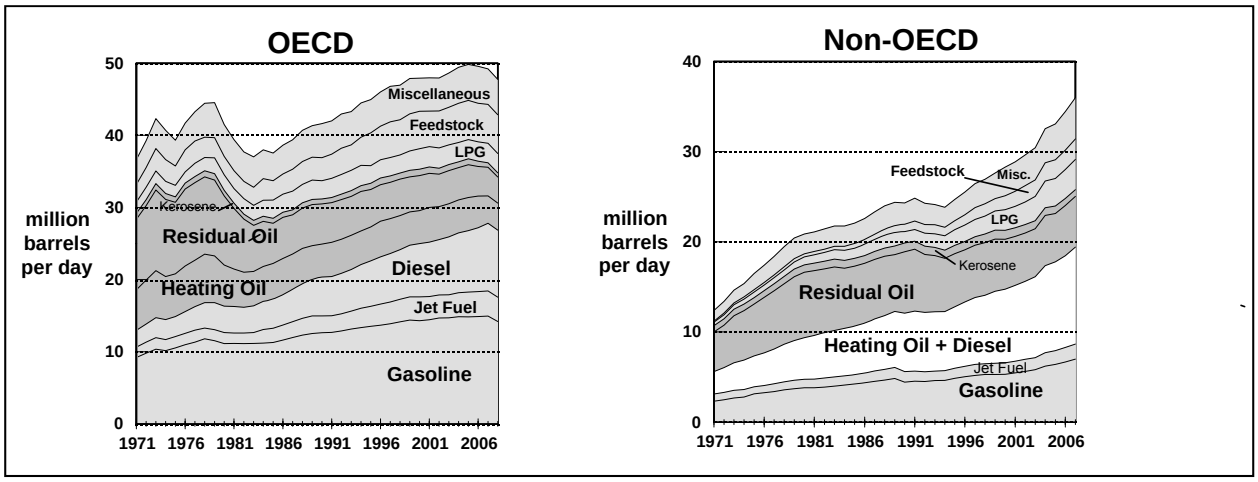
We examine world oil demand since 1971, disaggregated into three groups of oil products[1] (see Figure 2):

- Transport Oil: Gasoline, Jet Fuel, Diesel (Light Fuel Oil used in Transport)
- Fuel Oil: Residual Oil, Heating Oil (Light Fuel Oil not used in Transport), Kerosene (non Jet Fuel)
- Other Oil: Feedstock (petrochemical inputs: Naphtha and Liquefied Petroleum Gases, LPG), non-feedstock LPG, and Miscellaneous

Note that only for the OECD does the IEA disaggregate Light Fuel Oil into Diesel Oil and Heating Oil. For Non-OECD countries, the IEA does not disaggregate Diesel Oil and Heating Oil. As discussed at the end of this section, we disaggregate the Non-OECD into five groups: Oil Exporters, FSU, China, Income Growers and Other Countries.

The OECD graph of Figure 2 shows significant increases in levels of Transport Oil and Other Oil, and decreases in levels of Fuel Oil; oil product shares move in the same direction as the levels. The Non-OECD graph of Figure 2 shows increasing demand levels for almost all products; shares are increasing for Other Oil and decreasing for Residual Oil and Kerosene.

Figure 2. Oil Product Demand Levels, OECD (1971-2008) and Non-OECD (1971-2007)




The biggest reductions in oil demand have occurred in fuel-switchable uses of oil within the OECD, such as electricity generation and home heating: 7 mbd drop in fuel oil demand 1978-85, 2 mbd drop in 2003-2008. Within the Non-OECD, similarly large reductions occurred after the economic collapse of the FSU; total oil demand fell by 5 mbd, from 8.7 mbd in 1989 to 3.7 mbd in 1999. Due to this FSU

[1] See Downey(2009) for more details about oil products.

reduction, Non-OECD demand remained relatively flat from 1988-1994; the FSU declines offset demand growth elsewhere.

Figure 3. Per-capita Oil Product Demand and Real Income, OECD (1971-2008) and Non-OECD (1971-2007)

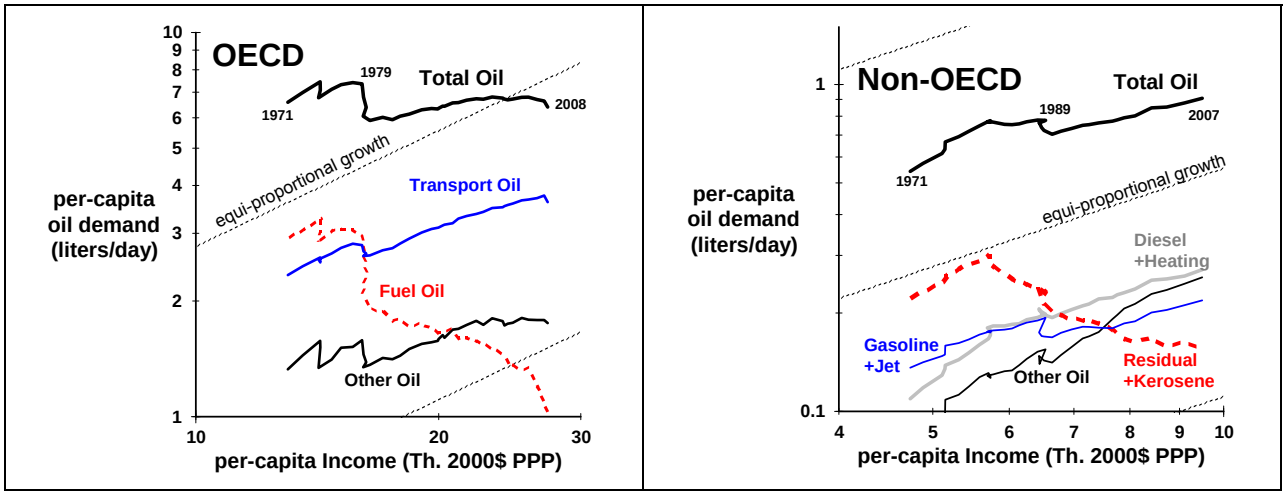



Figure 3 compares the growth of per-capita oil demand with per-capita income, for the OECD and Non-OECD since 1971. The scales are logarithmic, which facilitates growth-rate comparisons between oil growth and income growth. Movement parallel to the diagonal lines indicates equi-proportional growth in oil demand and income; steeper [less steep] movement indicates that oil is growing faster [slower] than income. Transport and Other Oil demand in both the OECD and Non-OECD have grown almost as rapidly as income, despite two major increases in price. Were it not for reductions in Fuel Oil, Total Oil demand would have grown as rapidly as income, in both the OECD and Non-OECD.

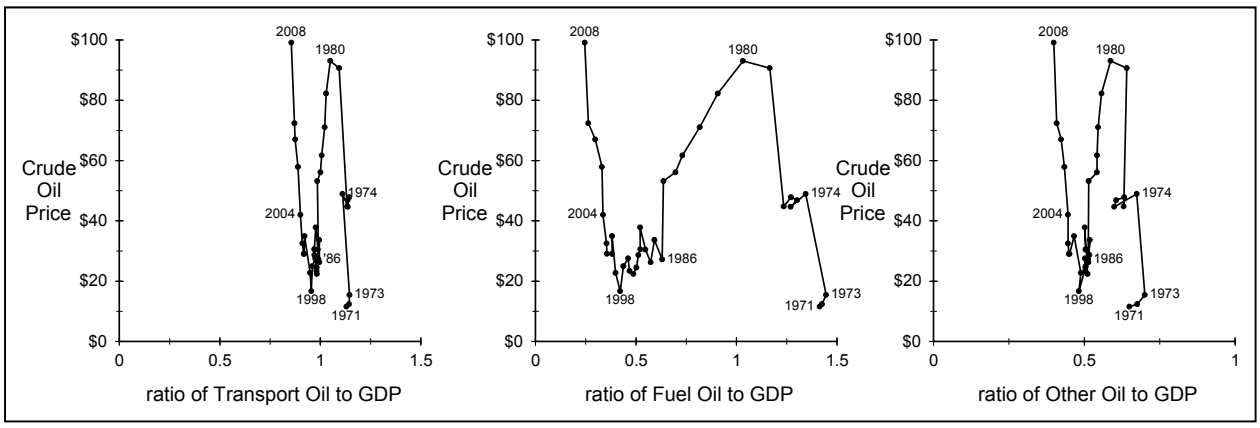
Substantial declines in OECD per-capita Total Oil have occurred only after major price increases: in 1973-74 and 1979-80, with a more moderate demand decline in 2004-08. The declines were due primarily to dramatic reductions in Fuel Oil demand. In contrast, Non-OECD Total Oil has increased steadily since 1971, about as fast as income; the only substantial decline followed the FSU economic collapse in 1989.

An important aspect of demand, especially for OECD fuel oil, is that it did not respond symmetrically to price changes; the demand reductions following the price increases of the 1970's were not reversed by the price collapse of the 1980's. Figure 4 depicts graphs for price versus the oil/GDP ratio. We see the 1973-80 price quintupling being almost completely reversed by 1986, to be followed by the 1998-2008 price quintupling. Fuel oil demand fell after the 1973-80 price increases, and continued to fall even after

price collapses in 1980-86 (due to delayed responses to the previous price increases): the demand reductions were not reversed when the price increase was reversed. Fuel oil demand fell again when price increases again in 1998-2008. It was good news for the OECD that these demand reductions were not reversed in the 1980s when the oil price increases of the 1970s were reversed. But the bad news is the OECD has picked almost all of fuel-switching's low-hanging fruit; it did not grow back, so it cannot be picked again.

In contrast with Fuel Oil, the OECD has achieved only modest reductions in demand for Transport and Other Oil, but the demand response has been less asymmetric with respect to price changes. The smaller demand reductions *have* been partly reversed when the oil price increases of the 1970's were reversed in the 1980's. For example, the average weight of new vehicles in the USA was reduced from 4060 pounds in 1975 to 3200 pounds in 1980, only to increase again to 4089 pounds by 2005[2]. Some of the fuel-efficiency improvements were offset by making vehicles heavier and more powerful after oil prices collapsed in the 1980s. Hence transport oil demand reduction *can* be partly re-done because it was partly un-done[3].

Figure 4. Crude Oil Price ($2008/b) and OECD Demand/GDP ratio: Transport Oil, Fuel Oil, and Other Oil: 1971-2008.




[2] Data from Robert Heavenworth, US EPA.

[3] If there were perfect reversibility and no lagged response, all points would fall on a single line. Generally speaking, the greater the distance between the lines the greater the asymmetry.

