Price and Income Responsiveness of World Oil Demand, by Product

By

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Abstract

Oil demand is estimated using price decomposition terms to analyze the effects of price and income upon world oil demand, disaggregated by product: residual oil (used primarily for generating electricity) and other oil. Equations are estimated for each of six groups of countries, using data from 1971-2006. Most of the demand reductions since 1973-74 were due to fuel-switching away from residual oil, especially in the OECD. Demand for other oil has been much less price-responsive, and has grown almost as rapidly as income. Assuming constant real prices and our estimated elasticities, we project slightly weaker near-term demand growth than the International Energy Agency (IEA) and the U.S. Department of Energy (DOE), but *much* stronger long-term growth: 17% higher by 2030.

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1. Introduction

Inflation-adjusted oil prices are now close to their previous peak levels from more than two decades ago. A driving factor behind this rapid price recovery has been demand growth that has far exceeded supply expansions. As long as world economic growth remains strong, these conditions are likely to pressure oil markets.

The relationship between oil consumption, price and economic activity can be modeled in many ways. Gately and Huntington(2002) analyzed the per-capita demand for energy and for oil, as a function of per-capita income and the real price of crude oil, in various groups of countries using 1971-97 data. That analysis allowed for the possibility that demand might respond asymmetrically to increases and decreases in price or income.

This paper employs a similar model to analyze oil demand *disaggregated by product*: residual oil (used primarily for generating electricity) and other oil, using almost another full decade of data, for almost all countries of the world. The analysis explores the sensitivity of the model's elasticity estimates to the additional decade's data and compares projections from these models with those of IEA(2007), DOE(2007) and OPEC(2007).

We find that most of the demand reductions since 1973-74 were due to fuel-switching away from residual oil, especially in the OECD. These fuel-switching demand reductions were not un-done when oil prices collapsed in the 1980s – strong evidence of asymmetric price-responsiveness – and thus cannot be re-done when oil prices increase again. However, the world still uses 10 million barrels per day (mbd) of residual oil – 12% of total demand, down from 28% in 1973 – making further reductions possible. Demand for other oil has been much less price-responsive and has grown almost as rapidly as income, especially in the Non-OECD countries.

Given the declining share of residual oil – with its higher price-responsiveness – we expect that total oil demand will be less price-responsive in the future than in the past, given that the easiest demand reductions have already been achieved by fuel-switching away from residual oil in electricity generation. Likewise, given the growing Non-OECD share of total world demand and its higher income-responsiveness, we expect that the growth in world oil demand will continue to be strong. With constant real prices and no major policy changes, we project slower demand growth than IEA and DOE for the next decade, as the world adjusts to the 2003-2007 price tripling. Beyond 2015, however, we project much faster demand growth than IEA and DOE, so that by 2030 our projections are 20 mbd higher than theirs. Such rapid demand growth is unlikely to be supplied by conventional oil resources at constant real prices, which would necessitate either major new alternatives to conventional oil or significant price increases from current levels.

In Section 2, we summarize how oil demand – disaggregated into residual and other oil – has changed over time and relative to income, by country group. Section 3 describes the demand equations that we shall use, and Section 4 summarizes the econometric results, for each of the groups of countries. 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 Issues

The following two graphs present world oil demand since 1965[1], both over time (Figure 1) and relative to real income (Figure 2). The scales in Figure 2 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.

There are dramatic differences between residual oil and other oil. Residual oil demand, which increased even faster than income prior to 1973, stopped growing after the 1973-74 price shock, and declined significantly after the second price shock in 1979-80. Other oil demand grew slightly faster than income before 1973, declined slightly after the two price shocks, and has grown almost as fast as income since the mid-1980s.

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[1] British Petroleum (2007) is the source of world demand data that are used in Figures 1 and 2.. Everywhere else in the paper, IEA is the source of the data, by country and by product.

Fig. 1. Total World Oil Demand, 1965-2006

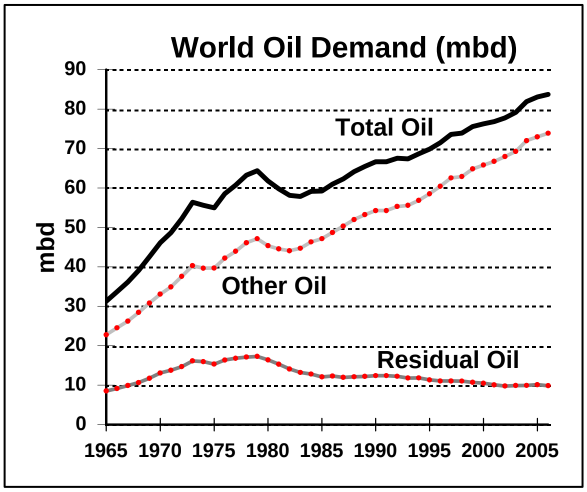


Fig. 2. Total World Oil Demand and Real Income, 1965-2006

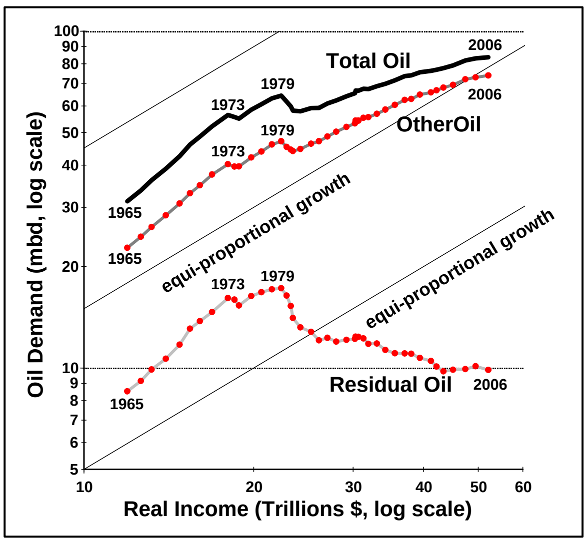
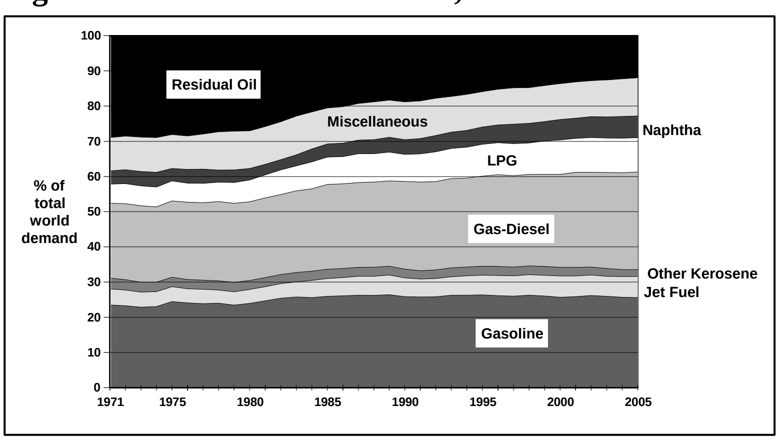


Fig. 3 World Oil Product Shares, 1971-2005



We disaggregate total oil demand by product, distinguishing between residual oil (heavy fuel oil) and "other oil" – all other oil products: gasoline, jet fuel, other kerosene, gas-diesel, LPG, naphtha, and miscellaneous. The share of residual oil has declined steadily since 1973, while every other oil product's share has increased or held constant, as shown in Figure 3. The changes over time among all other products' shares are dwarfed by the changes in residual oil's share.

