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The Asymmetric Effects of Changes in Price and Income on Energy and Oil Demand

by

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Abstract

This paper estimates the effects on energy and oil demand of changes in income and oil prices, for 96 of the world's largest countries, in per-capita terms. We examine three important issues: the asymmetric effects on demand of increases and decreases in oil prices; the asymmetric effects on demand of increases and decreases in income; and the different speeds of demand adjustment to changes in price and in income. Its main conclusions are the following: (1) OECD demand responds much more to increases in oil prices than to decreases; ignoring this asymmetric price response will bias downward the estimated income elasticity; (2) demand's response to income decreases in many non-OECD countries is not necessarily symmetric to its response to income increases; ignoring this asymmetric income response will bias the estimated income elasticity; (3) the speed of demand adjustment is faster to changes in income than to changes in price; ignoring this difference will bias upward the estimated response to income changes. Using correctly specified equations for energy and oil demand, the long-run elasticity for increases in income is about 0.55 for OECD energy and oil, and 1.0 or higher for Non-OECD Oil Exporters, Income Growers and perhaps all Non-OECD countries. These income elasticity estimates are significantly higher than current estimates used by the US Department of Energy. Our estimates for the OECD countries are also higher than those estimated recently by Schmalensee-Stoker-Judson (1998) and Holtz-Eakin and Selden (1995), who ignore the asymmetric effects of prices on demand. Higher income elasticities, of course, will increase projections of energy and oil demand, and of carbon dioxide emissions.

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I Introduction

This paper analyses the determinants of commercial energy and oil demand, for 96 of the world's largest countries (listed in Appendix A), using 1971-97 data on a per-capita basis. Our primary interest is estimating the long-run income elasticity of demand. This parameter has important implications for future energy and oil demand, and for emissions levels for carbon dioxide and other pollutants – not to mention its effect on the future prices of oil and other forms of energy. However, estimation of this parameter is relatively sensitive to the assumed specification of demand as a function of income and price. We are especially interested in whether there are:

- asymmetric effects on demand between increases and decreases in price
- asymmetric effects on demand between increases and decreases in income
- differences in the speed of demand adjustment for changes in price and for changes in income
- differences across countries and various groups of countries.

To address these issues, we examine various specifications of the demand equation for various groups of countries.

The paper was motivated by several articles in the literature whose income-elasticity estimates for energy or for the closely associated carbon emissions appear too low, and even negative in some cases – namely Schmalensee, Stoker, and Judson (SSJ, 1998), Judson, Schmalensee, and Stoker (JSS, 1999) and Holtz-Eakin and Selden (HS, 1995). For the highest-income (OECD) countries, SSJ (1998) estimated income-elasticities are substantially below the 0.55 level that we estimate for the OECD in this paper; in fact, their estimates were not even positive: SSJ (1998) estimate an income elasticity of –0.30 for carbon emissions and –0.22 for energy. As for HES (1995), although they do not report elasticities, their estimated coefficients suggest an income elasticity of 0.36 for the highest-income countries considered by SSJ (1998).

Another motivation was provided by demand projections by the US Department of Energy's Energy Information Administration (EIA) that used income elasticities that were extremely low, for the developing countries especially[1]. For example, they used an income elasticity of about 0.65 for energy and oil in Asian Developing Countries excluding China.

Our conclusions are the following:

- the long-run income elasticity of energy and oil is about 0.5 for the OECD countries and approximately 1.0 for the Non-OECD countries;
- demand has responded more to increases than to decreases in price, not only in the developed OECD countries and also in many developing countries; wrongly assuming that demand is perfectly price-reversible (i.e. symmetry between the effects of increases and decreases in price), or omitting price entirely, will bias downward the estimated income elasticity[2];
- demand has responded more to increases in income than to decreases in income, for some groups of countries such as the Non-OECD Oil Exporters; wrongly assuming that demand is perfectly income-reversible (i.e. symmetry between the effects of increases and decreases in income) can bias downward the estimated income elasticity;

[1] See *International Energy Outlook 2000*.
[2] See also Gately (1992, 1993), Dargay-Gately (1995a, 1995b)

- the speed of adjustment to changes in price is slower than to changes in income;
- there are important differences across countries, not only between the developed OECD countries and the Non-OECD countries, but also among several Non-OECD sub-groups: the Oil Exporting countries, the Growing Income countries, and the Other Countries; this heterogeneity characterizes countries' experience with regard to the rate of income growth and its variability over time, as well as the relationship between income growth and the demand for energy and oil.

The outline of the paper is as follows. In Section II we describe important features of the data, namely: the fundamental influence of income growth upon the demand for energy and oil; the asymmetric effects on demand of price increases and decreases; the asymmetric effects on demand of income growth and decline; and the substantial heterogeneity across countries, not only between the OECD and the Non-OECD countries but also among the Non-OECD countries themselves. In Section III we describe the various specifications of the demand equations that we shall examine. Section IV presents the econometric results for these alternative specifications of the demand for energy and for oil, for several groups of countries: for the OECD countries, for the Non-OECD countries, and then for three sub-groups within the Non-OECD countries whose behavior differs substantially from each other: the Oil Exporters, the Income Growers (those developing countries with the fastest income growth), and the Other Countries. Section V summarizes our conclusions.

II. Background Issues

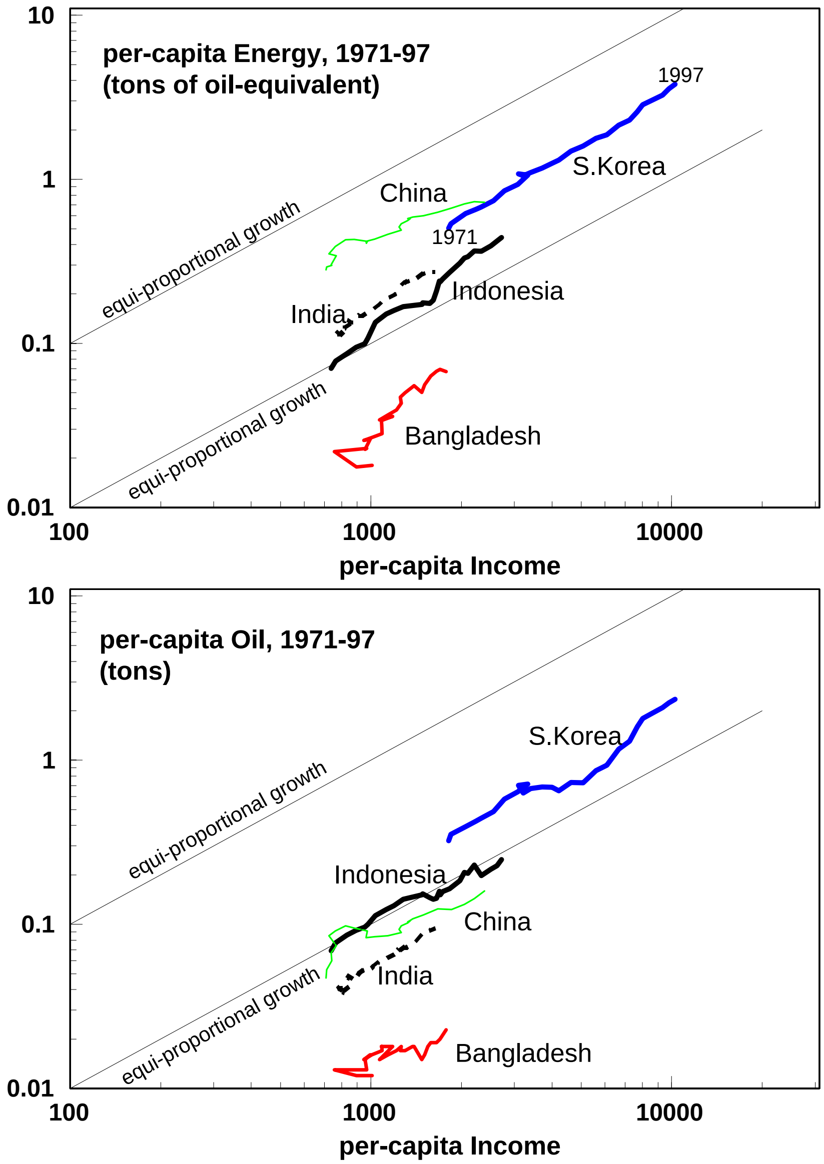
Important Determinants of the Growth of Energy and Oil Demand: Income and Price, and Heterogeneity across countries

We assume that a country's per-capita energy and oil demand are determined by changes in income and price. These effects on demand may be asymmetric. That is, the demand-reducing effect of price increases may not necessarily be completely reversed by a comparable reduction in price. Likewise, the demand-increasing effect of an increase in income may not necessarily be completely reversed by a comparable decrease in income.

In several graphs below, we illustrate important phenomena that we shall attempt to capture in our econometric modeling.