These factors – the nearly complete switching away from Fuel Oil in the OECD and FSU, and the rest of the world's rapid economic growth and almost-as-rapid growth of Transport and Other Oil – have brought about a remarkable change in the world's ability to reduce demand when price increases sharply. Table 1 contrasts the substantial demand reductions that occurred after the price quintupling of the 1970's and the minimal demand response to the price quintupling of 1998-2008[4]. In both cases, the decline in world oil demand was primarily the result of OECD fuel-switching in electricity generation and home heating. After the last decade's price quintupling there has been much less demand reduction in the OECD: not 19% per capita as in 1973-84 but only 3% in 1998-2008. Non-OECD per-capita demand grew slightly faster in 1998-2008 (23% vs. 20% in 1973-84), due primarily to much faster income growth. World oil per-capita demand, instead of dropping 13% in 1973-84, actually grew in 1998-2008, albeit slowly (4%), as income grew more than twice as much in 1998-2008 as in 1973-84. The lessened demand response in 1998-08 was due to faster Non-OECD income growth, a larger Non-OECD share of Total World Oil (37% in 1998 vs. 27% in 1973), and most importantly, the fact that OECD Fuel Oil – the most price-responsive product in the most price-responsive region (as our econometric results below will demonstrate) -- comprised 33% of Total World Oil in 1973 but only 14% in 1998.

[4] Strictly speaking, of course, we should note that comparisons are complicated by the fact that we have yet to see all the demand reductions in response to the last decade's price quintupling.

Table 1. Oil demand response to price quintuplings in 1973-84 and 1998-2008

| | 1973 | 1984 | % change 1973-1984 | 1998 | 2008 | % change 1998-2008 |
|---|---|---|---|---|---|---|
| Crude Oil Price (2007 $/b) | $16.01 | $96.62 (1980) | 504% | $17.32 | $97.26 | 461% |
| | | | | | | |
| OECD | | | | | | |
| Real Income per capita (Th.$) | $14.3 | $17.0 | 20% | $22.7 | $27.3 | 20% |
| Total Oil per capita (liters/day) | 7.27 | 5.98 | -19% | 6.66 | 6.33 | -3% |
| Fuel Oil per capita (liters/day) (a) | 3.28 | 1.89 | -42% | 1.52 | 1.06 | -30% |
| *Fuel Oil share of Total OECD Oil* | *45%* | *32%* | | *23%* | *17%* | |
| *OECD share of Total World Oil* | *73%* | *63%* | | *63%* | *56%* | |
| *OECD Fuel Oil share of Total World Oil* | *33%* | *20%* | | *14%* | *9%* | |
| | | | | | | |
| Non-OECD | | | | | | |
| Real Income per capita (Th.$) | $2.3 | $2.9 | 27% | $3.5 | $5.8 | 66% |
| Total Oil per capita (liters/day) | 0.78 | 0.94 | 20% | 0.92 | 1.14 | 23% |
| Residual Oil per capita (liters/day) * | 0.27 | 0.30 | 12% | 0.21 | 0.18 | -17% |
| *Residual Oil share of Total Non-OECD Oil* | 32% | 31% | | 23% | 16% | |
| *Non-OECD share of Total World Oil* | *27%* | *37%* | | *37%* | *44%* | |
| *Non-OECD Residual Oil share of Total World Oil* | *9%* | *12%* | | *8%* | *7%* | |
| | | | | | | |
| World | | | | | | |
| Real Income per capita (Th.$) | $5.1 | $5.9 | 16% | $7.2 | $9.8 | 35% |
| Total Oil per capita (liters/day) | 2.37 | 2.05 | -13% | 2.05 | 2.11 | 3% |
| Residual Oil per capita (liters/day) (b) | 0.66 | 0.45 | -32% | 0.31 | 0.23 | -24% |
| *Residual Oil share of Total World Oil* | 28% | 22% | | 15% | 11% | |

(a) Source: IEA, "Fuel Oil" = Residual Oil + Heating Oil + Kerosene

(b) Source: BP(2009) p. 14, Consumption by Product Group, "Fuel Oil"

As we have seen in the above graphs and as will be demonstrated in our econometric results below, there are important differences in the responsiveness of oil demand to changes in price and income between the OECD and Non-OECD. There are also substantial differences across countries, and especially within the Non-OECD. We analyze six groups of countries; the Non-OECD disaggregation is similar to that in Gately and Huntington (2002)[5].

- **OECD**, where oil demand has been more price-responsive and less income-responsive than in any of the other groups (19% of world population, 60% of oil demand, and 26% of oil demand growth since 2000)
- **Income Growers,** where oil demand has increased almost as rapidly as income, and has been almost unaffected by price changes. The criteria for inclusion: increases of per-capita income in at least 27 years from 1972-2005 and an average annual growth rate of 3%. (27% of world population, 10% of oil demand, and 16% of demand growth since 2000)
- **China**, where demand has grown similarly to that of the Income Growers, but only after the 1970s (21% of world population, 8% of oil demand, 31% of demand growth since 2000).
- **Oil Exporters**, where oil demand growth has been least responsive to price increases and even relatively unresponsive to declining per-capita income in the 1980s**:** (9% of world population, 10% of oil demand, 24% of demand growth).
- **Former Soviet Union** (FSU), where oil demand fell symmetrically with income after the 1989 collapse of the Soviet Union and the rapid decline of oil production, but has increased slowly since 1997 as declining demand for residual oil has almost offset growth in other oil demand (5% of world population, 4% of oil demand, no demand growth since 2000).
- **Other Countries**: 49 countries; excluded are only a few small countries for which data is unavailable for the entire time period (19% of world population, 8% of oil demand, 5% of demand growth since 2000).

[5] OECD includes all 30 current members. Oil Exporters include 12 OPEC members plus Bahrain, Brunei, Ecuador, Gabon, Oman, Qatar. China excludes Hong Kong and Chinese Taipei. Income Growers include Chile, Chinese Taipei, Cyprus, Dominican Republic, Egypt, Hong Kong, India, Malaysia, Malta, Myanmar, Pakistan, Singapore, Sri Lanka, Thailand, Tunisia, Vietnam, Yemen. Former Soviet Union includes Russia, Azerbaijan, Kazakhstan, Turkmenistan, Uzbekistan, Armenia, Belarus, Estonia, Georgia, Kyrgyzstan, Latvia, Lithuania, Moldova, Tajikistan, Ukraine.

## 3. Demand Model

Since our aim is to estimate aggregate oil demand models for a large group of countries, the model used will of necessity be a simple one. We choose a reduced-form model in which long-run oil demand is assumed to be a function of economic activity and energy prices. In such a model, aggregate output, as measured by real gross domestic product (GDP), is assumed to represent the energy-using capital stock, i.e. buildings, equipment and vehicles. Ideally, we would also like to include the prices of substitute fuels as well as oil product prices. However, prices of substitute fuels exist for very few countries; in fact, even oil product prices are only available for a small sub-set of countries. For this reason, crude oil prices are used instead of product prices for most of the analysis and the prices of other energy sources are excluded from the demand model. The implications of these simplifications for our results are discussed in conjunction with the presentation of the econometric results.

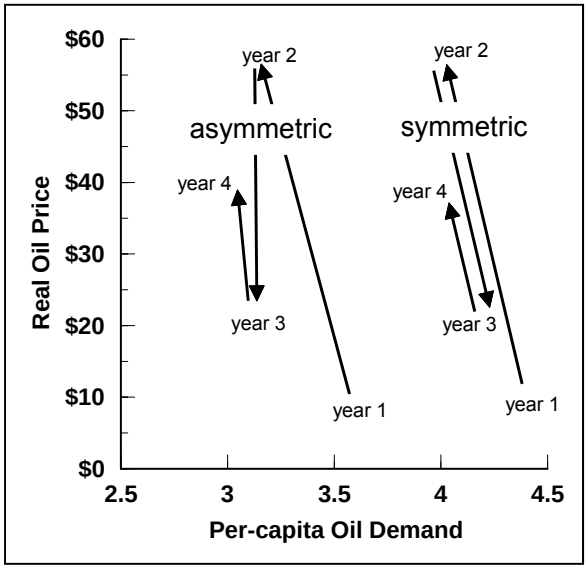
Since oil consumption does not respond instantaneously to changes in price and income (GDP), but instead changes slowly over time as the capital equipment adjusts, the relationship is modeled as a lagged-adjustment process. Specifically, per-capita oil demand for each country is expressed as a function of per-capita income, the price of oil, and lagged oil consumption. The model is estimated using pooled cross-section/time-series data for the individual countries included in each of the country groupings defined in the previous section. In order to allow for differences amongst countries that are not explicitly included in the model, a separate constant (intercept) is estimated for each country – what is called a "fixed effects" model. The fixed (country) effects incorporate any regional differences among countries, including variations in long-term energy policies across countries.[6] All variables are converted to logarithms, so that the model is of the constant elasticity form.

All economic variables are expressed in real terms. GDP data (using PPP) are in constant 2005 international dollars. For the oil price, we use the world price of crude oil, also in constant dollars. Although we would prefer to use real end-user prices in local currencies, as mentioned above, these are available for only a few large OECD countries (and used below), so that the global market could only be analyzed using crude prices. The use of crude oil prices makes our model less suitable for analyzing demand in individual countries – for which country-specific prices would be important for understanding the impact of taxes, subsidies and other oil policies – but it should provide a reasonable description of how demand for groups of countries respond to the price of crude oil. Appendix A discusses data sources and the construction of the data set.

[6] We also examine the inclusion of fixed time effects, as suggested by Griffin and Schulman(2005), and the issue of whether they are exogenous to changes in price; these are discussed in Appendix C.

We adopt the approach used by Gately and Huntington (2002) to analyze aggregate oil and energy demand in 96 different countries. The use of this approach allows us to test whether their previous estimates of the response to price and income are robust to more recent data (after 1996). It also allows us to understand whether oil demand disaggregation by product significantly influences oil consumption patterns and their responses to price and income.

Figure 5. Demand Response to Oil Price Changes: Asymmetric and Symmetric

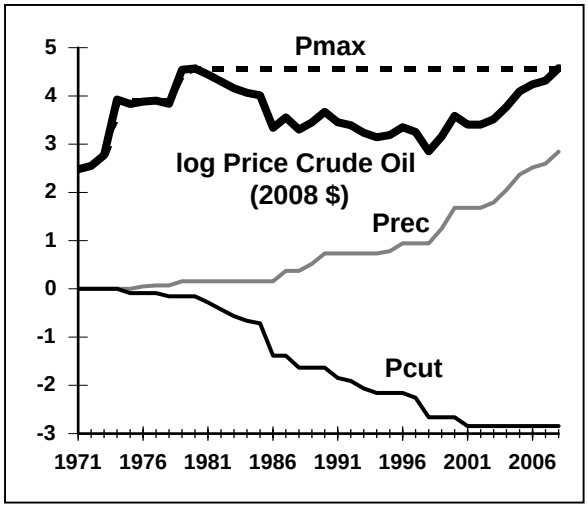



In order to allow for the possibility of asymmetric demand responses to price increases and decreases as well as to prices above previous maximum historical levels, we decompose the logarithm of the price variable into three series[7] (Figure 6):

- The maximum historical price, $P_{max,t}$, which equals the highest logarithmic price between the initial year (1971) and the current year, t;
- The cumulating series of price cuts, $P_{cut,t} \leq 0$, which is monotonically non-increasing in logarithms;
- The cumulating series of sub-maximum price recoveries, $P_{rec,\,t} \geq 0$, which is monotonically non-decreasing in logarithms.

[7] This approach was used by Haas and Schipper(1998) for residential energy demand, Walker and Wirl(1993) for road transport fuel, and Gately and Huntington(2002) for aggregate oil and energy demand.