The global patterns of oil product demand are reflected in almost every region: flat or declining demand for residual oil, but other oil demand growing almost as rapidly as income. Yet there are important differences across countries in the responsiveness of oil demand to changes in price and income. Based upon these differences – illustrated in Figure 4 by per-capita regional graphs analogous to Figure 2 – we divide the world into six groups of countries[2].

- **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 unresponsive to declining per-capita income in the 1980s**:** (9% of world population, 10% of oil demand, 24% of demand growth).

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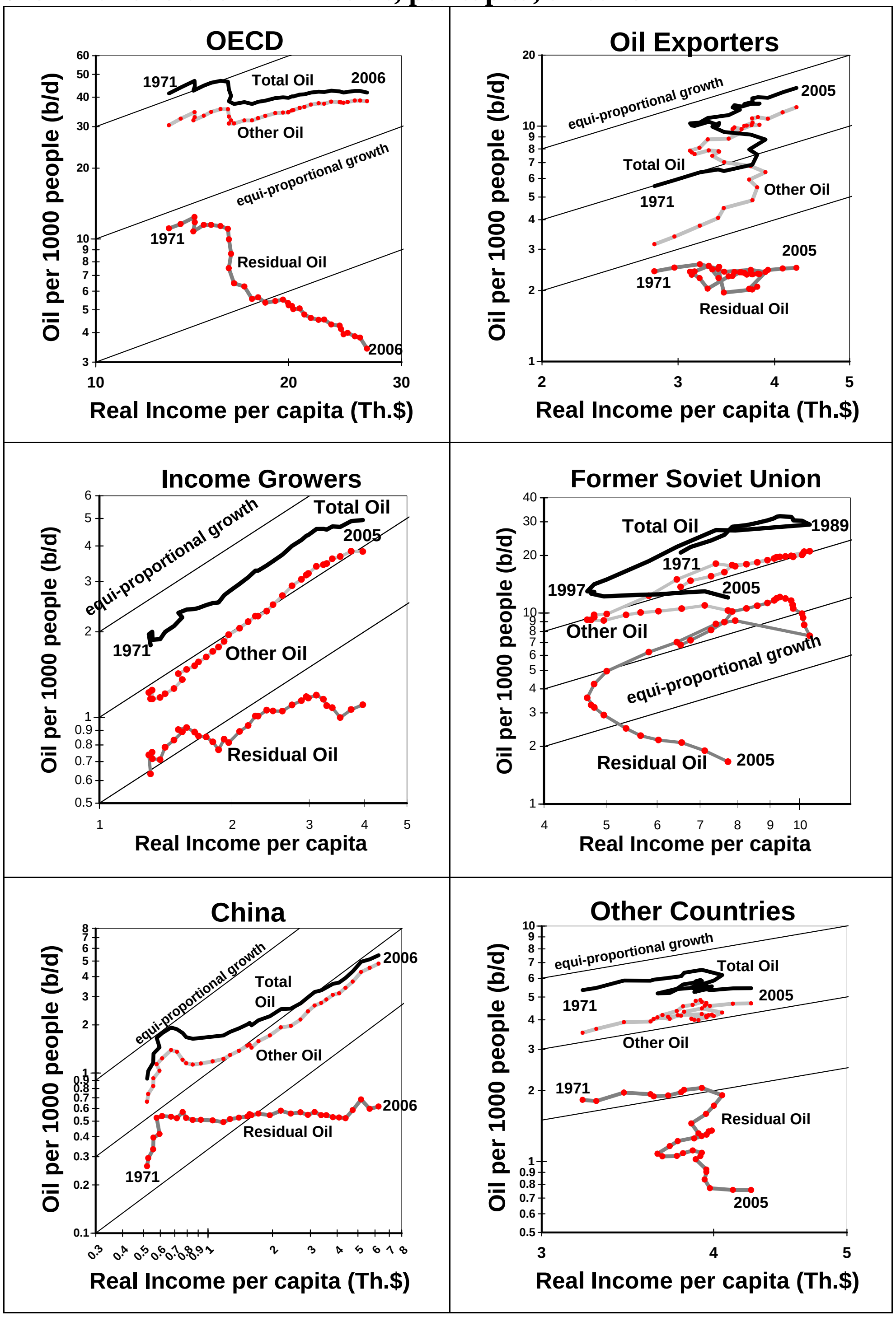
[2] OECD includes all 30 current members. Oil Exporters include 12 OPEC members plus Bahrain, Brunei, Ecuador, Gabon, Oman, Qatar. China excludes Hong Kong and Chinese Taipei. Income Growers include Chile, Chinese Taipei, Cyprus, Dominican Republic, Egypt, Hong Kong, India, Malaysia, Malta, Myanmar, Pakistan, Singapore, Sri Lanka, Thailand, Tunisia, Vietnam, Yemen.

- **Former Soviet Union** (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 been flat since 1997 as declining demand for residual oil has 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).