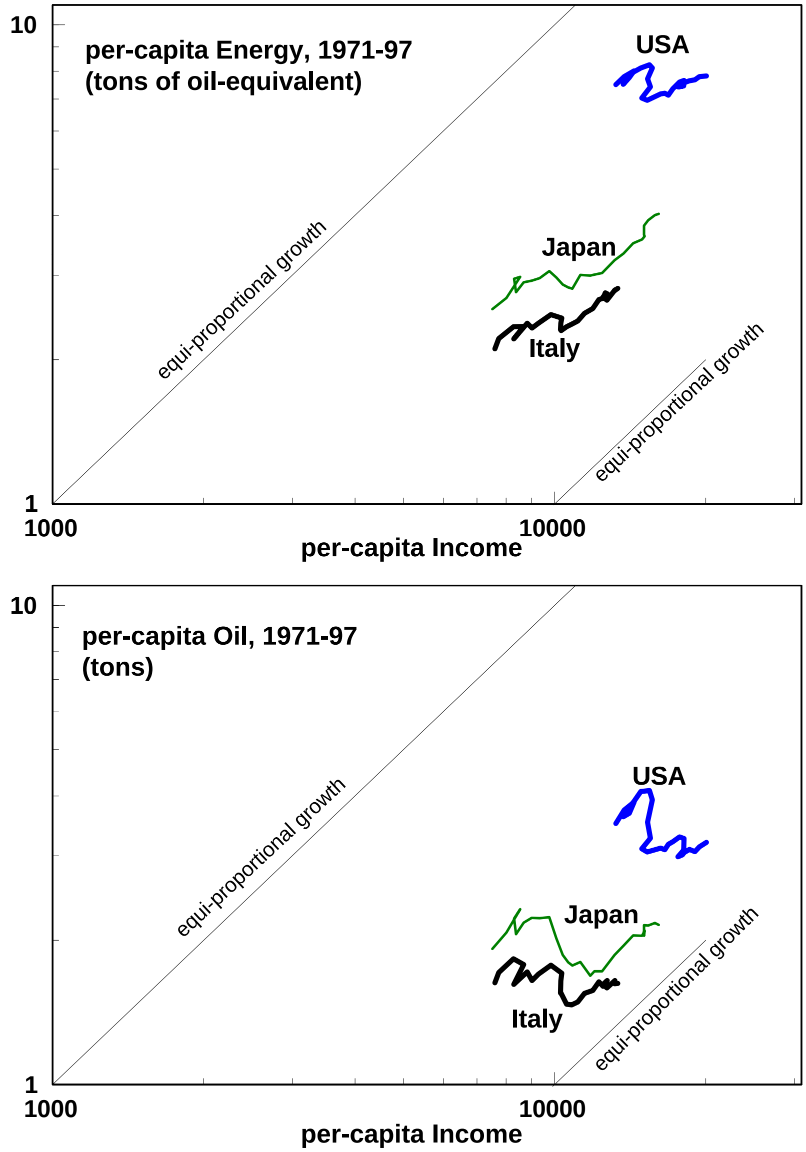
- The role of income growth is illustrated by Figure 1, which shows the 1971-97 time-paths of per-capita energy and oil demand vs. per-capita income, for five large Asian countries. We see that their energy and oil demand increased about as fast as income over this period.
- The asymmetric effects on demand of increases and decreases in the price of oil are illustrated by Figure 2, which shows similar time-paths for three large OECD countries: Italy, Japan, and the USA. We see that the demand reductions caused by the oil price increases of the 1970's are not reversed by the oil price decreases of the 1981-86 period.
- The asymmetric effects on demand of changes in income are illustrated in Figure 3, which shows time-paths for three countries whose incomes have decreased for some or all of the 1971-97 period: Saudi Arabia, Bulgaria, and Zaire. We see that the demand-increasing effects of income increases are not simply reversed by the effects of income decreases.

Figure 1. Growth in Income and Demand, for 5 Asian Countries



The top graph of Figure 1 depicts the 1971-97 time-paths of per-capita energy demand against per-capita income (moving left to right, with increasing income), for five large Asian countries. The bottom graph shows the analogous time-paths for per-capita oil demand. In each graph, the scales are logarithmic -- which allows for order-of-magnitude differences among countries, and which facilitates growth-rate comparisons across countries and between energy [or oil] growth and income growth. Movement parallel to the diagonal lines indicates equi-proportional growth in energy and income; steeper [less steep] movement indicates that energy is growing faster [slower] than income. For example, in the top graph we see that South Korea had the fastest income growth (greatest horizontal movement) and that its energy demand increased as fast as its income (movement parallel to the equi-proportional lines). China's energy demand grew more slowly than its income, while Bangladesh's energy demand grew faster than its income.

Figure 2. Asymmetric Effects on Demand of Oil Price Increases and Decreases



In similar graphs, Figure 2 shows the 1971-97 time-paths of energy (and oil) demand versus income, for three large OECD countries: the USA, Japan, and Italy. These graphs, especially the lower graph for oil, also show indirectly the asymmetric effects of oil price increases (in 1973-74 and 1979-80) and subsequent price decreases during the1980s.[3] The effect of the oil price increases, especially after 1979-80, was to sharply reduce oil demand. Yet when these price increases were almost completely reversed in the mid-1980s, the oil demand reductions were not reversed at all in the USA, and were only slightly reversed in Italy and Japan.

[3] Oil price, 1971-97, is shown in Figure 5 below, in logarithmic form.

Figure 3. Asymmetric Effects on Demand of Income Growth and Decline

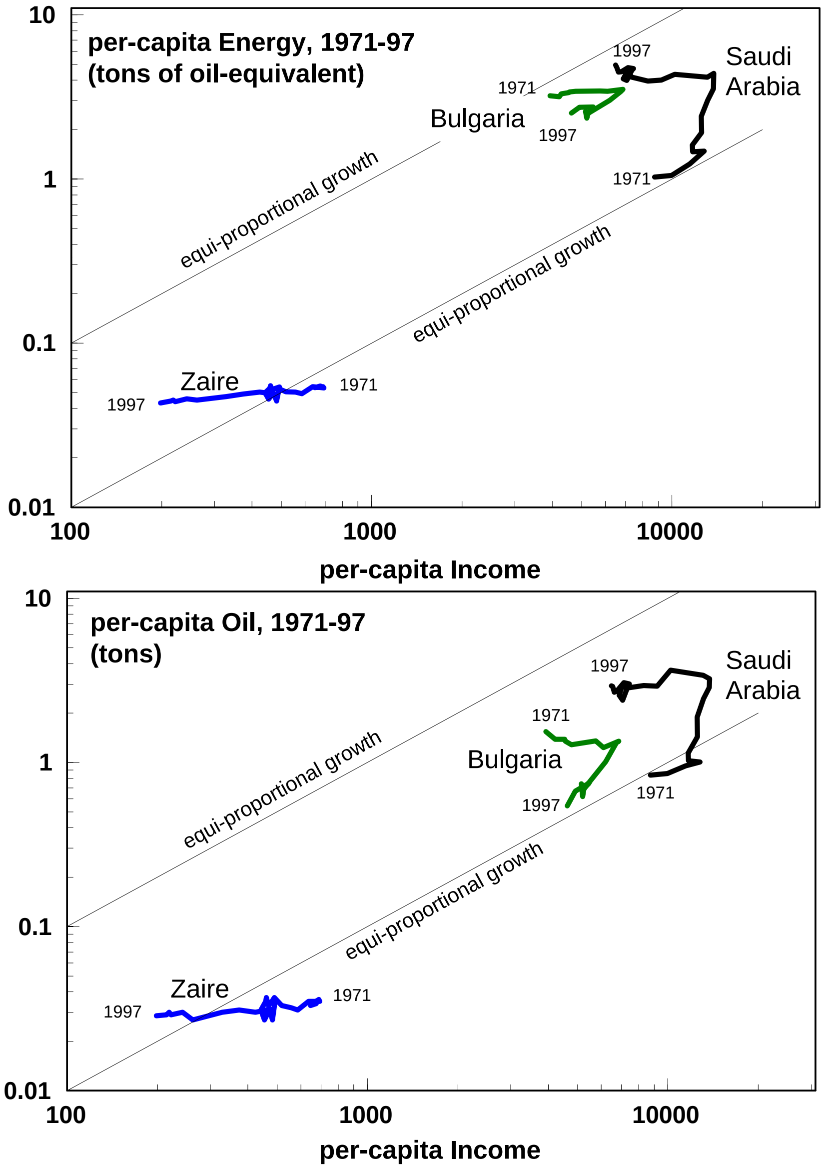


Figure 3 illustrates, for three Non-OECD countries, the possibility that income growth and decline can have asymmetric effects on demand. For Saudi Arabia, we see that in the 1970s demand grew together with (and often faster than) income, but the subsequent income declines in the 1980s did not reverse the demand growth of the 1970s. In Bulgaria the opposite happened: income grew in the 1970's but energy and oil demand were flat; subsequent income declines in the 1980s caused energy demand to decline at the same rate as income, and caused oil demand to decline even faster than income[4]. Finally, for Zaire we see the dismal decline in income (right-to-left movement) from 1971 to 1997 accompanied by almost no reduction in energy or oil demand.

[4] Strictly speaking, this decline in oil demand in the final decade might better be described as caused by a decline in oil exports from the Former Soviet Union.

In Figures 1-3, we have shown the 1971-97 time-paths of energy and oil demand versus income, for a total of eleven countries. These graphs have illustrated the heterogeneity of experience across countries in a variety of dimensions: in their income growth, both the average rate of growth and its volatility over time, as well as in the relationship of demand growth to changes in income and to changes in price. To summarize the relationship between the growth of income and the growth of energy and oil demand for *all* countries, we plot in Figure 4 each country's energy and oil demand growth rates versus their income growth rates. The names and 3-letter abbreviations of the 96 countries appear in Appendix A. The OECD countries are plotted in the two graphs on the left, and the Non-OECD countries in the two graphs on the right. The top graphs plot countries' energy growth rate on the vertical scale and their income growth rate on the horizontal. Similarly for the two bottom graphs: oil growth rate on the vertical, and income growth rate on the horizontal. The scales on all four graphs are the same: ranging from –5% to +10% annual growth.

The OECD countries all had relatively similar rates of income growth of about 2% annually, with the rates ranging between 1% and 4%. But the Non-OECD countries had widely different rates of income growth. Several Asian countries had income growth of 5% or greater: South Korea, Singapore, Malaysia, Indonesia, Thailand, and China. In contrast, several other countries experienced negative growth: Zaire, Angola, Zimbabwe, Cote d'Ivoire, Haiti, Saudi Arabia, Nigeria, Jamaica, and Venezuela.