Figure 6. Decomposition of Crude Oil Price




These price components do not simply allow us to test for asymmetric responses to price increases and decreases. They also postulate that a given increase in real oil prices may have a much different demand response when it happens over price ranges previously experienced (as in today's market) than when that same event occurs for the first time (as in the 1970s). Consumers should not respond as strongly to a repeat of previous price experiences, because they have already adjusted their equipment for these new conditions in previous periods. In this respect, the specification incorporates technical progress in the economy's capital stock configuration due to higher oil prices. One interpretation of asymmetric price effects is that (some) price increases induce energy-saving technical change, which is not un-done when prices fall. Examples are efficiency improvements in vehicles and heating systems: see Walker-Wirl(1993) and Haas-Schipper(1998). Asymmetric price effects could also reflect fuel-switching that is not reversed by price cuts, as is evident in the demand for residual and heating oil. We expect that the relative magnitude of these decomposed price coefficients would be as follows:

$$| \text{coefficient of } P_{max} | > | \text{coefficient of } P_{rec} | > | \text{coefficient of } P_{cut} | > 0 \ .$$

Similarly, to account for the possibility of asymmetric demand response to increases and decreases in income, we decomposed the logarithm of income (Y) in a similar manner, with the series $Y_{max}$ and $Y_{rec}$ being non-negative and non-decreasing and $Y_{cut}$ being non-positive and non-increasing. This decomposition is described in more detail in Gately-Huntington (2002). This asymmetric response could happen in some countries when recessions do not cause people to shed their equipment as quickly as when expansions cause them to accumulate new capital stock. In practice, as shown below, this alternative specification is appropriate primarily for the oil consumption decisions within the Oil Exporters. We expect that the relative magnitude of these decomposed income coefficients would be as follows:

$$\text{coefficient of } Y_{max} > \text{coefficient of } Y_{rec} > \text{coefficient of } Y_{cut} > 0 \ .$$

The most general specification allows the lagged-adjustment process to be different for income and price by including separate adjustment coefficients for income ($\theta_y$) and price ($\theta_p$). Allowing the above decomposition of both income and price, we estimate the following log-linear regression[8]:

$$
\begin{aligned}
(1)\ D_{c,t} = k_{1c} + (\theta_p + \theta_y) * D_{c,t-1} - (\theta_p * \theta_y) * D_{c,t-2} \\
+ \beta_m P_{max,\,t} + \beta_c P_{cut,\,t} + \beta_r P_{rec,\,t} \\
- \theta_y * ( \beta_m P_{max,\,t-1} + \beta_c P_{cut,\,t-1} + \beta_r P_{rec,\,t-1} ) \\
+ \gamma_m Y_{max,c,t} + \gamma_c Y_{cut,\,c,t} + \gamma_r Y_{rec,\,c,t} \\
- \theta_p * ( \gamma_m Y_{max,\,c,t-1} + \gamma_c Y_{cut,\,c,t-1} + \gamma_r Y_{rec,\,c,t-1} )
\end{aligned}
$$

where D and Y are per capita levels, $k_{1c}$ are the constants for the individual countries (fixed country-effects) and the other parameters are the same across countries. This approach provides separate estimates for each of the parameters, including $\theta_p$ and $\theta_y$. As noted earlier, we address the issue of fixed time effects in Appendix C.

The estimates of the coefficients of equation (1) will be consistent, and normal tests of significance will be valid, only under the condition that the variables in (1) are stationary. Since our variables are expressed in logarithmic form, we tested for stationarity of the log variables using a number of unit-root tests. Results of these tests are presented in Appendix B. In some cases the tests give conflicting results, and the conclusions are not the same for all products and regions. In general we find that log demand per capita is stationary for the majority of products in the majority of regions. The most obvious exception is for Other Countries. Log prices are stationary in all cases, and log GDP/capita is stationary in the OECD, but generally non-stationary in the other regions. These results suggest that estimation of a model in differenced form might be preferable in some cases. However, the results for the OECD generally support the level model described above and, for the sake of consistency, all regions and products are estimated using the same initial model.

We employed the general specification (1) for each of the six country groups, and then used statistical tests to determine whether a simpler specification would be warranted. We used Wald tests to determine whether or not the decomposed price coefficients are equal to each other, and similarly for the decomposed income coefficients. If we could not reject symmetric responsiveness of demand to changes in price [income], then we used a simpler symmetric specification with a single coefficient for price [income].

[8] See Gately and Huntington (2002) for the derivation. Estimation uses weighted least squares, with weights determined by the log of country population.

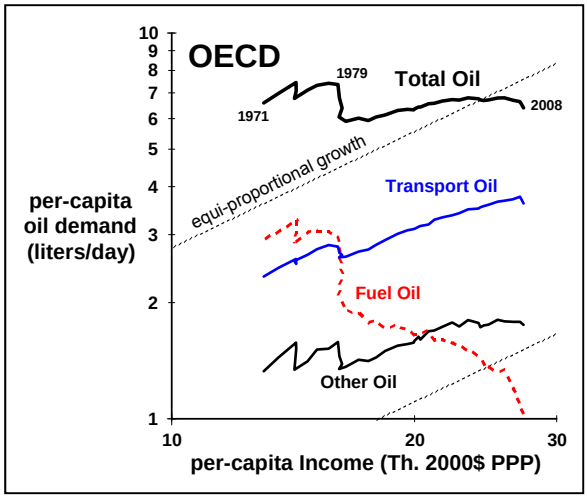
We also tested the significance of the lagged-adjustment coefficients for price and income, $\theta_p$ and $\theta_y$. If either coefficient was not statistically different from zero, then it was dropped from the specification; and if a Wald test could not reject equivalence between $\theta_p$ and $\theta_y$ then only a single coefficient $\theta$ was used. Finally, if the coefficient for price was not significant, then it was dropped from the specification -- as it was for the Oil Exporters, China, and the Former Soviet Union. These statistical tests resulted in different special cases of the general equation (1) being used for the different groups of countries.

- For OECD: symmetric response to income changes ($\gamma_m = \gamma_c = \gamma_r$), no lagged adjustment to income changes ($\theta_y = 0$).
  (2) $D_{c,t} = k_{1c} + \theta_p D_{c,t-1} + \beta_m P_{max,t} + \beta_c P_{cut,t} + \beta_r P_{rec,t} + \gamma Y_{c,t} - \theta_p \gamma Y_{c,t-1}$
- For Income Growers: symmetric demand response to price changes ($\beta_m = \beta_c = \beta_r$) and income changes ($\gamma_m = \gamma_c = \gamma_r$), and separate lagged adjustments to price and income.
  (3) $D_{c,t} = k_{1c} + (\theta_p + \theta_y) * D_{c,t-1} - (\theta_p * \theta_y) * D_{c,t-2} + \beta * P_t - \theta_y * \beta * P_{t-1} + \gamma * Y_{,c,t} - \theta_p * \gamma Y_{c,t-1}$
- For China, and for the Former Soviet Union : a simple specification that omits price and uses only income and lagged adjustment to income.
  (4) $D_t = k_1 + \gamma * Y_t + \theta_y * D_{c,t-1}$
- For Oil Exporters: specification excludes price and uses decomposed income, and lagged adjustment to income changes:
  (5) $D_{c,t} = k_{1c} + \gamma_m Y_{max,c,t} + \gamma_c Y_{cut,c,t} + \gamma_r Y_{rec,c,t} + \theta_y * D_{c,t-1}$
- For Other Countries: equation (1).

# 4. Econometric Results

## *4.1 Results for OECD Countries*

Figure 7. OECD Oil Demand and Income, per capita, 1971-2008




The demand specification is equation (2): asymmetric price-response, symmetric income response, with lagged-adjustment for price but instantaneous adjustment for income. Results are shown in Table 2, for all 30 OECD countries and also for just the largest countries (G-7 OECD), using both crude oil and product prices.[9]

The table shows the estimated coefficients, the long-run elasticities and the results of the tests regarding price asymmetry. In all cases, both prices and income have a significant effect on the demand for total oil and the three product groups. We also conclude that symmetry in the response to rising and falling prices is rejected in all cases, although the type of asymmetry is not the same for all products. The lagged adjustment coefficients are relatively high, indicating slow adjustment to changes in price.

The long-run price elasticity is much higher for Fuel Oil than for Transport and Other Oil , with Total Oil in between, as expected. The use of product prices rather than crude oil prices increases the price elasticity, also as expected. This is most obvious for Transport Oil, which is not surprising since transport oil prices differ from crude prices more than do other product prices, due to high taxes on gasoline and diesel.

Income elasticities are relatively high, for Total Oil and for each of the products, indicating that demand growth would have been much higher, were it not for the substantial increases in price. For all 30 OECD countries, the income elasticity ranges from 0.56 for Fuel Oil to 1.11 for Other Oil, with Transport Oil at 0.91 and Total Oil at 0.80.

[9] Although product prices are not available for most of the OECD countries, they are available for the G-7 countries: USA, Canada, Japan, France, Germany, Great Britain, and Italy.