Fig. 4. Oil Demand and Real Income, per capita, since 1971



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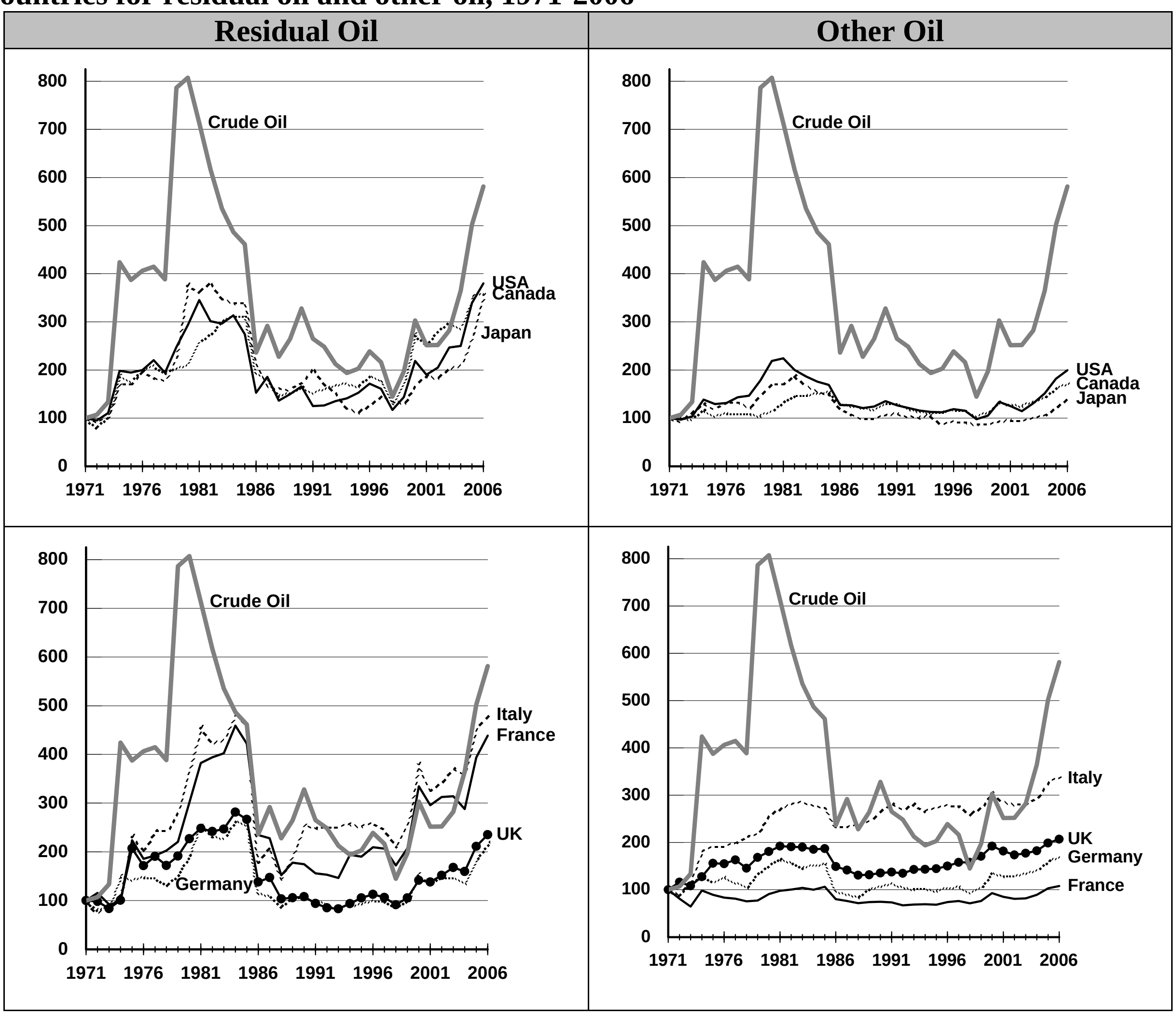
Shown in Figure 5 are real price indices (1971=100) for world crude oil and for end-user prices in the G-7 countries (USA, Canada, Japan, France, Germany, Great Britain, and Italy). Note the following about these real price indices:

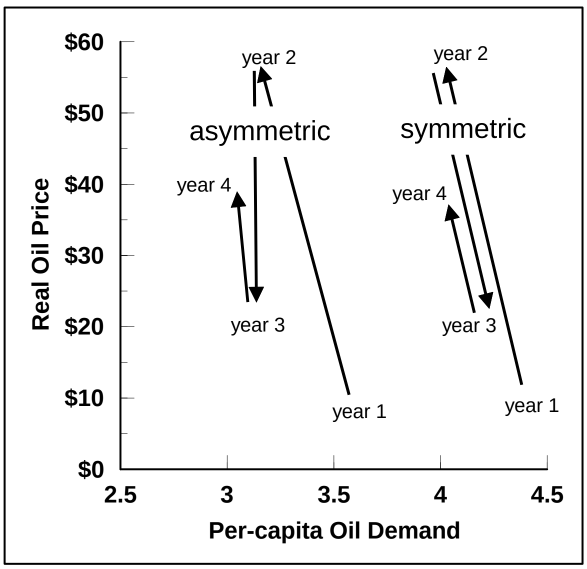
- The variation in crude oil prices has been much greater than the variation in end-user prices;
- The variation in end-user prices for residual oil has been much greater than for other oil;
- Despite the 2004-2006 doubling in crude oil price, it remains about 25% below its 1980 peak;
- For both residual and other oil, end-user price increases in the past decade, especially since 2004, have brought prices back to their previous maximum levels of 1980.

Fig. 5. Real price indices (1971=100): world crude oil price and end-user prices in the G-7 countries for residual oil and other oil, 1971-2006



One important issue in the econometric analysis of oil demand is whether or not demand has responded symmetrically to increases and decreases in price. Gately-Huntington (2002) and earlier papers have argued that the demand reductions in response to the price shocks of the 1970s were not reversed when prices collapsed in the 1980s. That is, demand responded asymmetrically – large demand reductions when price increased but little or no demand recovery when price decreased. Figure 6 depicts these possibilities; on the right, demand responds symmetrically to price increases and decreases[3], while, on the left, demand responds asymmetrically: the demand reductions caused by the price increase are only partially reversed by the price cuts.

Figure 6. Demand Response to Oil Price Changes: Asymmetric and Symmetric



Analogously, we also allow for the possibility of asymmetric response to income changes; see Gately-Huntington(2002) for a more detailed discussion. This is an important phenomenon for the Oil Exporters especially: their oil demand continued to increase even when their income was declining.

[3] The slight offsets in the symmetric curve are intended to convey symmetric movement up and down a single curve, and are not intended to imply that the curve shifts. Sequentially numbered years do not imply instantaneous adjustment to price changes.

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3. Demand Model

Oil consumption (*D*) within a particular economy can be conceptually represented as the following conditional oil demand function:

$$D = f(W, S, Z),$$

where *W* represents a vector of input prices including capital, labor, materials, petroleum and a set of substitute fuels, *S* is a vector of energy service demands including vehicles, floorspace, and other activity variables, and *Z* incorporates a vector of policy variables that influence fuel choice (vehicle fleet efficiency standards, expansion of publicly owned nuclear power, etc.). An evaluation of any one country's oil consumption pattern would require an intensive data set incorporating as many of the above variables as possible.

When the analysis shifts from an indepth coverage of one or several countries to a much broader coverage of almost 100 countries, data problems prevent the adequate representation of many of these detailed variables. Data often does not exist for many of the activity variables like vehicles and floorspace. Instead, analysts frequently adopt a "top-down" approach that assumes that these activity variables are tied to the economy's aggregate output, as measured by real (inflation-adjusted) gross domestic product (GDP). For similar reasons, a comprehensive set of input and other fuel prices is not available, as many countries outside of the OECD do not collect energy price series. This problem makes it difficult to represent interfactor and interfuel substitution opportunities across a range of countries. Moreover, the availability of substitute fuel may reflect political decisions about nuclear power expansion (e.g., in France) rather than interfuel pricing structures. These complications suggest a much more rudimentary form for the estimating equation if one wants to extract useful insights from international pooled data.

We adopt the approach used by Gately and Huntington (2002) that has been used successfully to represent the aggregate oil demand conditions in 96 different countries. Since oil consumption changes slowly as the capital equipment adjusts, the relationship is modeled as a lagged-adjustment process. Pooled cross-section/time-series data for various groups of countries are used to explain per-capita oil demand for each country as a function of per-capita income for each country, the price of oil, and lagged oil consumption, with a separate constant estimated for each country – what is called a "fixed effects" model. The fixed effect incorporates any regional differences among countries, including variations in long-term energy policies across countries. Per capita oil consumption and GDP data are used, and they are converted to logarithms (as are oil prices). Appendix A discusses data sources and the construction of the data set.

The use of the Gately-Huntington 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.