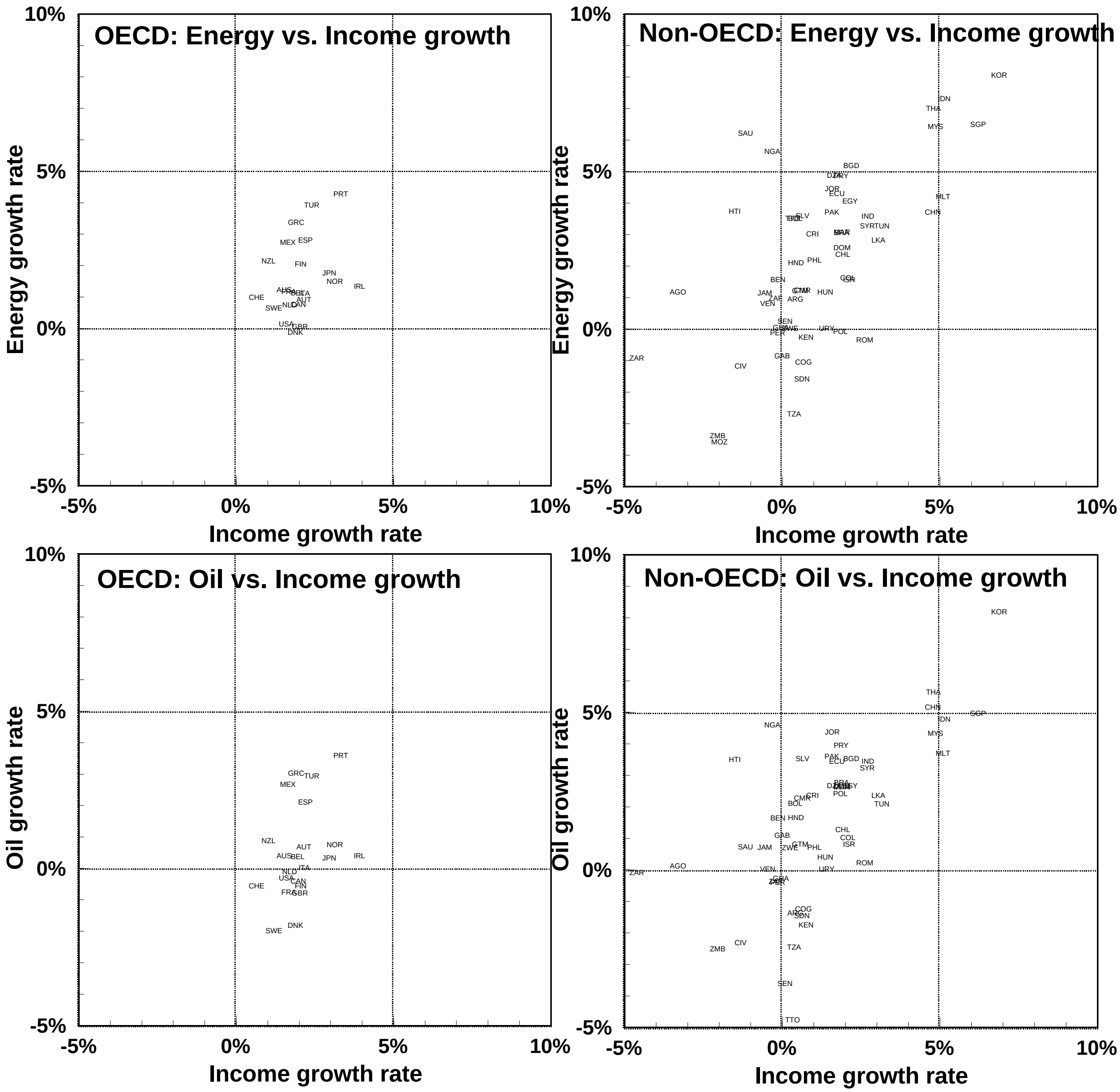
There were also importance differences across countries in the relationship between energy growth and income growth, and between oil growth and income growth. In the simplest case, if energy (or oil) demand were growing at the same rate as income, a country's point would be plotted on the 45-degree line: the energy (oil) growth rate would be the same as the income growth rate. The closest to that case would be the upper left graph, OECD energy vs. income growth, where many of the points are close to the 45-degree line; only a few are far removed, with energy growth much lower than income growth: Ireland, Norway, Japan, Great Britain, Denmark, and the USA. In the lower left graph, OECD oil vs. income growth, most of the countries had oil demand growth rates considerably lower than their income growth rates, and many had negative growth rates for oil demand, reflecting the demand reductions in response to the two price shocks of the 1970s. Those countries whose oil demand grew as rapidly as their income were those that started at the lowest income levels in the OECD: Portugal, Greece, Mexico, Turkey, and Spain.

The Non-OECD countries exhibited much greater heterogeneity, not only in their rates of income growth but also in the relationship between their energy (or oil) growth rates and their income growth rates. Although some countries' energy and income growth rates were similar (e.g., Singapore at 7%, Tunisia at 3%, Chile at 2%, Cote d'Ivoire at –1.5%), there were many more countries whose energy growth rates were much greater than their income growth rates. Some had negative income growth but positive growth in energy demand, such as Saudi Arabia, Nigeria, Haiti, and Angola. Others had positive rates of income growth but negative growth in energy demand: Romania, Kenya, Congo, Sudan, and Tanzania. Similarly heterogeneous were the Non-OECD countries' relationships between oil demand growth and income growth: countries with virtually no income growth had oil demand growth that ranged from about +5% (Nigeria) to -5% (Trinidad & Tobago).

This heterogeneity, within the Non-OECD especially, will frustrate our efforts to use a standard econometric specification. We address this difficulty below, by clustering the Non-

OECD countries into three groups that are somewhat more homogeneous: the Oil Exporters, the Income Growers, and Other Countries.

Figure 4. Energy and Oil Demand Growth vs. Income Growth: average annual % growth rates 1971-97



III. Demand Model

Data: Sources and Units

- Income, 1971-97: Real GDP per capita in constant dollars (Chain Index), expressed in international prices, base 1985. Sources: Data for 1971-92 from Penn World Tables 5.6. Data for 1993-97 calculated from growth rates of deflated PPP per-capita income data from World Bank, 1999 World Development Indicators.
- Energy Consumption, 1971-97: Total Final Consumption of "modern", commercial energy only (excluding "Combustible Renewables and Waste": traditional biomass fuels such as wood) in tons of oil-equivalent per person; Source: International Energy Agency.
- Oil Consumption, 1971-97: Total Final Consumption of oil products plus Oil used in Transformation (e.g. for electricity generation) in tons per person; Source: International Energy Agency.
- Population 1971-97, US Census Bureau, International Data Base, Table 1 www.census.gov/ipc/www/idbnew.html
- Price of international crude oil, 1971-97: US Dept. of Energy, Energy Information Administration, Refiner Acquisition Real Cost of Imported Crude Oil, 1992$/barrel

Definitions

D_{ct} log of per-capita demand, either energy or oil, in country c in year t.
Y_{ct} log of real per-capita GDP, in country c in year t
P_t log of real price of oil

Model Specification

Various specifications shall be examined for the demand for energy (or oil), and the results presented and compared. This approach addresses the heterogeneity across countries and the likelihood that some specifications will be more appropriate for some groups of countries than for others. It also takes account of an important conclusion from the surveys by Dahl (1991, 1993, 1994), that the estimated income and price elasticities are dependent upon the specification chosen.

The simplest specification makes current demand a log-linear function only of current income:

(1) $D_t = k + \gamma Y_t$

A second specification would allow demand to be determined by current and past values of income, in which the weights for past values of income decline geometrically. Such a specification, commonly called a Koyck-lag equation, is equivalent to the following function of current income and lagged demand:

(2) $D_t = k + \gamma Y_t + \theta D_{t-1}$

We expect that the lagged-demand coefficient θ would have a value between 0 and 1. The implied speed of adjustment to changes in income, measured by $1- \theta$, could range from instantaneous (when $\theta = 0$) to very slow (when θ approaches 1).

A similar Koyck-lag model could also assume that demand is determined by both income and price[5] together with lagged demand[6]:

(3) $D_t = k + \beta P_t + \gamma Y_t + \theta D_{t-1}$

This specification assumes that the effects of past price levels decline geometrically, and at the same rate as the effects of past income levels. That is, the speed of demand adjustment (1-θ) is the same for changes in price and for changes in income.

Since it not necessarily true that the speed of demand adjustment to changes in price would be the same as the speed of demand adjustment to changes in income, we also consider a specification in which lagged-adjustment coefficients for price and income are estimated separately:[7]

(4) $$D_t = k * (1- \theta_p) * (1- \theta_y) + (\theta_p + \theta_y) * D_{t-1} - (\theta_p * \theta_y) * D_{t-2} + \beta P_t - \theta_y \beta P_{t-1} + \gamma Y_t - \theta_p \gamma Y_{t-1}$$

More complicated specifications of the demand equation take account of two important phenomena:

- imperfect price-reversibility: the demand response to a price increase is not completely reversed by an equivalent price decrease;
- imperfect income-reversibility: the demand response to an income increase is not completely reversed by an equivalent income decrease.