Table 2. OECD Results, using data for 1971-2008

| Product | row # | Prices used | Countries | equation coefficients | | | | | long-run elasticities | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | lagged price adjustment | Pmax | Pcut | Prec | Income | Pmax | Pcut | Prec | Income |
| Total Oil | 1 | Crude Oil | 30 OECD | 0.91 (t=87.4) | -0.055 (t=-10.) | -0.018 (t=-5.6) | -0.027 (t=-7.4) | 0.80 (t=15.5) | -0.60 | -0.20 | -0.29 | 0.80 |
| | | | | | reject symmetry | | | | reject symmetry | | | |
| | 2 | Crude Oil | G-7 OECD | 0.85 (t=29.0) | -0.058 (t=-9.5) | *-0.007* (t=-1.0) | -0.031 (t=-6.4) | 0.89 (t=7.81) | -0.40 | *-0.05* | -0.21 | 0.89 |
| | | | | | reject symmetry | | | | reject symmetry | | | |
| | 3 | Oil Products | G-7 OECD | 0.87 (t=34.4) | -0.117 (t=-7.1) | *-0.014* (t=-0.9) | -0.085 (t=-6.6) | 0.98 (t=8.26) | -0.87 | *-0.10* | -0.63 | 0.98 |
| | | | | | reject symmetry except βmax=βrec | | | | reject symmetry except βmax=βrec | | | |
| Fuel Oil = Residual Oil + Heating Oil + Non-jet Kerosene | 4 | Crude Oil | 30 OECD | 0.96 (t=82.5) | -0.075 (t=-6.2) | -0.026 (t=-3.4) | -0.054 (t=-6.0) | 0.56 (t=4.00) | -1.67 | -0.59 | -1.20 | 0.56 |
| | | | | | reject symmetry | | | | reject symmetry | | | |
| | 5 | Crude Oil | G-7 OECD | 0.93 (t=29.2) | -0.083 (t=-6.0) | *-0.018* (t=-1.1) | -0.052 (t=-4.3) | 1.04 (t=3.88) | -1.13 | *-0.25* | -0.71 | 1.04 |
| | | | | | reject symmetry | | | | reject symmetry | | | |
| | 6 | Oil Products | G-7 OECD | 0.89 (t=30.4) | -0.145 (t=-6.5) | *-0.017* (t=-0.7) | -0.090 (t=-5.0) | 1.06 (t=4.05) | -1.27 | *-0.15* | -0.79 | 1.06 |
| | | | | | reject symmetry | | | | reject symmetry | | | |
| Transport Oil = Gasoline + Jet Fuel + Diesel Oil | 7 | Crude Oil | 30 OECD | 0.92 (t=86.8) | -0.017 (t=-4.2) | -0.016 (t=-5.0) | -0.023 (t=-6.2) | 0.91 (t=15.9) | -0.22 | -0.21 | -0.30 | 0.91 |
| | | | | | cannot reject symmetry | | | | cannot reject symmetry | | | |
| | 8 | Crude Oil | G-7 OECD | 0.94 (t=49.2) | -0.029 (t=-4.3) | -0.021 (t=-5.2) | -0.030 (t=-6.9) | 0.68 (t=7.27) | -0.47 | -0.34 | -0.49 | 0.68 |
| | | | | | reject symmetry except βmax=βrec | | | | reject symmetry except βmax=βrec | | | |
| | 9 | Transport Oil | G-7 OECD | 0.93 (t=64.4) | -0.101 (t=-5.2) | -0.053 (t=-5.9) | -0.063 (t=-6.9) | 0.69 (t=8.41) | -1.41 | -0.74 | -0.88 | 0.69 |
| | | | | | reject symmetry except βcut=βrec | | | | reject symmetry except βcut=βrec | | | |
| Other Oil = Feedstock + LPG + Miscellaneous | 10 | Crude Oil | 30 OECD | 0.91 (t=92.5) | -0.023 (t=-3.6) | -0.015 (t=-2.9) | -0.027 (t=-4.4) | 1.11 (t=11.9) | -0.27 | -0.18 | -0.31 | 1.11 |
| | | | | | reject symmetry except βmax=βrec | | | | reject symmetry except βmax=βrec | | | |
| | 11 | Crude Oil | G-7 OECD | 0.86 (t=29.4) | -0.047 (t=-4.7) | *-0.006* (t=-0.7) | -0.025 (t=-2.8) | 1.20 (t=5.86) | -0.34 | *-0.04* | -0.18 | 1.20 |
| | | | | | reject symmetry except βmax=βrec | | | | reject symmetry except βmax=βrec | | | |
| | 12 | Oil Products | G-7 OECD | 0.82 (t=24.8) | -0.094 (t=-3.7) | *0.041* (t=1.67) | -0.071 (t=-3.2) | 1.40 (t=7.65) | -0.52 | *0.23* | -0.39 | 1.40 |
| | | | | | reject symmetry except βmax=βrec | | | | reject symmetry except βmax=βrec | | | |

Notes:

1. No autoregressive terms were found significant in any equation, except AR1 in the equations in rows 1, 4, and 8.

2. Fuel Oil equations used a dummy variable for the 1984 coal strike in Great Britain, when Residual Oil was substituted for coal in electricity generation. The coefficient value was +0.40, with the expected positive sign, and it was significant.

3. When a time-trend variable was also included in these equations, its coefficient was usually negative but not significant. It was negative and significant only for Fuel Oil when Crude Oil prices were used: rows 4 & 5.

4. When time dummy variables were also included in equations #3, 6, 9, 12, the price coefficients became smaller and not significant. Few of the time dummy coefficients were significant: none for Transport Oil, 3 for Fuel Oil, 6 for Other Oil, and about half of those for Total Oil.

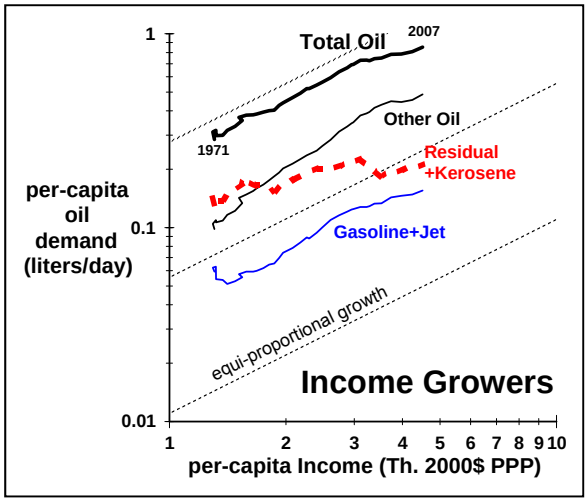
5. In row 7 equation, symmetry could not be rejected for βmax=βcut or for βmax=βrec, but it could be rejected for βcut=βrec and for βmax=βcut=βrec

6. When a lagged-income adjustment term was included in these equations, its coefficient was usually negative or not significant. In the few cases when it was positive and significant, its magnitude was very small (less that 0.1), indicating rapid adjustment.

These results indicate that the demand response to the historic price increases of the 1970's ($P_{max}$) was *much* greater than the response to the price recoveries ($P_{rec}$) since then, as indicated by the OECD data in Table 1. Another way to measure this difference in price responsiveness would be to divide the data sample into two halves, and estimate the demand equation separately: first with data from 1971 to 1989, and then with data from 1989 to 2008. Using this alternative method, for the G-30 total-oil equation the long-run elasticity for price increases was four times greater for the 1971-89 period as for the 1989-2008 period (-0.65 versus -0.15). Similar differences were calculated for the product groups, for the earlier and later periods respectively: Fuel Oil -1.04 and -0.48; Transport Oil -0.13 and -0.08; Other Oil -0.45 and -0.16.

## *4.2 Results for Income Growers*

Figure 9. Income Growers' Oil Demand and Income, per capita, 1971-2007




The results in Table 3 indicate high income-elasticities -- 0.92 for Gasoline[10] + Jet, 1.17 for Other Oil, and 0.49 for Residual + Kerosene. These are illustrated in Figure 9: both Gasoline + Jet and Other Oil are moving almost parallel to the equi-proportional growth lines, which indicate unitary income-elasticity. Price responsiveness is low, and it is not statistically significant. Symmetric price-responsiveness could only be rejected for Residual + Kerosene, which shows a response to $P_{max}$ which is twice that to price recoveries and price cuts.

Table 3. Income Growers' Results, using crude oil prices, 1971-2007

| Product | equation coefficients | | | | | | long-run elasticities | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | lagged price adjustment | lagged income adjustment | Price | | | Income | Price | | | Income |
| Total Oil | 0.61 (t=5.7) | 0.60 (t=5.4) | Price (cannot reject symmetry) *-0.03* (t=-1.) | | | 0.35 (t=3.6) | Price (cannot reject symmetry) *-0.07* | | | 0.87 |
| Residual + Kerosene | 0.88 (t=26.) | 0.48 (t=5.0) | Pmax -0.10 (t=-2.3) | Pcut -0.05 (t=-2.0) | Prec -0.04 (t=-2.0) reject symmetry | *0.25* (t=1.8) | Pmax -0.79 | Pcut -0.40 | Prec -0.37 reject symmetry | *0.49* |
| Gasoline + Jet Fuel | 0.64 (t=7.5) | 0.50 (t=4.4) | Price (cannot reject symmetry) *-0.03* (t=-1.8) | | | 0.46 (t=4.4) | Price (cannot reject symmetry) *-0.08* | | | 0.92 |
| Other Oil | 0.41 (t=4.1) | 0.71 (t=12.) | Price (cannot reject symmetry) -0.04 (t=-2.4) | | | 0.35 (t=4.9) | Price (cannot reject symmetry) -0.07 | | | 1.17 |

Notes:

i. A coefficient that was not statistically significant is italicized.

*ii.* Wald tests allowed us to reject the hypothesis of symmetric price-responsiveness for Residual + Kerosene. However, for total oil and for the other two product groups, we could not reject symmetry so we assumed symmetric price-responsiveness.

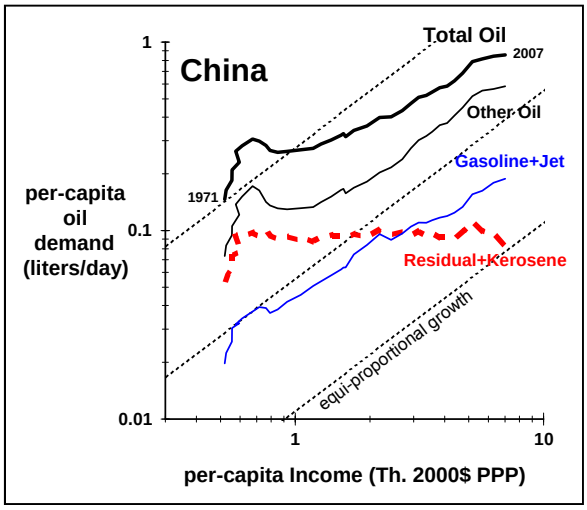
*iii.* The Adjusted $R^2$ for almost all specifications were very high, usually above 0.99.

*iv.* In each of the equations, an autoregressive term was found to be significant.

[10] Income elasticities near 1.0 for gasoline demand in developing countries are consistent with even higher income elasticities of vehicle ownership; see Dargay, Gately and Sommer(2007).

## *4.3 Results for China*

Figure 10. China's Oil Demand and Income, per capita, 1971-2007




Estimation using the full data set, starting in 1971, yields results that are very sensitive to the starting year of data. Only if the early years are dropped from the data can we get econometric results that are reasonable and stable. Hence, we use data starting in 1980. Economic and political reasons in support of this approach can be found in Kwan and Kwok (1995).

We examined a variety of alternative model specifications for China, with the response to price changes being symmetric or asymmetric, lagged or instantaneous, but the oil price was never found to be significant. A reason for this may be that the domestic product prices set by the government in China were not directly related to crude prices, so that the crude prices used in the model are a poor reflection of prices actually paid by consumers. Hence the results presented here only include income and lagged income adjustment.

Income elasticities are relatively high for most products except Fuel Oil: 0.74 for Gasoline + Jet and 0.98 for Other Oil. For Residual + Kerosene, the income elasticity is not significantly different from zero. These results are not surprising, given the movement of these oil product demands and income shown in Figure 10.

Table 4. China's Results, using data for 1980-2007.

| Product | equation coefficients | | long-run income elasticity |
|---|---|---|---|
| | lagged income adjustment | Income | |
| Total Oil | 0.78 (t=13.) | 0.16 (t=5.1) | 0.74 |
| Residual + Kerosene | *0.32* (t=1.6) | *0.02* (t=1.1) | *0.02* |
| Gasoline + Jet Fuel | 0.52 (t=3.1) | 0.36 (t=3.0) | 0.74 |
| Other Oil | 0.78 (t=19.) | 0.22 (t=7.4) | 0.98 |

Notes:

i. A coefficient that was not statistically significant is italicized.
ii. The Adjusted $R^2$ for almost all specifications were very high, usually above 0.99.
iii. No autoregressive term was found to be significant in any of the equations.