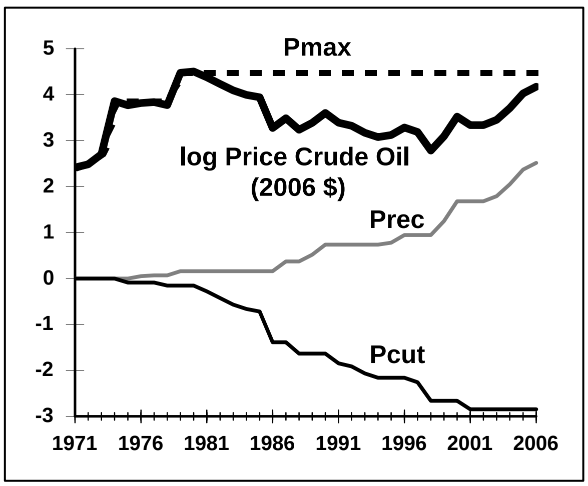
In order to allow for the possibility of asymmetric demand responses to price increases and decreases as well as to prices above previous maximum historical levels, we decompose the logarithm of the price variable into three series (Figure 7):

- 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.

These price components do not simply test for asymmetric or nonlinear price 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.

Similarly, to account for the possibility of asymmetric demand response to increases and decreases in income, we decomposed the logarithm of income in a similar manner. 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.

Fig. 7: Decomposition of Crude Oil Price



The most general specification allows the lagged-adjustment coefficients for income (θ_y) and price (θ_p) to be estimated separately. Allowing the above decomposition of both income and price, we estimate the following log-linear regression[4]:

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

where D and Y are per capita levels, k_{1c} are the constants for the individual countries and the other parameters are the same across countries. This approach provides separate estimates for each of the parameters, including θ_p and θ_y.

4 See Gately and Huntington (2002) for the derivation.

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 panel unit-root tests, and if non-stationarity were indicated we tested for cointegration. Results of these tests are presented in Section 4 along with the econometric results.

We used Wald tests of coefficient equality to determine whether or not the decomposed price coefficients are equal to each other, and similarly for the decomposed income coefficients. Significance tests (at the 5% level) were used to choose between the above general specification (1), which included price and income components, and a more specific specification where price and/or income were entered as a single variable. These tests resulted in different findings for the various sets of countries:

- For OECD and for Other Countries: 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 no lagged adjustment to income changes ($\theta_y = 0$).

  (3) $D_{c,t} = k_{1c} + \theta_p D_{c,t-1} + \beta P_t + \gamma Y_{c,t} - \theta_p \gamma Y_{c,t-1}$
- For China: a simple specification that omits price and uses only current year's per-capita income and a constant term.

  (4) $D_t = k_1 + \gamma Y_t$
- For Oil Exporters and Former Soviet Union: specification excludes price and uses decomposed income, and lagged adjustment to income changes:

  (5) $D_{c,t} = k_{1c} + \gamma_m Y_{max,c,t} + \gamma_c Y_{cut,\,c,t} + \gamma_r Y_{rec,\,c,t} + \theta_y {*}\, D_{c,t-1}$

The basic specification includes fixed country effects (dummy variables for each of the countries k_{1c}) but not fixed time effects (dummy variables for each of the years). Holtz-Eakin and Selden (1995) and Schmalensee, Stoker, and Judson (1998) use fixed time effects in their pooled estimates of carbon dioxide emissions, because their specifications exclude prices and technical progress, two key explanatory factors. In our work, the oil demand specifications include the possibly asymmetric effects of price increases and decreases, in an attempt to capture *price-induced* energy-saving technical change. Adeyemi and Hunt (2007) show that this approach is superior for explaining OECD industrial energy demand than using fixed time effects as proxies to measure energy-saving technical change (and other unspecified variables), as Griffin and Schulman(2005) had done. Moreover, Huntington (2006), using the Griffin-Schulman data, shows that when fixed time effects are added, symmetry in the response to price continues to be rejected. 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). In addition, these fixed time effects generally exhibit large changes from one year to the next, especially in years around major price increases, and therefore must be incorporating the effects of price as well as other unspecified variables that affect all countries similarly.

4. Econometric Results

Here we discuss the econometric results for each group of countries, concentrating on the four groups for which the results were most satisfactory: the OECD, the Income Growers, China, and the Oil Exporters. Results for the Former Soviet Union and Other Countries were less satisfactory; they are available from the authors.

4.1 Results for OECD Countries

The following equations for per-capita demand -- for total oil, residual oil, and other oil – use equation specification (2), with asymmetric price-response, symmetric income response, with lagged-adjustment for price but instantaneous adjustment for income. From the unit-root tests[5],

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[5] Several panel unit root tests are reported in EViews 5: Levin, Lin & Chu t, Breitung t-stat, Im, Pesaran and Shin W-stat, ADF –Fisher Chi-square, PP – Fisher Chi-square and Hadri Z-stat. The different tests produced conflicting results in some cases, and our conclusions are based on the majority results. Only the Fisher ADF Chi-square are reported here: for total oil, other oil and residual oil are 109.8 (6 lags), 87.5 (7 lags) and 166.9 (5 lags), thus rejecting a unit root at the 95% probability or better. Per capita income is trend stationary with a test statistic of 81.1 (3 lags) and the oil price is stationary with a test statistic of 275.5 (0 lags)

we conclude that the logged variables are stationary, so that the model in equation (2) can be estimated in level form. Table 1 shows results for all 30 OECD countries using crude oil prices. Table 2 compares these with results for only the G-7 countries using either crude oil prices or end-user product prices.

Table 1. OECD Results, using Crude Oil Prices, 1971-2006

			equation coefficients					long-run elasticities			
Product	Prices used	Countries	Income	Pmax	Pcut	Prec	lagged price adjustment	Income	Pmax	Pcut	Prec
Total Oil	Crude Oil	30 OECD	0.88	-0.040	-0.017	-0.028	0.93	0.88	-0.55	-0.22	-0.38
			(t=19.1)	(t=-12.)	(t=-5.7)	(t=-7.6)	(t=120.)				
				reject symmetry					reject symmetry		
Residual Oil	Crude Oil	30 OECD	0.64	-0.079	-0.021	-0.051	0.95	0.64	-1.45	-0.38	-0.92
			(t=4.9)	(t=-9.0)	(t=-2.4)	(t=-4.9)	(t=97.7)				
				reject symmetry					reject symmetry		
Other Oil	Crude Oil	30 OECD	0.83	-0.032	-0.020	-0.026	0.93	0.83	-0.44	-0.27	-0.35
			(t=16.2)	(t=-8.5)	(t=-6.1)	(t=-6.0)	(t=100.)				
				reject symmetry (except Pmax=Prec)					reject symmetry (except Pmax=Prec)		

Notes:

i. All coefficients are statistically significant at the 5% level.

ii. For decomposed price coefficients, we performed a Wald test of the null hypothesis that the three coefficients are equal, using a 5% cutoff for the F-statistic probability. For all equations shown in this table, the Wald test allowed us to reject the null hypothesis that the decomposed-price coefficients were equal.

iii. Similar Wald tests were also done for price-increase symmetry between the coefficients for P_{max} and P_{rec}, and for symmetry between the coefficients for P_{cut} and P_{rec}. Those tests allowed us to reject those types of symmetry in all cases except for other oil, for which price-increase symmetry could not be rejected.

iv. Wald tests also allowed us to reject the hypothesis that the long-run elasticities were the same for residual oil and other oil, when those two equations were estimated simultaneously.