The phenomenon of imperfect price-reversibility has been analyzed extensively, initially by Dargay and Gately; see Dargay (1992), Gately (1992, 1993), Dargay and Gately (1994 , 1995a, 1995b), Gately and Streifel (1997), Walker and Wirl (1993), and Haas and Schipper (1998). The basic idea is that higher energy prices induced investment in more energy-efficient equipment and retrofitting of existing capital, such as greater insulation. But when prices fell, the response was not to reverse this retrofitting or to switch back to less energy-efficient capital -- although there may well have been more intensive usage, such as driving more miles or adjusting thermostats to more comfortable levels. Thus, the responses to price increases and decreases could potentially be

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[5] It would be preferable to have refined petroleum prices for the oil equations and delivered energy prices for the energy equations for each country. However, this data is unavailable for most countries, especially in the developing world. Analysts frequently ignore all prices when pooling data from many countries; instead they employ year-dummy variables that could incorporate energy prices, but could also represent technology and other time-dependent events. Rather than ignore prices altogether, we will include the world price of oil as an important independent variable in estimating energy and oil demands. Since delivered oil and energy prices are unavailable for most countries, we apply the consistent treatment that the world crude oil price is the primary price variable of interest in our specifications.

[6] This specification is closest to the one whose results are most commonly reported in Pesaran *et al.* (1998).

[7] Such a specification is described in Johnston (1984), equation 9-14, page 347.

quite different.[8]

In this approach, instead of using the logarithm of price in the demand equation, the following three-way decomposition of the logarithm of price has been substituted: the cumulating series of increases in the maximum historical price, the cumulating series of price cuts, and the cumulating series of price recoveries (sub-maximum increases in price). In this paper we use the following:

Decomposition of P_t, the log of price

(i) $P_t = P_1 + P_{max,\,t} + P_{cut,\,t} + P_{rec,\,t}$;

where P_1 = log of price in starting year t=1, which is 1971

$P_{max,\,t}$ = cumulative increases in log of maximum historical price;
monotonically non-decreasing: $P_{max,\,t} \geq 0$

$P_{cut,\,t}$ = cumulative decreases in log of price;
monotonically non-increasing: $P_{cut,\,t} \leq 0$

$P_{rec,\,t}$ = cumulative sub-maximum increases in log of price;
monotonically non-decreasing: $P_{rec,\,t} \geq 0$

The following graph depicts the (log) price of oil and its decomposition into three price series.

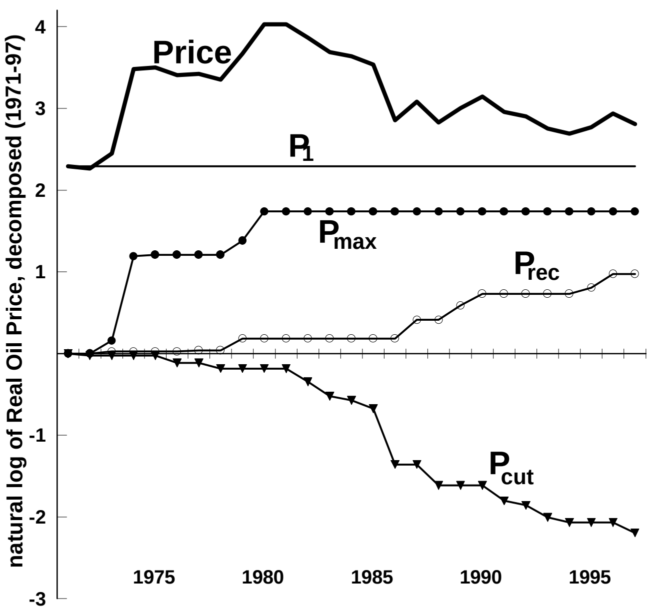

Figure 5. Decomposition of the Logarithm of Price

[8] Observed asymmetries in the oil demand response to the world crude oil price could technically be due to various reasons: (1) there is asymmetry between demand and delivered prices, and/or (2) there is asymmetry between a country's delivered oil prices and the world crude price. Similarly, asymmetry in energy demand could be in its response to price or in the response of delivered fuel prices to the world crude oil price. Although price controls, taxes, and alternative fuel mixes could all complicate this story, we believe that it is essential to include a price variable, no matter how imperfect, to adequately test the hypotheses of interest.

It has also been argued that the demand effects of changes in income are not necessarily perfectly reversible, which most demand equations assume implicitly. The hypothesis of imperfectly income-reversible demand is suggested in Dargay-Gately (1995a, Figure 19), in which the effects on demand of income increases are not symmetric to the effects of income decreases. Possible explanations for such asymmetry include the following. Some sectors may expand more strongly than others when the economy grows, while other sectors may decline more strongly than others when the economy contracts; these sectors may have different energy intensities. In addition, even when incomes decline in many developing countries, the process of urbanization may continue, requiring a continuing shift from traditional biomass fuels toward modern, commercial fuels

To examine this possibility we use an approach analogous to our price decomposition. We decompose the logarithm of per-capita income into three component series: the cumulating series of increases in maximum income, the cumulating series of income declines, and the cumulating series of income recoveries (sub-maximum increases in income), as follows:

Decomposition of the Y_t, the log of per-capita income

(ii) $Y_t = Y_1 + Y_{max,\, t} + Y_{cut,\, t} + Y_{rec,\, t}$;

where Y_1 = log of GDP in year t=1, which is 1971

$Y_{max,\, t}$ = cumulative increases in log of maximum historical per-capita GDP;
monotonically non-decreasing: $Y_{max,\, t} \geq 0$

$Y_{cut,\, t}$ = cumulative decreases in log of per-capita GDP;
monotonically non-increasing: $Y_{cut,\, t} \leq 0$

$Y_{rec,\, t}$ = cumulative sub-maximum increases in log of per-capita GDP;
Monotonically non-decreasing: $Y_{rec,\, t} \geq 0$

The following graph depicts the log of per-capita income for Saudi Arabia and its three-way decomposition.

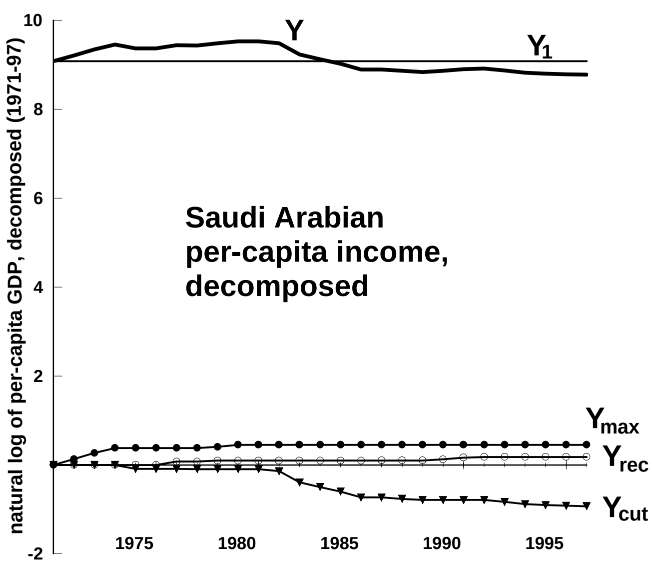

Figure 6. Decomposition of the Logarithm of Per-capita Income

Combining the decomposition of price (i) and the decomposition of income (ii) into equation (4) gives us the following equation:

$$
\begin{aligned}
(5)\quad D_t = {} & k_0 * (1-\theta_p) * (1-\theta_y) + (\theta_p + \theta_y) * D_{t-1} - (\theta_p * \theta_y) * D_{t-2} \\
& + k_p P_1 + \beta_m P_{max,\,t} + \beta_c P_{cut,\,t} + \beta_r P_{rec,\,t} \\
& - \theta_y * (k_p P_1 + \beta_m P_{max,\,t-1} + \beta_c P_{cut,\,t-1} + \beta_r P_{rec,\,t-1}) \\
& + k_y Y_1 + \gamma_m Y_{max,\,t} + \gamma_c Y_{cut,\,t} + \gamma_r Y_{rec,\,t} \\
& - \theta_p * (k_y Y_1 + \gamma_m Y_{max,\,t-1} + \gamma_c Y_{cut,\,t-1} + \gamma_r Y_{rec,\,t-1})
\end{aligned}
$$

where k_0, $k_p P_1$, and $k_y Y_1$ are constants that become combined with the other constants to form a single constant k:

$$
\begin{aligned}
(5a)\quad D_t = {} & k + (\theta_p + \theta_y) * D_{t-1} - (\theta_p * \theta_y) * D_{t-2} \\
& + \beta_m P_{max,\,t} + \beta_c P_{cut,\,t} + \beta_r P_{rec,\,t} \\
& - \theta_y * (\beta_m P_{max,\,t-1} + \beta_c P_{cut,\,t-1} + \beta_r P_{rec,\,t-1}) \\
& + \gamma_m Y_{max,\,t} + \gamma_c Y_{cut,\,t} + \gamma_r Y_{rec,\,t} \\
& - \theta_p * (\gamma_m Y_{max,\,t-1} + \gamma_c Y_{cut,\,t-1} + \gamma_r Y_{rec,\,t-1})
\end{aligned}
$$

In the econometric results below, we use pooled cross-section/time-series data for various groups of countries, using energy (or oil) demand for each country, income for each country, and the price of oil, with a separate constant estimated for each country – what is called a "fixed effects" model.[9] In the most general specification, in which both income and price are decomposed and the lagged-adjustment coefficients for income and price are estimated separately, we estimate the following regression:

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

where k_{1c} are the constants for the individual countries and the other parameters are the same across countries.