## *4.4 Results for Oil Exporters*

Figure 11. Oil Exporters' Oil Demand and Income, per capita, 1971-2007

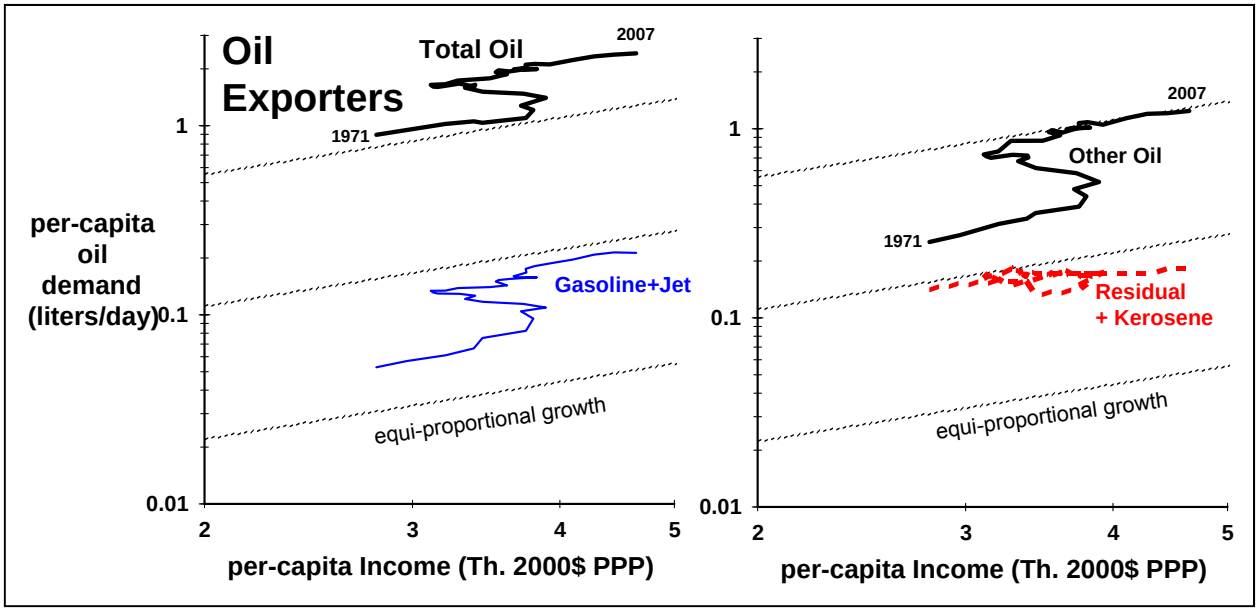



Table 5. Oil Exporters' Results, using data for 1971-2007.

| Product | equation coefficients | | | | long-run elasticities | | |
|---|---|---|---|---|---|---|---|
| | lagged income adjustment | Ymax | Ycut | Yrec | Ymax | Ycut | Yrec |
| Total Oil | 0.86 (t=45.) | 0.141 (t=3.6) | 0.048 *(t=3.1)* | 0.099 *(t=3.5)* | 1.00 | 0.34 | 0.70 |
| | | reject symmetry except ymax=yrec | | | | | |
| Residual + Kerosene | 0.88 (t=56.) | *0.000 (t=-0.)* | *-0.022 (t=-1.0)* | -0.126 (t=-2.6) | *0.00* | *-0.17* | -1.02 |
| | | reject symmetry | | | | | |
| Gasoline + Jet Fuel | 0.85 (t=58.) | 0.153 (t=6.7) | 0.058 (t=5.3) | 0.120 (t=4.4) | 1.01 | 0.39 | 0.79 |
| | | reject symmetry except ymax=yrec | | | | | |
| Other Oil | 0.83 (t=35.) | 0.176 (t=2.9) | *0.037 (t=1.5)* | 0.095 (t=2.1) | 1.06 | *0.23* | 0.57 |
| | | reject symmetry except ymax=yrec | | | | | |

Notes:

i. A coefficient that was not statistically significant is italicized.

*ii.* The Adjusted $R^2$ for almost all specifications were very high, usually above 0.99.

iii. In the Total Oil equation, two autoregressive terms were found to be significant, and one autoregressive term in the Other Oil equation. In the other two equations, no autoregressive terms were found to be significant.

The equation for Oil Exporters includes only income and lagged adjustment. Its results are reasonable, except for Residual + Kerosene for which the income elasticities have the wrong sign. Whenever price was included specification (symmetric or asymmetric, lagged or instantaneous), it was never found to be significant.

Symmetric response to income is rejected for Total Oil and for all products[11]. Thus demand growth related to rising income is only partially reversed when income falls. The response to income decreases has the correct sign but is much smaller than the response to income increases[12]. These effects can be observed in Figure 11; when income decreases in the 1980s, demand keeps rising (albeit very slowly) due to lagged adjustment to income increases in the 1970s.

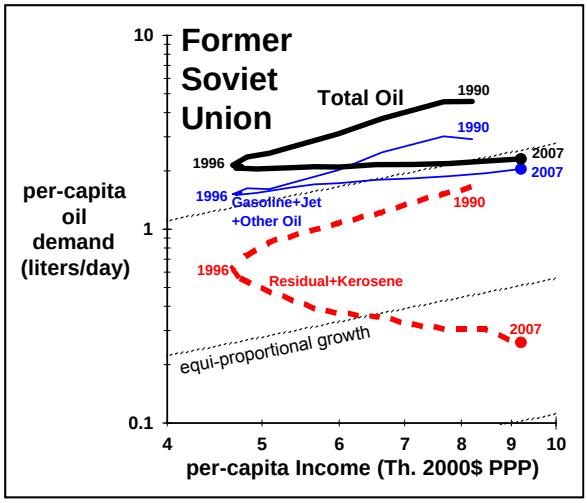
Income elasticities ($Y_{max}$) are about 1.0 for Total Oil and for oil products other than Residual + Kerosene. As can be seen in Figure 11, this is consistent with the movement of demand parallel to the equi-proportional growth lines (when income is increasing), which indicate unitary income elasticity.

[11] If income response were assumed instead to be symmetric, then the income elasticity falls by half or more: to about 0.25 for Total, to 0.58 for Gasoline + Jet Fuel, and to 0.46 for Other Oil.

[12] Since the cumulative series $Y_{cut}$ is non-positive, the small positive coefficient $\gamma_c$ would eventually reduce demand if income decreases were sustained long enough.

## *4.5 Former Soviet Union:*

Figure 12. Former Soviet Union: Oil Demand and Income, per capita, 1990-2007




The equation used (4) is the same as for China, using only income with lagged adjustment. Prices were excluded because they were never significant.[13] Only part of the data series was used, starting in 1996 when income started to grow again, after the economic turmoil following the collapse.

The results seem reasonable, except that Residual + Kerosene has an income elasticity that is negative.[14] The income elasticities for Gasoline + Jet Fuel and Other Oil are 0.5 and 0.6 respectively.

Table 6. Former Soviet Union Results, using data 1996-2007

| Product | equation coefficients | | long-run income elasticity |
|---|---|---|---|
| | lagged income adjustment | Income | |
| Total Oil | *0.14* *(t=1.0)* | 0.37 (t=2.5) | 0.43 |
| Residual + Kerosene | 0.73 (t=14.) | *-0.16* *(t=-1.)* | *-0.61* |
| Gasoline + Jet Fuel | *0.14* *(t=0.7)* | 0.43 (t=2.5) | 0.50 |
| Other Oil | 0.44 (t=6.3) | 0.34 (t=6.0) | 0.60 |

Notes:

i. A coefficient that was not statistically significant is italicized.

*ii.* The Adjusted $R^2$ for almost all specifications were very high, usually above 0.96.

*iii.* In the equations for Total Oil and Gasoline + Jet Fuel, an autoregressive term was found to be significant.

Fuel-switching away from Residual Oil in the FSU since 1990 is similar to demand reductions in the OECD. Total oil demand fell by 5 mbd as the FSU collapsed: from 8.7 in 1989 to 3.7 in 1999. Residual oil demand fell the most and has continued falling, by 2.3 mbd from 1990 through 2008. Other oil demand has recovered moderately in last decade, as per-capita income has resumed its growth. However,

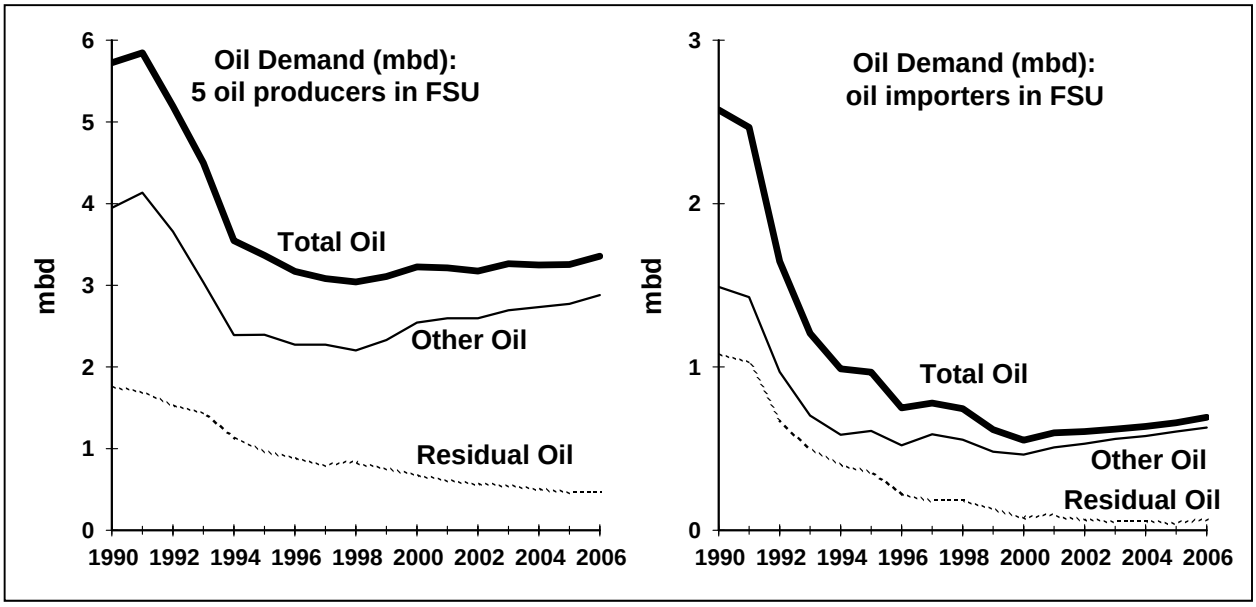
[13] In the five oil-producing countries of the FSU, domestic end-user prices for gasoline and diesel are substantially lower than in the USA, and are comparable to the prices within OPEC countries: Metschies(2005).

[14] Also, the lagged adjustment coefficient is significant only for Total Oil and Gasoline + Jet Fuel, suggesting that demand adjustment was close to instantaneous.

as in the OECD, the fuel-switching from Fuel Oil has been almost completed and future demand growth will be dominated by what happens to the demand for Transport and Other Oil.