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

vi. The above specifications used AR terms as follows:
total oil and residual oil: no AR terms; other oil: AR1 only.

Given the OECD graph in Figure 4, these econometric results are what one would expect and are generally reasonable. Income elasticity is higher for other oil than for residual oil, while the price elasticity is higher for residual oil than for other oil. Asymmetric price-responsiveness was found for all three product groupings, with the asymmetry being greatest for residual oil: its P_{max} elasticity was three times greater than its P_{cut} elasticity. Some of this asymmetric response may have been the result of government policy regarding electricity generation, to switch permanently from residual oil to alternatives such as natural gas, coal, and nuclear. Undoubtedly, this asymmetry reflects fuel-switching, rather than improved energy efficiency.

Table 2. Comparison of elasticities, using crude oil prices versus end-user oil product prices, for 30 OECD countries and for G-7 countries only

			long-run elasticities			
Product	Prices used	Countries	Income	Pmax	Pcut	Prec
Total Oil	Crude Oil	30 OECD	0.88	-0.55	-0.22	-0.38
					reject symmetry	
	Crude Oil	G-7 OECD	0.91	-0.39	***-0.02***	-0.18
					reject symmetry	
	Oil Products	G-7 OECD	1.02	-0.84	***-0.02***	-0.61
					reject symmetry (except Pmax=Prec)	
Residual Oil	Crude Oil	30 OECD	0.64	-1.45	-0.38	-0.92
					reject symmetry	
	Crude Oil	G-7 OECD	0.97	-1.99	***-0.26***	-0.49
					reject symmetry (except Pcut=Prec)	
	Residual Oil	G-7 OECD	1.09	-2.38	***-0.49***	-0.73
					reject symmetry (except Pcut=Prec)	
Other Oil	Crude Oil	30 OECD	0.83	-0.44	-0.27	-0.35
					reject symmetry (except Pmax=Prec)	
	Crude Oil	G-7 OECD	0.92	-0.29	-0.06	-0.19
					reject symmetry	
	Other Oil	G-7 OECD	0.87	-0.36	***-0.02***	-0.24
					reject symmetry (except Pmax=Prec)	

Notes:

i. The elasticity corresponding to a coefficient that was not statistically significant at the 5% level is boldfaced, italicized and underlined.

ii. For decomposed price coefficients, we performed a Wald test of the null hypothesis that the three coefficients are equal, using a 5% cutoff for the F-statistic probability. For all equations shown in this table, the Wald test allowed us to reject the null hypothesis that the decomposed-price coefficients were equal.

iii. Similar Wald tests were also done for price-increase symmetry between the coefficients for P_{max} and P_{rec}, and for symmetry between the coefficients for P_{cut} and P_{rec}. Those tests allowed us to reject those types of symmetry in all cases except as noted, in which case a specific type of symmetry could not be rejected.

iv. Wald tests also allowed us to reject the hypothesis that the long-run elasticities were the same for residual oil and other oil, when those two equations were estimated simultaneously, for each of the three combinations of prices used and number of countries.

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

vi. No autoregressive terms were found to be significant except for the following: AR1 for residual oil in G-7 countries using crude oil prices, and for other oil in 30 OECD countries using crude oil prices; AR1, AR2 & AR3 were used for other oil in G-7 countries using other oil product prices.

Table 2 allows comparison of results for the G-7 subset of OECD countries with those for the entire OECD, and for the G-7 countries using either crude oil prices or end-user product prices. For total oil, the G-7 results are similar to those for the entire OECD but the response to price decreases is close to zero and not statistically significant. The G-7 countries' demand is much more responsive to increases in end-user prices than to increases in crude oil prices, as would be expected if refinery margins and taxes did not change very much when crude oil prices varied. For other oil, the G-7 results are also similar to those for the entire OECD. The response to price decreases is negligible, and much smaller than for the entire OECD. As with total oil, the G-7 countries' demand is more responsive to end-user prices than to crude oil prices. For residual oil, the G-7 results show less responsiveness to P_{max} but *much* less responsiveness (if any) to price cuts, in comparison with the entire OECD.

The econometric results are robust to including additional years of data, from 1996 to 2006. That is, the elasticities are not sensitive to whether the data ends in 1996 or 1997, and so forth through 2006. For all three oil products, symmetry of all three price coefficients can be rejected for all ending years of the data, from 1996 to 2006. Detailed results are available from the authors.

4.2 Results for Income Growers

This group of countries with steadily growing per-capita income has experienced comparably steady growth in per-capita oil demand[6], about as fast as income growth: see Figure 4. Unit root tests indicate that the log of the per-capita oil demand variables are stationary over the observation period.[7]

The equation specification (3) assumes symmetric demand response to price changes and income changes, and no lagged adjustment to income changes.

Table 3. Income Growers' Results, using crude oil prices, 1971-2005

	equation coefficients			long-run elasticities	
	Income	Price	lagged price adjustment	Income	Price
Total Oil	0.79 (t=12.9)	-0.03 (t=-3.4)	0.82 (t=40.)	0.79	-0.18
Residual Oil	0.41 (t=3.4)	***<u>-0.02</u>*** (t=-1.3)	0.85 (t=39.)	0.41	***<u>-0.15</u>***
Other Oil	0.92 (t=15.)	-0.03 (t=-3.3)	0.81 (t=40.)	0.92	-0.17

Notes:

i. A coefficient that was not statistically significant is boldfaced, italicized and underlined.

ii. Wald tests allowed us to reject the hypothesis that the long-run elasticities were the same for residual oil and other oil, when those two equations were estimated simultaneously.

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

iv. No AR terms were used in these equations.

These results show relatively high income elasticities and low price elasticities, especially in comparison with those of the OECD. Undoubtedly, some of the low response to crude oil prices reflects the fact that government policies do not allow delivered prices to move fully with crude oil prices in many of these countries. The income elasticity of other oil is 0.92, so that other oil demand will grow almost as rapidly as income in these countries.

These elasticity estimates are not very sensitive to the ending year of the data, when the last year of data is extended from 1996 to 2005.

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[6] The criteria for inclusion of countries in this group: increases of per-capita income in at least 27 of 32 years from 1972-2005 and an average annual growth rate of 3%.

[7] The Fisher ADF Chi-square tests for total oil, other oil and residual oil are 159.9 (4 lags), 196.2 (4 lags) and 51.0 (1 lag), thus rejecting a unit root at 95% probability or better.

4.3 Results for China

As we see in Figure 4, there has been substantial variation in the growth rates of China's per-capita oil consumption and its income, and in their relationship to each other. During 1971-77, per-capita income grew slowly (2.7% annually) and oil demand grew four times as fast (11% annually). From 1977 to 1990, per-capita income grew rapidly (7.7% annually) but oil demand grew very slowly (0.9% annually). Since 1990, per-capita income has grown very rapidly (8.9% annually) and oil has grown about three-fourths as fast (6.5% annually).