The following can be said about the lagged-adjustment coefficients:

θ_p lagged price coefficient; $0 \le \theta_p \le 1$

$1-\theta_p$ is the speed of adjustment to changes in P;

if $\theta_p = 0$: adjustment to price change is instantaneous; no lag

θ_y lagged income coefficient; $0 \le \theta_y \le 1$

$1-\theta_y$ is the speed of adjustment to changes in Y;

if $\theta_y = 0$: adjustment to income change is instantaneous; no lag

Normally we would expect the price-lag coefficient to be larger than the income-lag coefficient; that is, we expect that demand adjusts more slowly to price changes than to income changes:

$0 \le \theta_y \le \theta_p \le 1$

With regard to the price coefficients, we expect that:

$\beta_m < 0$ demand response to change in P_{max}

$\beta_c < 0$ demand response to change in P_{cut} ; note that $P_{cut} < 0$

$\beta_r < 0$ demand response to change in P_{rec}

Normally we would expect that, in absolute values, $\beta_c < \beta_r < \beta_m$

With regard to the income coefficients, we expect that:

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9 See Hsaio (1986).

$\gamma_m > 0$ demand response to change in Y_{max}
$\gamma_c > 0$ demand response to change in Y_{cut}; note that $Y_{cut} < 0$
$\gamma_r > 0$ demand response to change in Y_{rec}
Normally we would expect the relative values to be $\gamma_c < \gamma_r < \gamma_m$
That is, we expect demand to rise more rapidly when income rises than it would decrease when income falls, and rise most rapidly when a new maximum income is reached.

IV. Econometric Results

Next we summarize the econometric results for the various specifications of the demand equations for energy and oil, for several regions. First we present results for the OECD countries, and then for the Non-OECD countries. Given substantial heterogeneity within the Non-OECD countries, as suggested by Figure 4 above, we then present results for more homogenous clusters of countries: the Oil Exporters, the Income Growers (developing countries with income growth exceeding 2% per annum), and then for the Other Countries.

As noted above, we emphasize the effects of alternative specifications upon the income and price elasticities; this is an important result from the surveys by Dahl (1991, 1993, 1994). We shall illustrate this for each of the regions, describing in detail the estimated elasticities that result from alternative functional specifications.[10]

IV.1 OECD Countries

Table 1. OECD Countries' Results

		Income coefficients				Oil Price coefficients				Lagged adj.coef.					
fuel	eq.	Y	Ymax	Ycut	Yrec	P	Pmax	Pcut	Prec	Income	Price	Long-run Income Elasticity	Long-run Price Elasticity	Adjusted R-sqared	Sum of Squared Residuals
energy	2	0.078								0.86		0.57		0.9958	1.0189
energy	3	0.052				-0.027				0.87		0.39	-0.20	0.9961	0.9321
energy	3a	0.151					-0.041	-0.014	-0.039	0.88		1.28	-0.35	0.9963	0.8924
								reject equality							
energy	6	0.588					-0.025	-0.014	-0.015	0.00	0.90	0.59	-0.24	0.9967	0.7959
								reject equality							
oil	2	0.032								0.90		0.31		0.9884	1.8220
oil	3	-0.016				-0.054				0.91		-0.18	-0.59	0.9907	1.4597
oil	3a	0.158					-0.076	-0.036	-0.078	0.89		1.48	-0.71	0.9913	1.3600
								reject equality							
oil	6	0.528					-0.075	-0.038	-0.048	0.06	0.88	0.56	-0.64	0.9916	1.2230
								reject equality							

Notes: i) A shaded cell indicates a coefficient that was not statistically significant.
(ii) The equation # listed above correspond to the equation # described in Section III above. The letter "a" following an equation number (e.g. 3a) indicates an asymmetric response was allowed, via decomposition of price and/or income.
(iii) When price or income is decomposed, we performed a Wald test of the null hypothesis that the three coefficients are equal. Below those coefficients we indicate whether the equality hypothesis was rejected or not rejected, using a 5% cutoff for the F-statistic probability.
(iv) Long-run income elasticity was calculated as $\gamma / (1- \theta_y)$; similarly for price. When income [price] is decomposed, the long-run elasticity for income [price] refers to changes in Y_{max} [P_{max}].
(v) The Sums of Squared Residuals are not comparable between Energy and Oil because different units were used in the regressions: tons for Energy and Thousand Barrels/Day for Oil.

[10] As noted by Pesaran (1998, p.66), there appears little point in applying unit root and cointegration tests on annual time series that span such a short period. The literature establishes the low power of these tests in small samples.

OECD: Energy Demand

Using a Koyck-lag equation with only income and lagged demand (equation 2), the income elasticity is 0.57. Also including price, a standard Koyck-lag equation (3), with price, income, and lagged demand, the income elasticity falls to 0.39.

If we allow demand to be imperfectly price-reversible (equation 3a), not only do we see the coefficients for price increases to be much larger than for price decreases, but also we see that the income elasticity is increased significantly, to 1.28. However, this estimate seems implausibly large.

When adjustment coefficients for both price and income are estimated separately as in equation (6) (results not shown in Table 1), the income adjustment coefficient is estimated to be negative but not significantly different from zero. With a modified version of equation (6) that estimates an adjustment coefficient only for price (with a zero coefficient for adjustment to income changes, i.e. instantaneous adjustment), the resulting income elasticity is 0.59, with a price elasticity of –0.24. This is the preferred specification[11], equation (6).

Thus, if the economy grows by 3% per annum, energy demand will grow by 1.8% per annum, and energy intensity will decline by 1.2% per annum if energy prices do not change. This long-term trend toward decreasing energy intensity is sometimes called by energy modelers the economy's "autonomous energy efficiency improvement, AEEI". It is autonomous in their models because it is unrelated to energy price movements. In fact, it could be due to trends in technology or in the structural mix of the economy, or other factors that have not included.

These OECD energy results can be contrasted with results of others such the energy and climate change estimates of SSJ (1998), JSS (1999), and HS (1995). Due to the unavailability of a full set of international energy prices, these authors ignore price entirely and allow time-effects to capture the complex asymmetric effects of prices and other factors. For the highest-income (OECD) countries, their estimated income elasticities are substantially below the 0.55 level that we estimate for the OECD in this paper. In fact, their estimates are not even positive: SSJ (1998) estimate an income elasticity of –0.30 for carbon emissions and –0.22 for energy. Although HS (1995) does not report elasticities, their estimated coefficients for carbon emissions imply an income elasticity of 0.36 for the highest-income countries.[12] Projections with such elasticities would allow for unwarranted optimism that demand would barely grow for the richest countries.

OECD: Oil Demand

With a simple specification with income and lagged price, the income elasticity is 0.31. However, when price is also included, equation (3), the income elasticity becomes negative, although not statistically significant. This would indeed be a puzzling result, that OECD oil demand would decrease when OECD income increased.

To resolve this puzzle, we allow demand to be imperfectly price-reversible (equation 3a). The resulting decomposed price coefficients indicate that price increases have a much greater

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[11] Decomposing income as well as price is not warranted. When such an equation was estimated, a Wald test could not reject the hypothesis that the income coefficients are equal.

[12] Since these studies ignore price, they do not incorporate any lagged adjustment terms. Energy demand and carbon emissions are functions of country intercept terms, time intercepts, and income which enters the equation nonlinearly. SSJ (1998) estimates a 10-knot piece-wise-linear spline function; HS (1995) use a polynomial function with income and income squared terms. HS (1995) adjusts for autocorrelation, but SSJ (1998) does not .

impact on demand than do price decreases; a Wald test of the hypothesis that these three coefficients were equal allowed us to reject the hypothesis. Moreover, the income coefficient is positive and statistically significant – although the income elasticity of 1.48 is implausibly large.

When adjustment coefficients for both price and income are estimated, in equation (6), the income adjustment coefficient was estimated to be positive, although not significantly different from zero. The resulting income elasticity is 0.56. Again there was clear evidence of imperfect price-reversibility: a Wald test allowed us to reject the hypothesis that the price coefficients were equal. Decomposing income as well as price was not warranted: a Wald test could not reject the hypothesis that the income coefficients are equal (results not shown).

The preferred specification is equation (6). The long-run price elasticity is –0.64, which is substantially above energy's response to price. Its long-run income elasticity is 0.56. Thus, if the economy grows by 3% per annum, oil demand will grow by 1.65% per annum, and oil intensity will decline by 1.35% per annum if price does not change.

These results confirm our conjecture that wrongly assuming that demand is perfectly price-reversible will bias downward the income elasticity. They also help to explain other estimates of income elasticities of demand for energy and oil in the literature that are much smaller, and sometimes even negative, when the price effect is ignored for the richest countries.

IV.2 Non-OECD Countries

Table 2. Non-OECD Countries' Results

		Income coefficients				Oil Price coefficients				Lagged adj.coef.					
fuel	eq.	Y	Ymax	Ycut	Yrec	P	Pmax	Pcut	Prec	Income	Price	Long-run Income Elasticity	Long-run Price Elasticity	Adjusted R-sqared	Sum of Squared Residuals
energy	1	0.859										0.86		0.9726	99.418
energy	2	0.159								0.84		0.86		0.9942	20.943
energy	3	0.166				-0.026				0.84		1.02	-0.16	0.9943	20.683
energy	3a		0.185	0.156	0.307		-0.028	-0.005	0.002	0.83		1.11	-0.17	0.9944	20.391
			reject equality				cannot reject equality								
energy	4	0.444				-0.019				0.00	0.88	0.44	-0.16	0.9943	20.542
energy	6		0.521	0.482	0.307		-0.008	-0.012	0.026	0.00	0.86	0.52	-0.01	0.9943	20.344
			cannot reject equality				reject equality								
oil	1	0.720										0.72		0.9755	81.129
oil	2	0.151								0.82		0.72		0.9934	21.755
oil	3	0.153				-0.029				0.82		0.84	-0.16	0.9935	21.438
oil	3a		0.179	0.150	0.220		-0.048	-0.001	0.018	0.82		1.01	-0.27	0.9936	21.230
			reject equality				cannot reject equality								
oil	6		0.530	0.455	0.068		-0.028	-0.008	0.037	0.00	0.84	0.53	-0.18	0.9935	21.248
			reject equality				reject equality								

Notes: see Table 1.