Although oil consumption has been increasing faster in the five oil-producing countries (Russia, Azerbaijan, Kazakhstan, Turkmenistan and Uzbekistan) than in the ten oil-importing countries (see Figure 13), this difference is largely attributable to differences in income growth.[15]

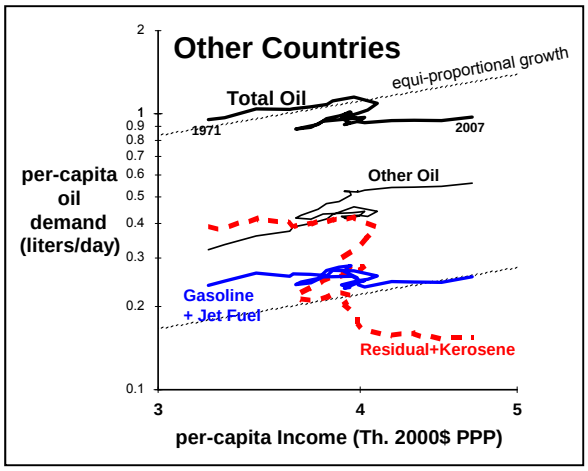
Figure 13. FSU Oil demand, in oil producing and oil importing countries




[15] When separate income coefficients were used for the two groups of countries, Wald tests could not reject equality between the two groups.

## *4.6 Other Countries*

Figure 14. Other Countries' Oil Demand and Income, per capita, 1971-2007




The equation for Other Countries (1) includes price and income, both being asymmetric, as well as separate lagged adjustment factors. Symmetric response to both price and income are rejected for Total Oil and for all products. The price effects are small, and comparable to those for the Income Growers. The income elasticities are about 1.0 for Total Oil and for products other than Fuel Oil, which is also similar to the Income Growers. The lagged adjustment coefficients for price and income are rather small, suggesting a rather rapid speed of adjustment. All these results -- price and income elasticities and speeds of adjustment -- could reflect the response of government officials allocating scarce foreign exchange rather than the behavior of consumers.

Table 7. Other Countries' Results, using crude oil prices, 1971-2007.

| Product | equation coefficients | | | | | | | | long-run elasticities | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | lagged price adjustment | lagged income adjustment | asymmetric price | | | asymmetric income | | | asymmetric price | | | asymmetric income | | |
| | | | Pmax | Pcut | Prec | Ymax | Ycut | Yrec | Pmax | Pcut | Prec | Ymax | Ycut | Yrec |
| Total Oil | 0.49 | 0.44 | -0.06 | -0.02 | *-0.01* | 0.56 | 0.58 | 0.22 | -0.12 | -0.04 | *-0.01* | 1.00 | 1.03 | 0.39 |
| | (t=36.) | (t=33.) | (t=-4.) | (t=-2.) | *(t=-0.6)* | (t=4.3) | (t=8.4) | (t=2.3) | | | | | | |
| | | | reject symmetry | | | reject symmetry except γmax=γcut | | | | | | | | |
| Residual + Kerosene | 0.39 | 0.52 | *-0.04* | *0.01* | *-0.02* | *0.13* | 0.73 | 0.36 | *-0.07* | *0.01* | *-0.03* | *0.27* | 1.53 | 0.74 |
| | (t=9.7) | (t=13.) | *(t=-1.7)* | *(t=0.4)* | *(t=-0.8)* | *(t=0.6)* | (t=5.0) | (t=2.2) | | | | | | |
| | | | cannot reject symmetry | | | reject symmetry except γmax=γrec | | | | | | | | |
| Gasoline + Jet Fuel | 0.48 | 0.44 | -0.07 | *-0.02* | *-0.01* | 0.58 | 0.65 | *0.19* | -0.13 | *-0.04* | *-0.01* | 1.03 | 1.16 | *0.34* |
| | (t=32.) | (t=29.) | (t=-3.) | *(t=-1.7)* | *(t=-0.4)* | (t=3.5) | (t=7.5) | *(t=1.6)* | | | | | | |
| | | | reject symmetry except βcut=βrec | | | reject symmetry | | | | | | | | |
| Other Oil | 0.49 | 0.41 | -0.04 | -0.03 | *-0.002* | 0.77 | 0.58 | 0.32 | -0.07 | -0.06 | *-0.003* | 1.30 | 0.98 | 0.54 |
| | (t=35.) | (t=28.) | (t=-2.) | (t=-2.) | *(t=-0.1)* | (t=4.8) | (t=6.8) | (t=2.7) | | | | | | |
| | | | reject symmetry except βmax=βrec | | | reject symmetry except γcut=γrec | | | | | | | | |

Notes:

i. A coefficient that was not statistically significant is italicized.

*ii.* The Adjusted $R^2$ for almost all specifications were very high, usually above 0.99.

*iii.* In each of the equations except Residual + Kerosene, an autoregressive term was found to be significant.

## *4.7 Summary of Elasticities for Various Groups of Countries*

Table 8. Summary Table of Long-Run Elasticities with respect to Real Income and Price of Crude Oil

| Country Group | Oil Product | Long-run elasticities of demand | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Income | | | | Price of Crude Oil | | | |
| | | symmetric | asymmetric | | | symmetric | asymmetric | | |
| | | Income | Ymax | Ycut | Yrec | Price | Pmax | Pcut | Prec |
| OECD | Total Oil | 0.80 | | | | | -0.60 | -0.20 | -0.29 |
| | Fuel Oil: Residual + Kerosene + Heating | 0.56 | | | | | -1.67 | -0.59 | -1.20 |
| | Transport Oil: Gasoline + Jet Fuel + Diesel | 0.91 | | | | | -0.22 | -0.21 | -0.30 |
| | Other Oil | 1.11 | | | | | -0.27 | -0.18 | -0.31 |
| Income Growers | Total Oil | 0.87 | | | | *-0.07* | | | |
| | Residual + Kerosene | *0.49* | | | | | -0.79 | -0.40 | -0.37 |
| | Gasoline + Jet Fuel | 0.92 | | | | *-0.08* | | | |
| | Other Oil | 1.17 | | | | -0.07 | | | |
| China | Total Oil | 0.74 | | | | | | | |
| | Residual + Kerosene | *0.02* | | | | | | | |
| | Gasoline + Jet Fuel | 0.74 | | | | | | | |
| | Other Oil | 0.98 | | | | | | | |
| Oil Exporters | Total Oil | | 1.00 | 0.34 | 0.70 | | | | |
| | Residual + Kerosene | | | | | | | | |
| | Gasoline + Jet Fuel | | 1.01 | 0.39 | 0.79 | | | | |
| | Other Oil | | 1.06 | *0.23* | 0.57 | | | | |
| Former Soviet Union | Total Oil | 0.43 | | | | | | | |
| | Residual + Kerosene | | | | | | | | |
| | Gasoline + Jet Fuel | 0.50 | | | | | | | |
| | Other Oil | 0.60 | | | | | | | |
| Other Countries | Total Oil | | 1.00 | 1.03 | 0.39 | | -0.12 | -0.04 | *-0.01* |
| | Residual + Kerosene | | *0.27* | 1.53 | 0.74 | | *-0.07* | *0.01* | *-0.03* |
| | Gasoline + Jet Fuel | | 1.03 | 1.16 | *0.34* | | -0.13 | *-0.04* | *-0.01* |
| | Other Oil | | 1.30 | 0.98 | 0.54 | | -0.07 | -0.06 | *-0.003* |

Notes: elasticities are italicized if estimated coefficient was not statistically significant. Elasticities are omitted if income elasticities had negative sign: for Residual+Kerosene for Oil Exporters and FSU.

Table 8 summarizes the long-run oil demand elasticities for each country group and oil product[16]. Income elasticities are fairly similar across groups of countries (excepting the FSU, where they are only ½ to 2/3 as large): about 0.75 to 0.85 for Total Oil, about 0.9 to 1.0 for Transport Oil and Other Oil, but much lower and more widely dispersed for Fuel Oil. Price responsiveness is highest in the OECD countries and moderately high in the Income Growers; however, in the remaining groups, price is rarely significant. Among oil products, price responsiveness is highest for Fuel Oil and lowest for Transport Oil[17].

Oil demand should be expected to increase almost as fast as income, in most countries. In the past, price increases have slowed demand growth, substantially in the OECD but less so elsewhere. Much of the easy demand reduction has already been achieved, especially in the OECD and FSU, because fuel-

[16] For total oil, these income and price ($P_{max}$) elasticities are similar to those estimated by Gately-Huntington(2002) using data through 1997, respectively: OECD 0.56 and -0.64; Income Growers 0.95 and -0.12; Oil Exporters 0.91 and 0; Other Countries 0.24 and -0.25.

[17] These elasticities are within the range of estimates from other studies; see the surveys done by Dahl (1993, 1994, 2007). Comparisons to other studies' estimates are complicated, however, because of differences in demand specification, country and product grouping, and the prices and time periods used in the estimation.

switching away from Residual and Heating Oil has been almost completed. Future demand reductions will be more difficult and will require significantly higher prices.

# 5. Projections and Comparisons with DOE, IEA and OPEC

Table 9. Oil Demand: Historical 1971-2008 and Projections to 2030, by region

| | OECD | | | FSU | | | Rest of World | | | World | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | total oil demand *(% world)* | per capita | | total oil demand *(% world)* | per capita | | total oil demand *(% world)* | per capita | | total oil demand | per capita | |
| | | oil | GDP | | oil | GDP | | oil | GDP | | oil | GDP |
| Units | mbd | liters /day | Th.$ /year | mbd | liters /day | Th.$ /year | mbd | liters /day | Th.$ /year | mbd | liters /day | Th.$ /year |
| **Historical Data** | | | | | | | | | | | | |
| 1971 | 36.6 | 6.6 | 13.0 | 5.3 | 3.5 | 6.8 | 6.7 | 0.4 | 1.6 | 48.7 | 2.1 | 4.7 |
| | *75%* | | | *11%* | | | *14%* | | | | | |
| 2008 | 47.6 | 6.4 | 27.3 | 4.1 | 2.3 | 10.0 | 33.2 | 1.1 | 5.6 | 84.9 | 2.1 | 9.8 |
| | *56%* | | | *5%* | | | *39%* | | | | | |
| average % growth rate, 1971-2008 | 0.7% | -0.1% | 2.0% | -0.7% | -1.1% | 1.1% | 4.4% | 2.54% | 3.4% | 1.5% | 0.0% | 2.0% |
| **Projections for year 2030** | | | | | | | | | | | | |
| DOE, IEO (2009) Reference Case | 50.0 | 6.1 | 39.9 | 5.5 | 2.7 | 23.0 | 51.1 | 1.2 | 12.8 | 106.6 | 2.0 | 16.9 |
| average % growth rate, 2008-2030 | 0.2% | -0.2% | 1.7% | 1.3% | 0.7% | 3.9% | 2.0% | 0.56% | 3.9% | 1.0% | -0.2% | 2.5% |
| IEA (2009) Reference Case | 44.5 | 5.4 | 36.7 | 5.9 | 2.9 | 18.1 | 57.5 | 1.4 | 10.3 | 107.9 | 2.1 | 14.7 |
| average % growth rate, 2008-2030 | -0.3% | -0.7% | 1.4% | 1.6% | 1.0% | 2.7% | 2.5% | 1.10% | 2.8% | 1.1% | -0.1% | 1.9% |
| OPEC (2009) Reference Case | 43.4 | 5.3 | 35.9 | 6.1 | 3.0 | 14.6 | 56.1 | 1.3 | 10.8 | 105.6 | 2.0 | 14.4 |
| average % growth rate, 2008-2030 | -0.4% | -0.9% | 1.3% | 1.8% | 1.2% | 1.7% | 2.4% | 0.99% | 3.0% | 1.0% | -0.2% | 1.8% |
| Our Reference Case 3-product projections | 51.3 | 6.2 | 39.9 | 5.7 | 2.8 | 23.0 | 77.2 | 1.8 | 12.8 | 134.2 | 2.6 | 16.9 |
| average % growth rate, 2008-2030 | 0.3% | -0.1% | 1.7% | 1.4% | 0.9% | 3.9% | 3.9% | 2.47% | 3.9% | 2.1% | 0.9% | 2.5% |

Notes: DOE and our projections assume that real price recovers gradually, from about $60 in 2009 to $110 in 2015 and $130 by 2030. IEA(2009) assumes $100 by 2020 and $115 by 2030. OPEC(2009) assumes nominal prices in the range of $70 to $100. Oil demand includes liquids such as biofuels.