Using the entire data set 1971-2005, we find that standard specifications with world oil prices perform poorly: the coefficient for price is never statistically significant and often has the wrong sign. This is not surprising, given that China had long been isolated from the world oil market; its oil consumption remained lower than its domestic oil production until the early 1990s.

We find reasonable econometric results with a simpler specification (4) that omits price and uses only current year's per-capita income and a constant term[8]. However, the income elasticities are very sensitive to the *starting* year of the data, with a sharp break[9] about 1977; see Figure 8. If the data start in 1977 or later, then the income elasticity estimates are fairly stable: 0.9 for other oil, 0.75 for total oil, less than 0.1 for residual oil. But if the data start before 1977, the income elasticity estimates are only half as large. Using different *ending* years for the data sample has relatively little effect, except that the inclusion of data years since 2004 results in somewhat higher income elasticities.

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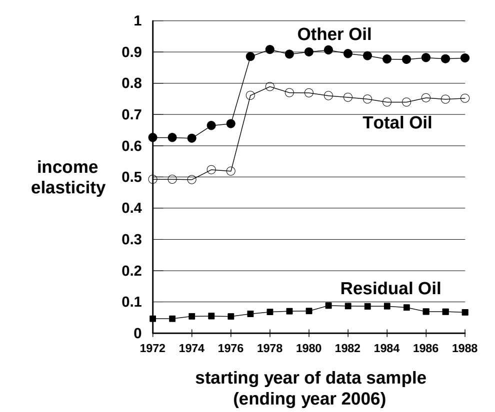
[8] The income coefficient equals the income elasticity. The specification also used an autoregressive AR(1) term; an AR(2) term was not statistically significant.

[9] In studying whether Chinese exports induced economic growth, Kwan and Kwok (1995) used a dummy variable (=1 if 1978 or later; otherwise, 0) to incorporate the impact of the "1978 Four Modernizations" which promoted an outward-looking approach where China's real export growth rose steadily.

Fig. 8 Sensitivity of China's income elasticity to different starting and ending years of the data sample

Different starting years (with ending year 2006)	Different ending years (with starting year 1980)



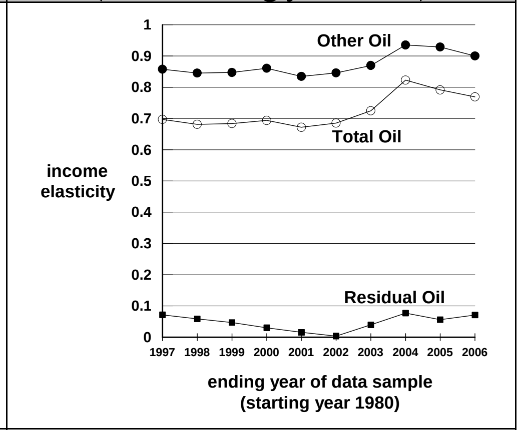


Table 4. China's Income Elasticities, using 1980-2006 data[10].

Total Oil	0.77 (t=9.)
Residual Oil	0.07 (t=2.3)
Other Oil	0.90 (t=14.)

Using data from the period 1980-2006, we find income elasticities (Table 4) that are consistent with China's demand growth and its relationship to income for the past quarter-century, as we can observe in Figure 4. The unit-root tests indicate that other oil, total oil and Income are trend stationary variables[11], so these estimates of the income elasticities can be considered reliable. The evidence on stationarity is less-clear cut for residual oil, and cointegration of residual oil and Income was rejected on the basis of a Johansen test, so the results for residual oil are questionable.

[10] IEA data 1971-2005 for China was extended to 2006 using the 2006 growth rates from BP(2007) for China's demand for residual and other oil.

[11] Since only one country is included here, panel unit-root tests are not required and ordinary ADF tests are used. The ADF tests are -3.35 (trend and 5 lags, P-value 0,08) for Total Oil, -4.60 (trend and 5 lags, P-value=0.006) for other oil, -3.08 (trend and 5 lags, P-value=0.13) for residual oil and -4.70 (trend and 6 lags, P-value=0.004) for income.

4.4 Results for Oil Exporters

The oil demand behavior of this group of countries is quite different from that of those countries that import some or all of their oil. As we see in Figure 4:

- Demand for other oil almost always grows faster than income (even when income is declining), sometimes much faster;
- Growth in demand for residual oil is erratic, and has no clear relationship with income growth;
- Total Oil Demand grew about as fast as income, except in the euphoric decade after 1973-74 when it grew much faster than income.

The equation specification that was used (5) excludes price, uses decomposed income to capture the possibility of asymmetric demand response, with lagged adjustment to income changes.[12]

Table 5. Oil Exporters' Results, using asymmetric income responses, 1971-2005

	equation coefficients				long-run elasticities		
	GDPmax	GDPcut	GDPrec	lagged adjustment	GDPmax	GDPcut	GDPrec
Total Oil	0.161 (t=44.)	0.049 (t=4.0)	0.097 (t=3.1)	***0.851*** (t=0.78)	1.08	0.33	0.65
	reject symmetry						
Residual Oil	0.085 (t=40.)	-0.015 (t=1.99)	***-0.144*** (t=-0.5)	0.842 (t=2.3)	0.54	-0.09	***-0.91***
	reject symmetry						
Other Oil	0.131 (t=36.)	0.034 (t=2.9)	0.095 (t=1.99)	***0.807*** (t=1.89)	0.68	0.18	0.49
	reject symmetry						

Notes:

i. A coefficient that was not statistically significant at the 5% level is boldfaced, italicized and underlined.

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

iii. No AR terms were used in the residual oil equation, AR1 was used in the other oil equation, and both AR1 and AR2 were used in the total oil equation.

[12] All unit-root tests indicate that all variables are stationary: the Fisher ADF Chi-square tests for total oil, Other Oil and residual oil are 72.2 (7 lags), 104.6 (7 lags) and 58.4 (1 lag), thus rejecting a unit root at the 95% probability or better.

4.5 Summary of Econometric Results

Table 6 summarizes the long-run elasticities of per-capita oil demand with respect to per-capita income and the real price of crude oil. To compare the elasticities with others in the literature, see the most recent survey by Dahl(2007). These estimates are satisfactory only for the OECD and the Income Growers. For China and the Oil Exporters, the measured effect of price was inconsistent with economic theory, since it was never significant. Hence our projections in the following section will employ elasticities for the latter groups that are modified by our judgment.

Table 6: Long-run elasticities of oil demand, by country group

Country Group	**Oil Product**	**Long-run elasticities of demand**							
		Income				**Price**			
		symmetric	asymmetric			symmetric	asymmetric		
		Income	Ymax	Ycut	Yrec	Price	Pmax	Pcut	Prec
OECD	Total Oil	0.88					-0.55	-0.22	-0.38
	Residual Oil	0.64					-1.45	-0.38	-0.92
	Other Oil	0.83					-0.44	-0.27	-0.35
Income Growers	Total Oil	0.79				-0.18			
	Residual Oil	0.41				***-0.15***			
	Other Oil	0.92				-0.17			
China	Total Oil	0.77							
	Residual Oil	0.07							
	Other Oil	0.90							
Oil Exporters	Total Oil		1.08	0.33	0.65				
	Residual Oil		0.54	-0.09	***-0.91***				
	Other Oil		0.68	0.18	0.49				

Several generalizations can be made about these elasticities. Price elasticities are much higher for OECD than for any other group, and higher for residual oil compared with other oil, especially for the OECD. The asymmetry of price responsiveness is much more pronounced for OECD than for Non-OECD, and for residual oil compared with other oil. Income elasticities for other oil are close to unity, even for OECD.