Non-OECD: Energy Demand

With the simpler specifications (equations 1, 2, or 3) the estimated income elasticity is between 0.86 and 1.02. When income and price are decomposed in a specification with lagged demand, equation (3a), there is partial evidence for asymmetric response to changes in income changes and in price, and the income elasticity (1.11) is slightly higher than in the previous specifications.

Notice that the income elasticity for either equations (3) or (3a) appears relatively high and slightly higher than unity. In fact, the estimated response of 1.02 in equation (3) appears comparable to what we will estimate for the same equation in the following sections for the oil exporters (1.11 in Table 3), for fast growers (1.17 in Table 4), and for all others (0.93 in Table 5). Thus, one might be tempted to conclude that disaggregation of the non-OECD countries would not change the estimates of the income elasticities. However, this conclusion would hold only if equation (3), which imposes the same adjustment process on price and income, is properly specified.

When the lagged-adjustment coefficients are estimated separately for income and price, that coefficient for income is negative (results not shown) – implying faster-than-instantaneous adjustment to income changes. Hence we examined a modified version of equation (4) in which income's lagged-adjustment coefficient was assumed to be zero and the lagged-adjustment coefficient was estimated only for price. A similar variant of equation (6) allowed for asymmetric response to changes in both income and price. In both specifications, (4) and (6), the estimated income-elasticity was relatively low: either 0.44 or 0.52.

The preferred specification would be equation (4), rather than equation (6). For the latter equation, a Wald test did not allow us to reject the hypothesis that the decomposed-income coefficients were equal. Moreover, in equation (6) none of the decomposed-price coefficients were statistically significant, although a Wald test did allow us to reject the hypothesis that the coefficients were equal.

Non-OECD: Oil Demand

The econometric results for oil were generally similar to those for energy. For the simpler specifications, the estimated income elasticity ranged from 0.72 to 0.84. When income and price were decomposed, in equation (3a), there was evidence of asymmetric response for income and perhaps for price. The relative magnitudes of the decomposed-income coefficients were somewhat unexpected: the largest coefficient was for income recoveries Y_{rec}.

Separate estimation of the lagged-adjustment coefficients resulted in the lagged-income coefficient being negative (results not shown). In a modified version of equation (6), income's lagged-adjustment coefficient was assumed to be zero and the lagged-adjustment coefficient was estimated only for price. There was evidence for asymmetric response to changes in both income and price: a Wald test allowed us to reject the hypotheses that the decomposed-income coefficients were equal; similarly for the decomposed-price coefficients. Of the three decomposed-price coefficients, only that for P_{max} was statistically significant. The estimated income-elasticity was 0.53. This equation (6) would be the preferred specification.

Note that for both energy and oil demand, the apparent income-elasticity for all Non-OECD countries grouped together is relatively small: only slightly greater than 0.5. This is no greater than that for the OECD countries. Such an estimated income elasticity is surprisingly small, especially with reference to Figure 1, where the time-paths for the 5 Asian countries move parallel to the equi-proportional growth lines, suggesting an income elasticity that is approximately 1.0.

However, these Non-OECD countries are extremely heterogeneous, as suggested in the scatterplots of Figure 4 above. Thus we shall cluster these countries into more homogeneous sub-groups, so that their differing behavior may be characterized more accurately. One natural group of Non-OECD countries are the Oil Exporters, who have abundant domestic resources of oil and gas, and whose prices for domestic consumption are often significantly below export prices. A second cluster of countries that we shall examine separately is what we call the Income Growers: those developing countries that have had average growth in per-capita income exceeding 2% annually. These countries are identified in Appendix A.

IV.3 Non-OECD Oil Exporters

Table 3. Non-OECD Oil Exporters' Results:

		Income coefficients				Oil Price coefficients				Lagged adj.coef.					
fuel	eq.	Y	Ymax	Ycut	Yrec	P	Pmax	Pcut	Prec	Income	Price	Long-run Income Elasticity	Long-run Price Elasticity	Adjusted R-sqared	Sum of Squared Residuals
energy	1	0.422										0.42		0.9208	48.359
energy	2	0.107								0.89		0.97		0.9928	4.400
energy	3	0.122				-0.020				0.89		1.11	-0.18	0.9928	4.378
energy	1a		1.67	0.11	0.74							1.67		0.9523	28.895
				reject equality											
energy	2a		0.10	0.14	0.36					0.87		0.82		0.9932	4.132
				reject equality											
oil	1	0.300										0.30		0.9647	14.948
oil	2	0.110								0.73		0.41		0.9873	5.274
oil	3	0.110				0.002				0.70		0.37	0.01	0.9872	5.374
oil	1a		0.97	0.09	0.14							0.97		0.9750	10.526
				reject equality											
oil	2a		0.31	0.08	0.11					0.66		0.91		0.9877	5.135
				reject equality											

Notes: See Table 1.

Oil Exporters: Energy Demand

In the simplest specification, equation (1), with just income but not lagged demand, the income elasticity is 0.42. When lagged demand is also included, equation (2), the income elasticity increases to 0.97. However, the lagged adjustment coefficient for income (0.89) seems implausibly high, implying that only 11% of the adjustment to changes in income would be accomplished in the first year.

With the standard Koyck-lag specification – equation (3) with both income and price -- the coefficients have the expected signs, although price is not significant. In fact, for all the equations examined, price is never statistically significant, whether standard price or decomposed price is used, or whether the income lag adjustment is estimated separately from the price lag coefficient. This should not be surprising for these countries, whose prices for domestic consumption are often significantly below export prices and little correlated with export prices.

If only decomposed income is used in the specification, equation (1a), then we see evidence of asymmetric response: the coefficient for increases in Y_{max} is much larger than for the other two coefficients; the coefficient for Y_{cut} is small and not statistically significant.

When lagged demand is also included with decomposed income, equation (2a), the income asymmetry result is blurred. The lagged coefficient is statistically significant, but the implied speed-of-adjustment for income changes is implausibly slow, at.13 (= 1-.87): that is, in the first year after the change in income, only 13% of the ultimate demand adjustment is accomplished. Moreover, the income coefficients have unexpected relative magnitudes: those for Y_{max} & Y_{cut} are similar in size but that for Y_{rec} is by far the largest.

Which would be the best specification for energy demand? In terms of Adjusted R^2 and SSR, the preferred specification would seem to be (2a), with decomposed income and lagged demand. However, two aspects of this specification are troubling: the high value for the lagged adjustment coefficient -- implying an implausibly slow speed of adjustment to changes in income -- and the surprising relative magnitudes of the coefficients for decomposed income. Hence none of the specifications yield results that are especially good.

Oil Exporters: Oil Demand

In the simplest specification with income only, equation (1), the income elasticity is surprisingly small, at 0.30. With income and lagged demand, equation (2), the long-run income elasticity is not much larger, at 0.41. If we also include price, equation (3), the results are no better. The price coefficient has the wrong sign, although it is not statistically significant. As with energy demand, the price coefficient is never statistically significant with the correct sign – whether standard price or decomposed price is used, or whether the lagged adjustment coefficient for price is estimated separately from that for income.

In a specification with only decomposed current income, equation (1a), the results are asymmetric; the coefficient for increases in Y_{max} is much larger (0.97) than the coefficients for Y_{cut} and Y_{rec}. A Wald test allows us to reject the hypothesis that the coefficients are equal.

If we decompose income and also include lagged demand in the equation, equation (2a) the results show asymmetric coefficients for income changes. A Wald test allows us to reject the hypothesis that the three income coefficients are equal. The long-run elasticity for increases in Y_{max} is 0.91.

Which is the best specification for oil demand? The preferred specification (as it was for energy demand) would be (2a), with decomposed income and lagged demand. However, the two problematic aspects of the *energy* equation (2a) are not relevant for the *oil* equation (2a): the value for the lagged adjustment coefficient is smaller and thus more plausible, and the relative magnitudes of the coefficients for decomposed income are closer to what might be expected.

It should be noted that the income elasticities in equations (2a) for energy and oil demand respectively are considerably higher than for the simpler specifications (1) or (2). This illustrates the importance of a specification that allows for asymmetric response to income increases and decreases. It provides support for our conjecture that ignoring the possibility of imperfectly income-reversible demand can cause an underestimate of the income elasticity.

IV.4 Non-OECD Income-Growers

Another group of Non-OECD countries whose experience has been fairly homogeneous is the group of countries that experienced steady growth in per-capita income over this period. In contrast to the many "developing" countries whose income growth was at best sporadic and often negative, there were 14 developing countries whose average annual growth in per-capita income has exceeded 2% (listed in order of their per-capita-income-growth rates) -- South Korea, Thailand, Malaysia, Tunisia, Syria, India, Sri Lanka, Egypt, Colombia, Israel, Singapore, Malta, Morocco, and Bangladesh. Two other developing countries, China and Indonesia, have also experienced this rate of income growth; China was excluded from this sub-group given its size and unique characteristics, and Indonesia was excluded because it is an Oil Exporting country.