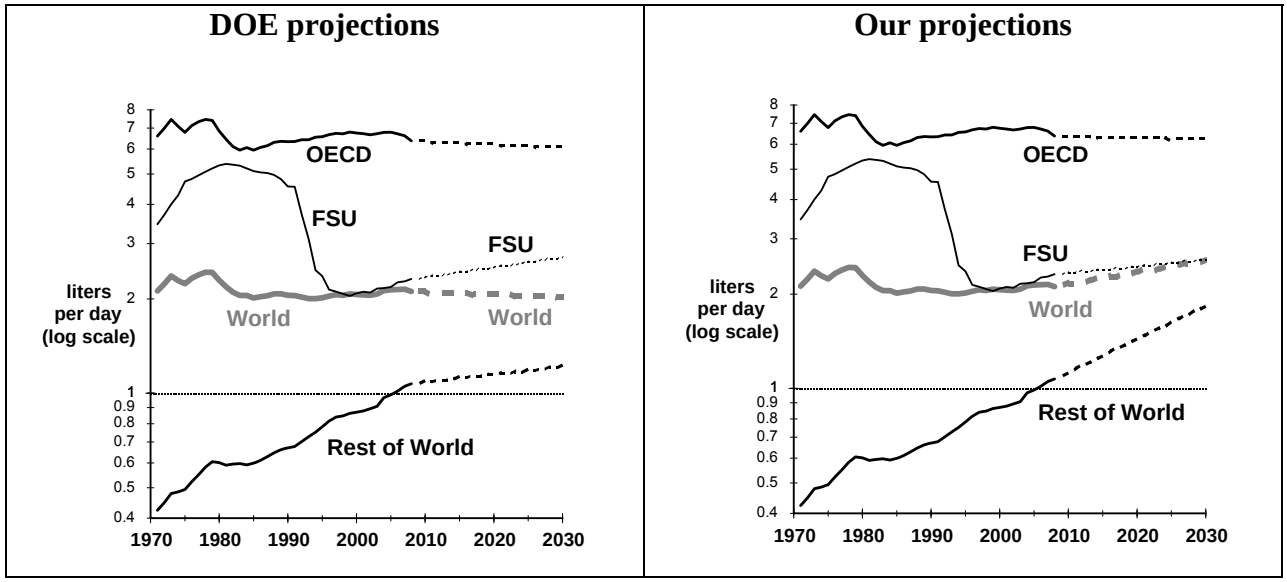
Table 9 summarizes historical data for 1971 and 2008, and projections for year 2030 by DOE(2009), IEA(2009), OPEC(2009), and our projections. Our projections assume DOE Reference Case assumptions for price and income growth, together with the price and income elasticity assumptions from Table 10 (reference assumptions).[18] The major difference between our world demand projection of 134 mbd for 2030 and the 106 mbd projected by DOE, IEA, and OPEC is Rest-of-World demand. None of the

[18] Our reference assumptions are based upon our econometric estimation, but modified judgmentally in a direction that will slow the growth of oil demand. For the OECD we employ elasticities for price increases that are based upon what was estimated: -0.3 for Transport and Other Oil, -1.2 for Fuel Oil. For the remaining groups (except for the Oil Exporters who are assumed to have zero price-elasticity) we assumed price elasticities only half as large as those for the OECD. This overstates the price elasticities that were estimated for the Income Growers and Other Countries, and also uses these for China and FSU, where price was found not significant. (For comparison, Smith (2009) assumed the global long-run crude-oil price elasticity of total oil demand to be -0.3.) The income elasticity for Fuel Oil is assumed to be zero in all regions except the Oil Exporters, where it is assumed to be 1. Income elasticities for Transport and Other Oil are based upon the econometric estimates: 1.0 for Oil Exporters, 0.9 for Income Growers and Other Countries, 0.75 for China, and 0.6 for FSU. For OECD we assumed 0.5, which is lower than was estimated, based upon likely carbon-reduction policies and saturation in vehicle ownership: see Dargay-Gately-Sommer(2007).

projections by DOE, IEA, or OPEC have Rest-of-World per-capita demand growing by even half its historical rate (2.54%). DOE has it growing at one-fifth of its historical rate, despite faster GDP growth. We project growth that is almost as rapid (2.47%) as the historical rate. Our projected Rest-of-World ratio of demand growth to income growth is 0.64, which is lower than the historical ratio (0.75) but dramatically higher than the ratios projected by DOE (0.14) and IEA (0.39) and OPEC (0.33).

Figure 15 shows per-capita demand, historical and projected, for both DOE and our projections. Most noticeable is the difference in Rest-of-World per-capita demand growth. DOE projects sharp deceleration from its historical rate to only one-fifth as fast, despite faster GDP growth projected in the future, growing only from 1.1 liters/day in 2008 to 1.2 in 2030. By contrast, we project growth to 1.8 liters/day by 2030. DOE's lower projections of demand are due to their assumption of income elasticities that are about one-half to two-thirds of what we have estimated, for each of the regions.[19]

Figure 15. Per-capita oil demand 1971-2008, and projections to 2030 using DOE Reference Case assumptions for crude oil prices and income growth: DOE projections and Our Projections




[19] The income elasticities for total oil demand assumed by DOE(2009) – which we calculate as the ratio of % growth in demand to 2030 to % growth in income for the DOE (2009) Low Price Case (in which the real price is assumed to be constant at $50 from 2015-2030) – range from one-half to two-thirds as large as what we have estimated for the various regions. On the other hand, DOE's assumed price elasticities are very small (in absolute value), ranging from -0.10 to -0.13 for the various regions -- calculated as the ratio of the % difference in 2030 oil demand between the DOE High Price Case ($150 by 2015, $200 by 2030) and the DOE Low Price Case ($50 in 2015-2030) to the average % difference in price. These are much smaller than what we have estimated for the OECD and the Income Growers, and are smaller than what we have assumed for all regions except the Oil Exporters. Given rising oil prices in the DOE Reference Case (used also in our projections), DOE's lower price-elasticities would have the effect of making DOE oil demand projections to 2030 higher than ours, but this effect is swamped by the very low income-elasticities that DOE assumes, making DOE demand projections *much* lower than ours.

Table 10. Long-run elasticities for oil product demand, with respect to crude oil price and income: reference parameter values used in our projections, and alternative values

| | Transport and Other Oil | | | Fuel Oil | | |
|---|---|---|---|---|---|---|
| **Price elasticity** | lower | **reference** | higher | lower | **reference** | higher |
| OECD | -0.2 | **-0.3** | -0.6 | -0.8 | **-1.2** | -2.4 |
| Income Growers | -0.1 | **-0.15** | -0.3 | -0.4 | **-0.6** | -1.2 |
| China | -0.1 | **-0.15** | -0.3 | -0.4 | **-0.6** | -1.2 |
| Oil Exporters | 0 | **0** | 0 | 0 | **0** | 0 |
| FSU | -0.1 | **-0.15** | -0.3 | -0.4 | **-0.6** | -1.2 |
| Other Countries | -0.1 | **-0.15** | -0.3 | -0.4 | **-0.6** | -1.2 |
| **Income elasticity** | lower | **reference** | higher | lower | **reference** | higher |
| OECD | 0.3 | **0.5** | 0.7 | 0 | **0** | 0 |
| Income Growers | 0.8 | **0.9** | 1 | 0 | **0** | 0 |
| China | 0.65 | **0.75** | 0.85 | 0 | **0** | 0 |
| Oil Exporters | 0.9 | **1** | 1.1 | 1 | **1** | 1 |
| FSU | 0.5 | **0.6** | 0.7 | 0 | **0** | 0 |
| Other Countries | 0.8 | **0.9** | 1 | 0 | **0** | 0 |

Table 11. Our projections of World Oil Demand (mbd) in 2030 for reference and alternative parameter values, using DOE Reference Case assumptions for GDP growth and crude oil prices

| Our projections of 2030 world oil demand (mbd) | | Income Elasticity | | |
|---|---|---|---|---|
| | | lower | **reference** | higher |
| Price Elasticity | lower | 131 | 141 | 152 |
| | **reference** | 124 | **134** | 144 |
| | higher | 112 | 120 | 128 |

Table 11 summarizes the effects upon our projections of various combinations of lower/higher parameter values for income and price elasticities. Using reference parameter values for income and price elasticities, we project 134 mbd. Using higher or lower parameter values will modify the projected level of demand. We consider price elasticities that are either 2/3 or double those of the reference assumptions, and income elasticities that are 0.1 lower or higher (+- 0.2 for OECD). The effects are in the expected direction: lower [higher] income-elasticities will slow [speed up] demand growth; conversely, lower [higher] price-elasticities will speed up [slow] demand growth. Our lowest projection (112 mbd) is still higher than the projections of DOE, IEA, and OPEC; moreover, it requires *much* lower income-elasticities and *much* higher price-elasticities than we have estimated.

## 6. Conclusions

World oil consumption has experienced dramatic share changes since 1971, shifting toward faster growing and less price-responsive products and regions. The OECD and FSU consumed 86% of world oil in 1971, compared with only 61% today. OECD use of fuel oil was 33% of total world oil in 1973, compared with 9% today.

Most of the easy reductions in demand – fuel-switching away from residual and heating oil, especially in the OECD – has been accomplished: we have picked the low-hanging fruit. Demand for these fuel-switchable oils has fallen by one-third, while the demand for transport and other oil has doubled. Hence, world oil demand is now dominated by transport and other oil, which are less price-responsive and more income-responsive than residual and heating oil. Similarly, the regional shift of world demand away from the OECD and FSU has the same effect – toward regions whose income growth and income-elasticities of demand are higher, and whose price-elasticities are lower, than for the OECD and FSU.