It is also useful to compare the out-of-sample projection error of the two disaggregated products' equations with that of the total oil equation.   We calculated the percent root-mean-squared errors of "dynamic" projections, based upon coefficient estimates for equations with data ending in 2003, comparing projected data with actual historical data (2004-2006 for OECD and 2004-2005 for Income Growers), assuming actual 2004-2006 prices and income levels. Projections from the total oil equation yield out-of-sample projection errors (0.5% for OECD, 4.0% for Income Growers) that are about 10% higher than those from summing the disaggregated product projections.

5. Projections

Here we make oil demand projections, annually to 2030, as a diagnostic tool for understanding other publicly available oil market projections. We make no attempt to insert our own assumptions about key determinants of future oil demand, such as the oil price path, economic growth or major policy changes. These projections use the following assumptions:

- Constant real crude oil prices, 2006-2030
- Projected growth rates for GDP and population, for each of our six country groups, are taken from DOE (2007), for each five-year period to 2030 – except that we assumed Other Countries' GDP would grow 1% more slowly than Income Growers. These world growth rates are considerably faster than those used even as recently as a few years ago.
- For OECD and Income Growers, we used estimated parameters from our equations for residual and other oil. Note that, although price is assumed to be constant in the future, the price elasticities are needed to calculate the lagged effects of the 2004-2006 price increases.
- For the Oil Exporters, we assumed that their income elasticities for Residual and Other would be the same as that for Income Growers, but there would be zero price-elasticity. This would be consistent with these countries continuing their policy of subsidizing energy-intensive economic activities, despite the higher opportunity costs.
- For China, FSU and Other Countries, we assumed the same price elasticities as for Income Growers. Income elasticities for residual oil in China and FSU were assumed to be half as large as those for Income Growers, and income elasticities for other oil assumed to be 80% that for Income Growers[13]. Other Countries' income elasticities were assumed to be half those of Income Growers.
- We calibrated the 12 equations (6 country groups, 2 products) to 2003 data – assuming long-run equilibrium for demand in 2003, given world oil prices. That is, given the short-run elasticities and lag speed, we calculated the constant term for 2003 so that simulated-equation-demand for 2003 was exactly equal to 2003 historical data. We then

[13] If instead we assumed that China's income elasticity for other oil would be what we had estimated (about 0.9, instead of 0.74 assumed here) then world oil demand would be 5 mbd higher by 2030, at 145 mbd.

used actual prices and per-capita GDP for 2004-2006 projections, and the assumed price (constant) and GDP growth rates for 2007-2030 projections of residual and other demand, which we summed to get total demand.

- Consistent with the DOE assumption of a baseline scenario, there would be no new major policy developments that would mitigate the growth of oil demand due to energy security, pollution, or climate change concerns.

Table 7. Elasticity assumptions used in our projections

	OECD	Income Growers	China	Oil Exporters	FSU	Other Countries
long-run income elasticity:						
Residual Oil	0.64	0.41	0.20	0.41	0.20	0.20
Other Oil	0.83	0.92	0.74	0.92	0.74	0.46
long-run price elasticity:						
Residual Oil	-0.92	-0.15	-0.15	0.00	-0.15	-0.15
Other Oil	-0.35	-0.17	-0.17	0.00	-0.17	-0.17

Table 8. Comparison of demand projections: this paper and those of IEA, DOE & OPEC

			Ratio of Oil Demand Growth to Real Income Growth, 2006-2030						annual World GDP growth to 2030 (%)	projected World Oil Demand (mbd)	
Source of Projections	projection years	Assumed real-price-path for oil	OECD Total	Non-OECD Total	China	MidEast	FSU & E.Eu.	World Total		2015	2030
DOE: IEO 2007	2004-2030	constant, 2006-2030, about $70	0.23	0.44	0.54	0.51	0.24	**0.34**	4.07%	97	**118**
IEA: WEO 2007	2006-2030	constant, 2006-2030, about $62	0.23	0.50	0.60	0.48	0.25	**0.36**	3.60%	99	**116**
OPEC 2007	2006-2030	constant $55 nominal	0.14	0.54	0.61	0.50	0.23	**0.40**	3.50%	97	**118**
this paper	**2006-2030**	**constant, 2006-2030, about $70**	**0.42**	**0.63**	**0.67**	**0.75**	**0.49**	**0.53**	**4.0%**	**98**	**138**
Others:											
IEA: WEO 2004	2001-2025	constant, 2001-2025: about $30	0.36	0.63	0.68	0.70	0.49	**0.50**			
DOE: IEO 2003	2001-2025	constant, 2001-2025: about $30	0.48	0.55	0.53	0.58	0.54	**0.58**			
DOE: IEO 2007	2004-2030	decline to $30 by 2015 then constan	0.41	0.54	0.63	0.62	0.36	**0.46**			

Notes: In this table, the MidEast region used by IEA and DOE is compared with our group of Oil Exporters, and their "FSU & E.Europe" is compared with our FSU region. The price assumption used by OPEC(2007, p.15) is "in the $50-60 range in nominal terms for much of the projection period, rising in the longer term with inflation".

Our demand projections use almost the same assumptions about price and income growth as DOE(2007), IEA(2007), and OPEC(2007). Figure 9 compares our projections with those of IEA and DOE; OPEC's projections are not plotted because they are almost identical to those of DOE. Figure 10 compares the ratios of demand growth to income growth, for each five-year period. Until 2015 our demand projections are slightly lower than those of IEA, DOE, and OPEC, presumably reflecting greater adjustment to the 2003-07 price increase, which suppresses demand growth. Beyond 2015, however, our projections grow faster; the ratio of demand growth to income growth increases, approaching the income elasticity, as the adjustment to the

2003-07 price tripling tapers off. In contrast, IEA, DOE[14], and OPEC[15] demand projections grow more slowly relative to income, implying declining income-elasticities and/or assuming greater effects of government policies and technological change.