Table 4. Non-OECD Income-Growers' Results:

fuel	eq.	Income coefficients Y	Ymax	Ycut	Yrec	Oil Price coefficients P	Pmax	Pcut	Prec	Lagged adj.coef. Income	Price	Long-run Income Elasticity	Long-run Price Elasticity	Adjusted R-sqared	Sum of Squared Residuals
energy	1	1.180										1.18		0.9883	6.2950
energy	2	0.228								0.82		1.23		0.9966	1.8410
energy	3	0.237				-0.029				0.80		1.17	-0.14	0.9967	1.7810
energy	3a		0.28	-0.05	0.24		-0.043	-0.016	-0.047	0.74		1.09	-0.17	0.9967	1.7240
				reject equality				cannot reject equality							
energy	6		1.078	-0.50	0.47	-0.023				0.00	0.72	1.08	-0.08	0.9964	1.8970
				reject equality											
oil	2	0.239								0.76		0.98		0.9970	2.1302
oil	3	0.226				-0.024				0.76		0.94	-0.10	0.9971	2.0666
oil	3a		0.34	0.14	0.29		-0.054	-0.011	-0.006	0.73		1.26	-0.20	0.9970	2.1617
				cannot reject equality				reject equality							
oil	6		0.95	0.04	0.29		-0.030	-0.003	0.019	0.00	0.75	0.95	-0.12	0.9970	2.1749
				reject equality				reject equality							

Notes: see Table 1.

Non-OECD Income-Growers: Energy Demand

In the specification with only income, equation (1), the income elasticity is 1.18. When lagged demand is also included, equation (2) the income elasticity is slightly higher, at 1.23. If the standard Koyck-lag specification that also includes price, equation (3), then price has the expected negative sign and the coefficient is statistically significant; the income elasticity is almost unchanged, at 1.17.

If the above specification is modified by using decomposed price and income, equation (3a), then we see evidence of asymmetric response for changes in income and, perhaps, for price. This equation's income elasticity, for increases in Y_{max}, is 1.09.

Separate estimation of the lagged income and price coefficients yielded a negative coefficient for lagged income adjustment, implying a speed of adjustment that is even faster than instantaneous (results not shown). Modifying that specification by assuming instantaneous income adjustment (that is, a zero lagged-adjustment coefficient for income) yields the most satisfactory results, in equation (6). There is asymmetric response to income changes; the income elasticity, for increases in Y_{max}, is 1.08. Thus income growth in the absence of energy price changes does not reduce energy intensity (energy/GDP ratio), and will increase it slightly.

Non-OECD Income-Growers: Oil Demand

For oil demand, almost regardless of the equation specification, the long-run income elasticity is about 1.0 – whether income is decomposed or not, whether price is included or not, whether price is decomposed or not, or whether the income lag coefficient is estimated separately or not. This result should not be surprising in view of Figure 1, which plots the 1971-97 time-paths of oil against income for several of these countries.

There is evidence of asymmetric price responsiveness – not previously found for this group of countries, indeed for any group of developing countries. There is also evidence of asymmetric income responsiveness.

Separate estimation of the lagged income and price coefficients yielded a negative coefficient for lagged income adjustment, implying a speed of adjustment that is even faster than instantaneous (results not shown). Modifying that specification by assuming instantaneous income adjustment (that is, a zero lagged-adjustment coefficient for income) yields the most satisfactory results, in equation (6).

Note the similarity to results for the OECD countries. Price is significant, although the price elasticities are lower than for the OECD; moreover, there is evidence of asymmetric response to price changes. Income elasticities are higher for these countries than for the OECD, which is not surprising given the relatively low levels of energy and oil demand from which these developing countries started in 1971. Finally, the speed of adjustment for income changes is considerably faster than the adjustment for price changes.

These estimates of the income elasticity are consistent with the estimates made for Asian countries by Pesaran *et al*. (1998) and Galli (1998); those Asian countries considerably overlap the above group of Income Grower countries. They are considerably higher than the income elasticities used by EIA in their *International Energy Outlook 2000* – about 0.65 for energy and oil demand in Developing Asia excluding China.

IV. 5 Non-OECD: Other Countries

The remaining Non-OECD countries – excluding the Oil Exporters and the Income Growers – were grouped together as the Other Countries. Within this remaining group there is, of course, substantial heterogeneity. But we did not attempt to identify any homogeneous clusters within this group.

Table 5. Non-OECD Other Countries' Results:

		Income coefficients				Oil Price coefficients				Lagged adj.coef.					
fuel	eq.	Y	Ymax	Ycut	Yrec	P	Pmax	Pcut	Prec	Income	Price	Long-run Income Elasticity	Long-run Price Elasticity	Adjusted R-sqared	Sum of Squared Residuals
energy	2	0.201								0.77		0.87		0.9925	14.254
energy	3	0.214				-0.026				0.77		0.93	-0.11	0.9926	14.097
energy	4	0.501				-0.018				0.00	0.81	0.50	-0.09	0.9926	13.962
energy	6		0.71	0.46	0.44	-0.019				0.00	0.80	0.71	-0.09	0.9926	13.920
			cannot reject equality												
oil	2	0.142								0.84		0.90		0.9915	13.861
oil	3	0.153				-0.035				0.85		1.02	-0.23	0.9917	13.572
oil	4	0.489				-0.029				0.00	0.87	0.49	-0.22	0.9919	13.123
oil	6		0.237	0.697	0.159		-0.035	-0.010	0.043	0.00	0.86	0.24	-0.25	0.9920	12.900
			reject equality				reject equality								

Notes: see Table 1.

Other Countries: Energy Demand

In the simplest specification, with income and lagged demand (equation 2), the income elasticity is 0.87. If price is also included, equation (3), the price coefficient has the expected sign and is statistically significant; the income elasticity is increased somewhat, to 0.93.

If separate lagged-adjustment coefficients are estimated for price and income, that for income is negative (results are not shown). With an alternative specification in which income's lagged-adjustment coefficient is assumed to be zero, equation (4), we get good results. All coefficients have the expected signs and are statistically significant. The income elasticity is relatively low, at 0.5.

If instead we use decomposed income, equation (6), the results are similar and there is evidence of asymmetric response to income changes. However, a Wald test does not allow us to reject the hypothesis that the decomposed-income coefficients are equal. Hence our preferred specification would be equation (4).

Other Countries: Oil Demand

For these countries' oil demand the results are generally similar to those for energy demand. The resulting income elasticities are similarly low – especially in comparison with those for the Income-Growers group of countries.

With income and lagged demand, equation (2), the income elasticity is 0.9. If we also include price, as in equation (3), all the coefficients have the expected signs and are statistically significant; income elasticity is about 1.

When the lagged-adjustment coefficients are estimated separately for income and price, the former is negative (results are not shown). If instead that lagged-adjustment coefficient for income is assumed to be zero, the resulting specification (4) provides useful results: all coefficients have the expected signs and are statistically significant.

Using a similar specification but using decomposed income and price, equation (6), yields the most interesting results, with evidence of asymmetric response for both income and price. The income asymmetry is unusual, although consistent with other evidence for these countries: the greatest demand response is to income declines[13]. The price asymmetry is more conventional: the greatest demand response is to increases in P_{max}, with the coefficients for P_{cut} and P_{rec} not being statistically significant.

For both energy and oil, these Other Countries' income elasticity – 0.5 or less -- is much lower than those for the two other sub-groups of the Non-OECD. For many of these countries, modern commercial fuels – especially oil – must be imported. Due to economic difficulties within these countries (as evident in the slow and uneven growth in income) and their common practice of extensive import controls and restrictions on foreign exchange use, the very slow growth of energy and oil demand may not truly measure the long-run income elasticity, but rather reflect their governments' decisions to limit imports of oil and energy. Such a conjecture might also explain these countries' unusual income-asymmetry for oil demand: oil demand falls much more when income declines than it increases when income rises. Such income decreases were common in these countries, and were likely accompanied by decreases in export earnings, which could have prompted import controls by the government that would have impacted disproportionately on oil consumption restrictions rather than consumer behavior.

IV. 6 Summary of Results for Long-run Income Elasticity of Energy & Oil Demand

Having described the details of the econometric results for a large number of alternative functional specifications of demand equations for energy and oil for several different groups of countries, let us now focus on the preferred specification for each. These are listed in Table 6. The elasticities for income and price, as well as other important aspects of these preferred equations are presented in Table 7.

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[13] Earlier work, in Dargay-Gately(1995, Figure 19), has suggested this possibility: that declining-income countries cut back on oil consumption most dramatically – especially for non-transportation uses, which on average constitute two-thirds of total oil demand.

Table 6. Preferred Demand Specifications for Each Region

			Income coefficients				Oil Price coefficients				Lagged adj.coef.					
region	fuel	eq.	Y	Ymax	Ycut	Yrec	P	Pmax	Pcut	Prec	Income	Price	Long-run Income Elasticity	Long-run Price Elasticity	Adjusted R-sqared	Sum of Squared Residuals
OECD	energy	6	0.588					-0.025	-0.014	-0.015	0.00	0.90	0.59	-0.24	0.9967	0.7959
									reject equality							
OECD	oil	6	0.528					-0.075	-0.038	-0.048	0.06	0.88	0.56	-0.64	0.9916	1.2230
									reject equality							
Non-OECD	energy	4	0.444				-0.019				0.00	0.88	0.44	-0.16	0.9943	20.5420
Non-OECD	oil	6		0.530	0.455	0.068		-0.028	-0.008	0.037	0.00	0.84	0.53	-0.18	0.9935	21.248
					reject equality				reject equality							
Oil	energy	1a		1.67	0.11	0.74							1.67		0.9523	28.895
Exporters					reject equality											
Oil	oil	2a		0.31	0.08	0.11					0.66		0.91		0.9877	5.135
Exporters					reject equality											
Income	energy	6		1.078	-0.50	0.47	-0.023				0.00	0.72	1.08	-0.08	0.9964	1.8970
Growers					reject equality											
Income	oil	6		0.95	0.04	0.29		-0.030	-0.003	0.019	0.00	0.75	0.95	-0.12	0.9970	2.1749
Growers					reject equality				reject equality							
Others	energy	4	0.501				-0.018				0.00	0.81	0.50	-0.09	0.9926	13.962
Others	oil	6		0.237	0.697	0.159		-0.035	-0.010	0.043	0.00	0.86	0.24	-0.25	0.9920	12.900
					reject equality				reject equality							

Notes: see Table 1.