The rest of the world now consumes 39% of world oil (but it has nearly 80% of world population), and its income is growing faster than in the OECD and FSU. Its per-capita oil demand has grown from 0.4 liters/day in 1971 to 1.1 liters/day in 2008, averaging about 2.5% annually. DOE(2009) projects that the rest-of-world's annual per-capita oil growth rate will slow dramatically (to 0.56% ), even assuming faster income growth than in 1971-2008, increasing only to 1.2 liters/day by 2030. IEA(2009) and OPEC(2009) make similar projections. In contrast, we project a rest-of-world growth rate similar to what has occurred historically, to 1.8 liters/day by 2030. This difference in projections amounts to an extra 20 mbd in rest-of-world demand by 2030 – roughly twice the current production of Saudi Arabia. Such rapid demand growth is unlikely to be supplied by conventional oil resources. Hence this imbalance would have to be rectified by some combination of higher real oil prices, much more rapid and aggressive penetration of alternative technologies for producing liquids, much tighter oil-saving policies and standards adopted by multiple countries, and slower world economic growth.

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# Appendix A

## Data Sources

Oil Demand: Total Oil, Transport Oil, Fuel Oil, Other Oil:
OECD, 1971-2008: IEA, *Energy Statistics of OECD Countries*, Paris, 2009
Non-OECD, 1971-2007: IEA, *Energy Balances of Non-OECD Countries*, Paris, 2009

Real GDP, PPP (constant 2005 international $) and Population:
World Bank, World Development Indicators

World crude oil prices (2008 $ per barrel), 1971-2008: *BP Statistical Review (2009)*

Real end-user price indices (including taxes) for each of the G-7 countries:
IEA, *Energy Prices and Taxes*

1) Fuel Oil. For 1978-2008 data we created a consumption-weighted average of the real prices for Residual Oil (using the series "Indices of Energy End-Use Prices: Heavy Fuel Oil, Real Index for Industry") and Heating Oil (Light Fuel Oil (LFO), Real Price Index for Households). For 1971-1978, we used the (nominal) series "Industry Price per ton of High Sulfur Fuel Oil" and "LFO nominal price for Households", deflated by the CPI; we then used the rate of change of these real prices to splice onto the 1978-2008 indices, creating the price index for 1977, then 1976, and back to 1971.
2) Transport Oil. For 1978-2008 data we created a weighted index of each country's real prices and consumption levels: Gasoline, Real Price Index for Households, weighted by Gasoline consumption; Automotive Diesel, simple average of Real Price Index for Households and for Industry, weighted by Road Transport use of Diesel. For 1971-1978, we created real price series based upon: Gasoline, nominal price for Households, deflated by CPI, weighted by Gasoline consumption; Automotive Diesel, simple average of nominal prices for Households and for Industry, deflated by CPI, weighted by Road Transport use of Diesel. We then used the rate of change of these real prices to splice onto the 1978-2008 indices.
3) Total Oil Products. For 1978-2008, we used the series "Real Price Index for Oil Products for Households and for Industry". For 1971-78, we created a weighted average of the 1971-78 price indices for oil products weighted by their respective shares in total oil. We then used the 1971-78 growth rates to splice backward to 1971 the 1978-2008 series.
4) Other Oil. We used the price series for Total Oil Products.

# Appendix B

Table B1. Results of stationarity tests (with up to 8 lags included)

| Region | Test | Per-capita Total Oil | | Per-capita Fuel Oil | | Per-capita Transport Oil | | Per-capita Other Oil | | Per-capita GDP | | Oil Price | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Statistic | Prob. Value | Statistic | Prob. Value | Statistic | Prob. Value | Statistic | Prob. Value | Statistic | Prob. Value | Statistic | Prob. Value |
| **OECD** | | | | | | | | | | | | | |
| | Levin, Lin & Chu t | -4.2 | 0 | *0.6* | *0.74* | -4.7 | 0 | -5.9 | 0 | -12.8 | 0 | -1.5 | 0.07 |
| | Im, Pesaran and Shin W-stat | -1.6* | 0.05 | *1.4* | *0.91* | *0.2* | *0.58* | -2.7 | 0 | -2.0* | 0.02 | -3.4 | 0 |
| | ADF - Fisher Chi-square | 76.1* | 0.08 | *52.4* | *0.75* | *57.4* | *0.57* | 96.4 | 0 | 93.5* | 0 | 81.8 | 0.03 |
| | PP - Fisher Chi-square | *61.7** | *0.41* | *57* | *0.59* | 77 | 0.07 | 101.7 | 0 | *51.0** | *0.79* | 87 | 0.01 |
| **Income Growers** | | | | | | | | | | | | | |
| | Levin, Lin & Chu t | -3.8* | 0 | -1.7* | 0.05 | -8.2* | 0 | -1.8 | 0.04 | -2 | 0.02 | -2.4 | 0.01 |
| | Im, Pesaran and Shin W-stat | -2.8* | 0 | -1.4* | 0.08 | –6.0* | 0 | *-0.4** | *0.36* | *3.8* | *0.99* | -3.7 | 0 |
| | ADF - Fisher Chi-square | 210.9* | 0 | 50.1* | 0.04 | 318.8* | 0 | 46.4* | 0.07 | *38.1* | *0.29* | 59.5 | 0 |
| | PP - Fisher Chi-square | 44.6* | 0.11 | 48.8* | 0.05 | *42.2** | *0.16* | *42.7** | *0.15* | *35.8* | *0.39* | 61.9 | 0 |
| **Oil Exporters** | | | | | | | | | | | | | |
| | Levin, Lin & Chu t | -6.5 | 0 | -3.9 | 0 | -7.1 | 0 | -6.5 | 0 | -2.6 | 0 | -2.3 | 0.01 |
| | Im, Pesaran and Shin W-stat | -3.9 | 0 | -2.4 | 0.01 | -6.5 | 0 | -5.4 | 0 | *-0.7* | *0.23* | -3.6 | 0 |
| | ADF - Fisher Chi-square | 72 | 0 | 50.2 | 0.02 | 114.9 | 0 | 93.4 | 0 | *37* | *0.25* | 55.9 | 0.01 |
| | PP - Fisher Chi-square | 101.1 | 0 | 72.6 | 0 | 107.3 | 0 | 130.4 | 0 | *41.7* | *0.12* | 58.2 | 0 |
| **China** | | | | | | | | | | | | | |
| | ADF - Fisher Chi-square | -3.8* | 0.03 | -3.5* | 0.06 | *-2.6** | *0.3* | -5.1* | 0 | -4.8* | 0 | | |
| | PP – MacKinnon p-values | -8.4* | 0 | -3.3* | 0.09 | *-2.6** | *0.3* | -7.3* | 0 | *-2.36** | *0.39* | | |
| **Other Countries** | | | | | | | | | | | | | |
| | Levin, Lin & Chu t | -2.2 | 0.01 | -2.1* | 0.02 | -2.0* | 0.02 | -5.5 | 0 | *1.1* | *0.86* | -3.9 | 0 |
| | Im, Pesaran and Shin W-stat | *0.2* | *0.56* | *0.31** | *0.62* | *-1.0** | *0.15* | *-0.51* | *0.31* | *2.8* | *1* | -6.1 | 0 |
| | ADF - Fisher Chi-square | *92.3* | *0.53* | *105.8** | *0.19* | 114.7* | 0.07 | 119.9 | 0.04 | *82.8* | *0.79* | 163.4 | 0 |
| | PP - Fisher Chi-square | *89.4* | *0.61* | *99.9** | *0.32* | *99.6** | *0.33* | 129.4 | 0.01 | *78.8* | *0.87* | 170.2 | 0 |
| **Former Soviet Union** | | | | | | | | | | | | | |
| | Levin, Lin & Chu t | -7.8 | 0 | -4.4 | 0 | -5.3 | 0 | -5.1 | 0 | -2.8* | 0 | | |
| | Im, Pesaran and Shin W-stat | -5.6 | 0 | *-0.3* | *0.4* | -4.7 | 0 | -4 | 0 | *-0.48** | *0.31* | | |
| | ADF - Fisher Chi-square | 85.3 | 0 | *31.1* | *0.41* | 77.4 | 0 | 66.2 | 0 | *31.4** | *0.3* | | |
| | PP - Fisher Chi-square | 94.2 | 0 | *31.8* | *0.38* | 57.7 | 0 | 42.9 | 0.06 | 93.3* | 0 | | |

Notes: * includes a linear time trend. Italics indicate non-stationarity.

## Appendix C

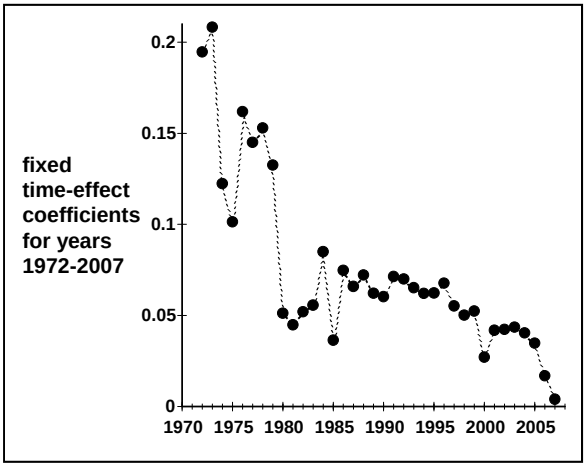
### Additional Results for OECD: Including Fixed Time-Effect Coefficients

Griffin-Schulman(2005) have argued that fixed time-effect coefficients ought to be included in the demand specification, to represent the effect of energy-saving technical change that is not dependent upon oil prices[20]. These coefficients, which are constant across countries for a given year, can vary over time in an unstructured manner.

If we assume constant improvement over time, then a time trend variable ought to capture this. However, when we estimate a time-trend variable, its coefficient is not significant for any of the Table 2 equations.

When we include fixed time-effects in the G-7 equations using product prices (total oil, transport oil, fuel oil, and other oil), *none* of the coefficients for price are statistically significant any longer. This result applies to equations with the single price variable for symmetric responses as well as those with the three price components for asymmetric responses. However, these results should not lead to the conclusion that oil demand is independent of oil prices, *whether these responses are symmetric or asymmetric*.

Figure C1. Fixed time-effect coefficients for G-7 total oil demand equation




Instead, such results reflect the strong negative correlation of -0.91 between $P_{max}$ and the fixed time-effects; see Figure C1: for the price-asymmetric total oil equation. This indicates that the demand reductions were most likely $P_{max}$-induced, which could reflect either endogenous technical change or fuel-switching that was not reversed by price cuts. These shift coefficients for (log) demand have an average value of +0.15 for years before 1980 and an average of +0.05 for 1980 and after. *Thus, these yearly coefficients shift down estimated demand by about 0.10 in years after the 1979-80 price shock.*

The correlation between these time-effect coefficients and per-capita demand is 0.75. Thus the fixed time-effects are tautological: higher demand levels are associated with higher time-effect coefficients before 1979-80 and lower demand levels are associated with lower time-effect coefficients after 1979-80. But these coefficients tell us nothing about the determinants of demand changes, in either the past or the

[20] See also Huntington(2006) and Adeyemi and Hunt (2007). Fixed time-effect coefficients can be included only in equations with product prices, not with crude oil prices.

future. Griffin-Schulman(2005) describe these time dummies as energy-saving technical change, and assume that they are independent of oil prices. In fact, these coefficients are highly correlated with $P_{max}$ and, tautologically, with demand itself. These dummies could be measuring anything, despite what the ventriloquist tells us.