Fig. 9. Projections of World Oil Demand (mbd)

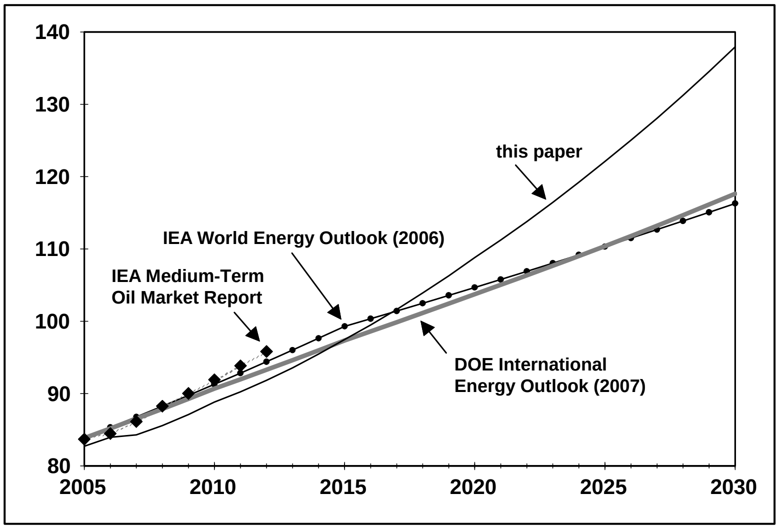
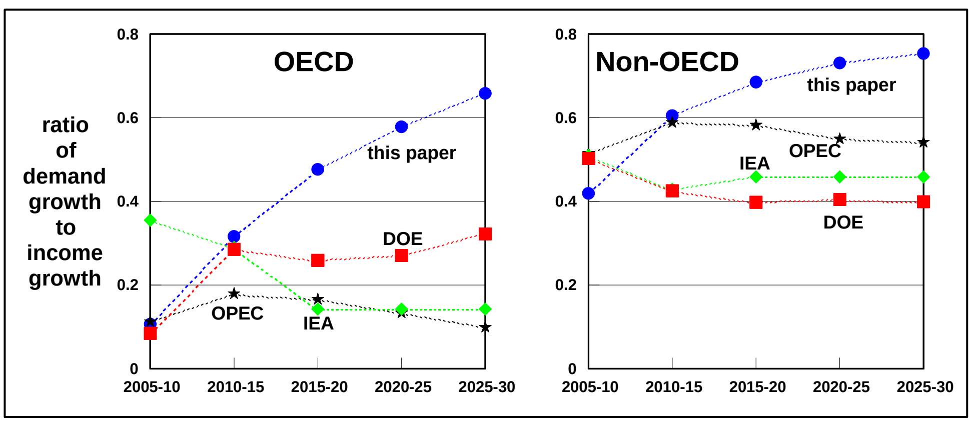


Fig. 10. Projected Ratios of Demand Growth to Income Growth



[14] Of these three projections, only DOE states explicitly its model's income elasticities of oil demand (as of 2005): 0.6 for developing countries and 0.4 for the OECD (DOE, *Annual Energy Outlook 2005*, p.42).

[15] Although OPEC(2007) provides no income elasticities of oil demand, many interesting details are provided. For example, they project growth in vehicle ownership for Developing Countries that is no faster than income growth. By contrast, Dargay-Gately-Sommer(2007) projects that vehicle ownership in China and other developing countries will grow much faster than income – up to twice as fast – as their per-capita incomes increase through the range of $3000 to $12000. This is consistent with the historical experience of all countries. By 2030, the differences between projections of total vehicle stock are very large: OPEC(2007) projects 125 million for China and 808 million for Non-OECD, while Dargay-Gately-Sommer(2007) projects 390 million for China and 1172 million for Non-OECD.

6. Conclusions

The story of world oil demand over the period 1973-2006 is a tale of two oil products. Demand for residual oil has fallen by one-third, while the demand for other oil has doubled. Demand for the two product groups are quite distinct, with residual oil demand being highly price sensitive and other oil being largely income driven.

Most of the reductions in oil demand were due to reductions in residual oil after the two price shocks of the 1970s – the result of fuel-switching to coal, natural gas, and nuclear for electricity generation, especially in the OECD, rather than improved technological efficiency. These fuel-switching demand reductions were not un-done when oil prices collapsed in the 1980s – strong evidence of asymmetric price-responsiveness – and thus cannot be re-done when oil prices increase again. However, further reductions are still possible since the world still consumes nearly 10 mbd of residual oil, although Oil Exporters use 15% of this amount, compared with less than 10% of other oil.

Now that residual oil's share of total oil has declined from 28% in 1973 to 12% today, future changes in total oil demand are dominated by what happens to other oil. In most of the developing world, demand for other oil has increased almost as rapidly as income since 1973, and half as fast as income in the OECD. The shift away from residual oil will make total oil demand more sensitive to income than previously.

The price-responsiveness of demand for other oil has been much smaller than for residual oil, especially among the Income Growers, China, and the Oil Exporters. There has been some evidence of asymmetric price-responsiveness for other oil, but only within the OECD – the result of fuel-efficiency improvements that were not abandoned when oil prices fell. However, some OECD reductions in transport oil have been partially reversed by oil price declines, as consumers have chosen vehicles that are heavier and more powerful.

Our analysis suggests – at current real prices – weaker demand growth over the next decade in comparison with IEA and DOE, but much stronger growth beyond 2015 if we use their oil price and economic growth assumptions. Over the period to 2030 we project that the ratio of world oil demand growth to income growth will be 0.53 as long as governments do not implement new energy-efficiency and climate change policies not included in the IEA and DOE projections. In contrast, they project that – at current real prices – this ratio will be only 0.36 (IEA) or 0.34 (DOE). By 2030, this would be a difference of 20 mbd between our projections and theirs – roughly twice the current production of Saudi Arabia. Since such rapid demand growth is unlikely to be supplied by conventional oil resources, it would appear that this imbalance would have to be rectified by some combination of higher real world 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, 1965-2006: *BP Statistical Review (2007).*
Used only for world totals in Figures 1 and 2.

Oil Demand: Total Oil, Residual Oil, Other Oil:
OECD, 1971-2006: IEA, *Energy Statistics of OECD Countries*, Paris, 2007
Non-OECD, 1971-2005: IEA, *Energy Balances of Non-OECD Countries*, Paris, 2007

Real GDP (billion 2000 US$ using PPPs) and Population: SourceOECD dataset, for all countries

GDP growth rates for recent years, from IMF *World Economic Outlook* April 2007 database.

World crude oil prices (2006 $ per barrel),1965-2006: *BP Statistical Review (2007)*

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

1) Residual Oil. For 1978-2006 data we used the series "Indices of Energy End-Use Prices: Heavy Fuel Oil, Real Index for Industry". For 1971-1978, we used the (nominal) series "Industry Price per ton of High Sulfur Fuel Oil", deflated by the CPI; we then used the rate of change of these real prices to splice onto the 1978-2006 indices, creating the price index for 1977, then 1976, and back to 1971.
2) Other Oil. For 1978-2006, we created a weighted index of each country's real prices and consumption levels from the following products: 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; Light Fuel Oil (LFO), Real Price Index for Households, weighted by LFO consumption by Households; LFO, Real Price Index for Industry, weighted by LFO consumption by Industry. 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; LFO nominal price for Households, deflated by CPI, weighted by LFO consumption by Households; LFO nominal price for Industry, deflated by CPI, weighted by LFO consumption by Industry. We then the rate of change of these real prices to splice onto the 1978-2006 indices, creating the price index for 1977, then 1976, and back to 1971.
3) Total Oil Products. For 1978-2006, 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 residual oil and other oil, weighted by their respective shares in total oil. We then used the 1971-78 growth rates to splice backward to 1971 the 1978-2006 series.