Table 7. Estimated Long-Run Elasticities for Energy and Oil Demand

Country Groups	Fuel	Elasticities:		Important Phenomena
		Income	Price	
OECD	Energy	0.59	-0.24	asymmetric response for price
OECD	Oil	0.55	-0.60	asymmetric response for price
All Non-OECD	Energy	0.44	-.01 to -0.16	asymmetric response for price, perhaps
All Non-OECD	Oil	0.53	-0.18	asymmetric response for both price & income
Non-OECD Oil Exporters	Energy	.82 to 1.0	-	oil price not significant; asymmetric response for income
Non-OECD Oil Exporters	Oil	0.91	-	oil price not significant; asymmetric response for income
Non-OECD Income-Growers	Energy	1.08	-0.08	asymmetric response for income & perhaps price
Non-OECD Income-Growers	Oil	0.95	-0.12	asymmetric response for both price & income
Non-OECD: Other Countries	Energy	.5 to .7	-0.09	apparently symmetric response for price & income
Non-OECD: Other Countries	Oil	0.24	-0.25	asymmetric response for both price & income; largest response to income declines

For all regional groupings, for both energy and oil (except for Other Countries' energy), the preferred specification involves asymmetric demand response to changes in price and/or income. This is an important result, insofar as few articles in the literature – other than those cited above – allow for this possibility that the demand response to price (or income) increases and decreases might be asymmetric. Yet we have shown that such asymmetry exists in the historical data: Wald tests on the decomposed price (or income) coefficients have allowed us to reject the null hypothesis that the coefficients are equal. Moreover, not only does such asymmetry exist, but ignoring it will bias the estimated elasticities not only for that variable but also for other variables. For example, wrongly specifying the demand equation as perfectly price-reversible will bias downward the estimated income elasticity; this result for the OECD countries has appeared previously (Gately, 1993) but it is worth repeating.

It is also important to model correctly the different speeds of demand adjustment to changes in price and changes in income: demand adjusts faster to income changes than to price changes.

For the OECD, income elasticity is 0.59 for energy and 0.56 for oil – when demand is properly specified as imperfectly price-reversible, and the lagged demand adjustment coefficients are estimated separately for price and income. Failure to allow for imperfect price-reversibility will bias downward the estimated income-elasticity.

For the Non-OECD Oil Exporters, asymmetric income responsiveness is an important phenomenon: income declines have not reversed the demand growth that resulted from income increases. When taken into account, the long-run elasticity with respect to increases in Y_{max} is about 0.9 for oil and 1.67 for energy. Oil price, however, is never a statistically significant variable in their demand equations.

For the Non-OECD Income Growers, the econometric results provide evidence of asymmetric response to price increases and decreases, and also to income increases and decreases. With correctly specified equations, the income elasticity is 0.95 for oil demand and 1.08 for energy demand.

For Other Non-OECD Countries, the remaining heterogeneous group, the preferred specifications suggest that the income elasticity of demand for energy and oil are quite low: 0.5 or smaller. However, such estimates might be too low, and could reflect the import controls imposed by these countries that limit imports of oil and other modern fuels when the growth of income is slow and uneven.

V. Conclusions

Future economic growth will have important implications for energy demand and its effect on energy prices as well as on key global emissions levels for carbon dioxide and other pollutants. The estimated income elasticity is particularly important for understanding long-run energy demand and environmental emissions projections. However, this parameter is relatively sensitive to the assumed functional relationships between energy use and prices and income.

The results of our analysis suggest that income elasticities of energy and oil demand are higher than those resulting from several other recent analyses, and higher than those used by the US Department of Energy's Energy Information Administration in their projections of energy and oil demand.[14] For the OECD countries' energy and oil demand we estimate that the long-run elasticity for income increases is about 0.55. For the Non-OECD countries we estimate that this elasticity is 1.0 or higher. As a result, projected future world energy and oil demands and carbon-dioxide emissions levels would be substantially higher, based upon our income-elasticity estimates than upon those of EIA and some other authors.

[14] Income elasticities that are significantly higher than those of EIA – and closer to those that we estimate – are used in the International Energy Agency's *World Energy Outlook 2000*.

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Appendix A: List of Countries and Abbreviations

OECD

AUS	Australia
AUT	Austria
BEL	Belgium
CAN	Canada
CHE	Switzerland
DNK	Denmark
ESP	Spain
FIN	Finland
FRA	France
GBR	United Kingdom
GRC	Greece
IRL	Ireland
ISL	Iceland
ITA	Italy
JPN	Japan
LUX	Luxembourg
MEX	Mexico
NLD	Netherlands
NOR	Norway
NZL	New Zealand
PRT	Portugal
SWE	Sweden
TUR	Turkey
USA	United States

Oil Exporters

ARE	United Arab Emirates
BHR	Bahrain
DZA	Algeria
ECU	Ecuador
GAB	Gabon
IDN	Indonesia
IRN	Iran, Islamic Rep.
IRQ	Iraq
KWT	Kuwait
NGA	Nigeria
OMN	Oman
QAT	Qatar
SAU	Saudi Arabia
VEN	Venezuela

Income Growers

BGD	Bangladesh
COL	Colombia
EGY	Egypt, Arab Rep.
IND	India
ISR	Israel
KOR	Korea, Rep.
LKA	Sri Lanka
MAR	Morocco
MLT	Malta
MYS	Malaysia
SGP	Singapore
SYR	Syrian Arab Republic
THA	Thailand
TUN	Tunisia

Other Countries

AGO	Angola
ARG	Argentina
BEN	Benin
BGR	Bulgaria
BOL	Bolivia
BRA	Brazil
CHL	Chile
CIV	Cote d'Ivoire
CMR	Cameroon
COG	Congo, Rep.
CRI	Costa Rica
CYP	Cyprus
DOM	Dominican Republic
ECU	Ecuador
ETH	Ethiopia
GHA	Ghana
GTM	Guatemala
HND	Honduras
HTI	Haiti
HUN	Hungary
JAM	Jamaica
JOR	Jordan
KEN	Kenya
MMR	Myanmar
MOZ	Mozambique
NIC	Nicaragua
PAK	Pakistan
PAN	Panama
PER	Peru
PHL	Philippines
POL	Poland
PRY	Paraguay
ROM	Romania
SDN	Sudan
SEN	Senegal
SLV	El Salvador
TTO	Trinidad and Tobago
TZA	Tanzania
URY	Uruguay
YEM	Yemen, Rep.
ZAF	South Africa
ZAR	Congo, Dem. Rep.
ZMB	Zambia
ZWE	Zimbabwe

HH: What I find interesting is that the first four equations look very similar to the previous results, tempting one to conclude that it doesn't make much difference. However, once you differentiate the lagged adjustments (e-f) it does make a difference. Schmalensee and the others ran them as a big group and did not worry about dynamic adjustments so maybe their approach is not so bad, unless you think that it is important to get the adjustments right. Pretty interesting story!

Comments inserted in Non-OECD Income Growers, Energy: next to last paragraph.

In contrast with the Table 2 results for all Non-OECD countries, notice the effect of replacing a joint adjustment for price and income with an adjustment only for price, i.e., shifting from equation 3a to 6. For the Income Growers, the income elasticity barely changes, from 1.09 to 1.08. Contrast this experience with that for all non-OECD countries above. The income elasticity for that group falls from 1.02 to 0.52 in replacing equation 3 with equation 6. In other words, when demand is specified to adjust at the same speed to changes in both price and income, the results from all Non-OECD look similar to those from the Income Growers and you would be tempted not to disaggregate the non-OECD countries. However, when you correctly note that income adjusts more quickly than price for both groups, you see that the Income Growers are a very different group than the other countries.

[DG: I didn't see this point, so I remade it (hopefully, increased its clarity) in the second paragraph under all non-OECD countries. What is interesting is that if you estimate equation (3)—same adjustment lag on price and income--across all the different non-OECD groups, you have pretty similar income elasticities. If you did not test for different adjustment lags on price and income, you would incorrectly conclude that disaggregation does not improve your estimates.}

Question for Hill:
Did SSJ or HES have results for the LDC that had relatively low income elasticities?

The SSJ estimates for energy's income elasticity ranged from –0.13 to 1.18 for the income group excluding the richest one. Their carbon income elasticity ranged from –0.28 to 1.29. Their high estimate appears comparable to what we estimate for fast growers. However, I don't think that we can say that they definitely understate it for the non-OECD.

Although not reported, the income elasticity for carbon emissions in HES reaches its maximum at the lowest income group and declines thereafter (since they use income and income squared). When the HES estimated coefficients for the effect of income and income-squared are applied to the income levels in SSJ's lowest income group, the inferred income elasticity is 0.57. This seems relatively low relative to our results.

TO BE DONE:
1. Hill: do we want to have a graph that shows asymmetric price response (like Fig.11 or 13 in Dargay-Gately AREE 1995 paper?, or Fig.5 & 6 in Dargay-Gately Energy Economics 1995 paper) . Similarly for asymmetric income responsiveness? ? {Let's add the graphs if they help the explanation. Otherwise we can refer people to earlier papers.}

b
IEA: WEO 2000:
Price assumptions p.40, Fig.1.4: flat real prices until 2010 then slowly increasing prices for oil & gas until 2020 with flat coal price.
If we compare En/Y ratios for '97-2010, IEA projections are pretty close to ours. If instead, '97-2020 is used (with gradual price increases for 2010-20 for gas & oil), then IEA has lower ratios.

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