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# THE RESPONSE OF WORLD ENERGY AND OIL DEMAND TO INCOME GROWTH AND CHANGES IN OIL PRICES

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**Abstract**

This paper reviews the paths of world energy and oil demand over the past three decades, both over time and relative to income growth. We focus on the effects of oil price changes on demand, not only the oil price increases of the 1970's but also the oil price decreases of the 1980's.

Compared with demand in the industrialized countries (OECD), demand in the Less Developed Countries (LDC) has been more responsive to income growth, less responsive to price increases, but more responsive to price decreases. In the industrialized countries there has been an asymmetric, smaller demand response to the price decreases of the 1980's than to the price increases of the 1970's. But in the LDC there is less evidence of demand being imperfectly price-reversible: the price reductions of the 1980's have reversed much more of the demand reductions that followed the price increases of the 1970's, in comparison with the OECD.

Transportation oil has grown consistently, in all regions of the world, about as rapidly as income growth, and it is less price-responsive than non-transportation oil demand.

The LDC has exhibited much greater heterogeneity than the OECD, both in income growth and in the relationship of demand growth to income growth. This is true not only between the oil exporting countries and the others, but also between those LDC whose per-capita incomes have been growing steadily and those whose incomes have declined or been stagnant. It is important to analyze the behavior of these groups separately. Otherwise, the aggregation will distort the effects on demand of the price changes and income growth.

We expect a smaller demand response to future price increases than to those of the 1970's. The demand response to future income growth will be not substantially smaller than in the past. Finally, given the prospect of growing dependence on OPEC oil, in the event of a major disruption the lessened responsiveness of demand to price increases could cause dramatic price increases and serious macroeconomic effects.

**Introduction**

In this article we review the past three decades experience with respect to energy and oil demand, with a focus on three main regions: the industrialized countries of the OECD (Organization for Economic Cooperation and Development: North America, Western Europe, Japan, Australia & New Zealand); the Oil Exporters (OPEC & Mexico); and the Other LDC (Less Developed Countries), excluding China unless specifically included. In addition to an examination of the historical determinants of total energy demand, we also examine the determinants of total oil demand and its two main components: transportation oil and non-transportation oil. This disaggregation of total oil is important because the two have moved differently over time, especially within the OECD.

Also for purposes of improving our understanding of the determinants of demand among the non-OECD countries, we examine the heterogeneity among the 61 LDC for which we have good data. This heterogeneity is most apparent in their growth rates of per-capita income, and in the relationship between demand growth and income growth. In particular, we examine separately three sub-groups of the Other LDC, based on their average annual growth rate of per-capita income from 1970-91:

Other LDC: Growing Income -- those with positive and steady growth in per-capita income;

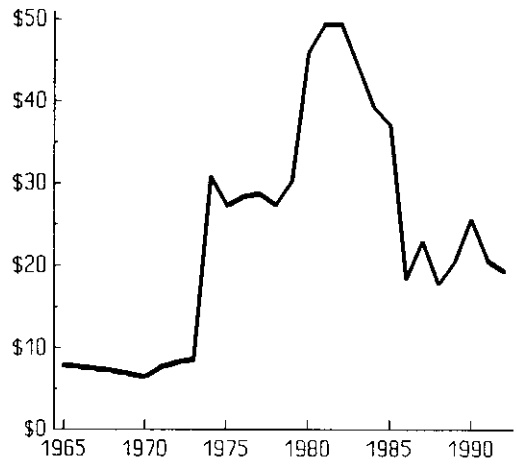
Other LDC: Declining Income -- those with negative growth in per-capita income;

Other LDC: Slow & Uneven Income Growth -- those with relatively sluggish and variable growth.

These three sub-groups have approximately fifteen countries each, as do the LDC Oil Exporters; the countries are identified below.

In addition to examining the effects of income growth on demand in the OECD and the various LDC regions, we also examine the effects on demand of the dramatic changes in world oil prices: the two major price increases of the 1970's and the almost equivalent price decreases of the 1980's. See Figure 1. We shall see that -- at least for the OECD -- the demand effects of the price decreases have not been symmetric with those of the price increases. That is, the demand reductions caused by the price increases of the 1970's have not been reversed by the price cuts of the 1980's.

**Figure 1** Real Price of Crude Oil, 1965-92
1992 $/barrel (Source: BP)



We also address a related issue: whether -- in the event of an oil price increase, either by OPEC or by increased domestic oil taxes -- we can expect as great a demand reduction as we experienced after previous price increases. Although the evidence is less clear on this issue, we believe that the answer to this question is also negative, at least for the OECD. That is, the demand response to future price recoveries will be smaller than the historical response to the price increases of the 1970's.

Up until recently, the majority of energy demand studies[1] had been based on "perfectly price-reversible" models, so that questions such as the two posed above could not be analyzed empirically. Despite the inability of these traditional models to explain the sluggish growth in demand following the oil price collapse in 1986, some analysts, most notably Hogan (1993), have been reluctant to abandon the conventional demand specification. However, as we have shown elsewhere, e.g. Dargay-Gately (1994b), the assumption of perfect price-reversibility must be rejected, for OECD non-transportation oil demand especially.

In order to provide an overview of the data, we first present some summary graphs. Shown in Figure 2 are the per-capita values for energy and oil demand in each of our three main regions. Shown in Figure 3 are population, total income, and per-capita income. The vertical scales in each graph are logarithmic, so that the slope of the curves indicate the percentage rate of growth: steeper curves have higher rates of growth.

There are two major differences between the OECD on the one hand and the Oil Exporters and Other LDC on the other:

1) the *level* of OECD demand per-capita is several times higher than for the other two groups: 4 to 5 times higher for energy, and 3 to 6 times higher for oil.
2) the *rate of change* in the OECD: per-capita energy demand has been relatively flat, and it has declined for oil, especially after the two price increases of the 1970's -- declines which were not reversed by the price cuts of the 1980's. In contrast, per-capita energy demand in the other two groups has grown during these years. Likewise, per-capita oil demand has also grown, despite being roughly constant in the early 1980's, following the 1979-80 price increase.

[1] For good examples of earlier work on energy and oil demand, see Griffin(1979), Pindyck(1979), and Hogan(1986).

Figure 2. Per-capita Energy and Oil Demand, 1970-90 (Tons of Oil Equivalent per person per year)

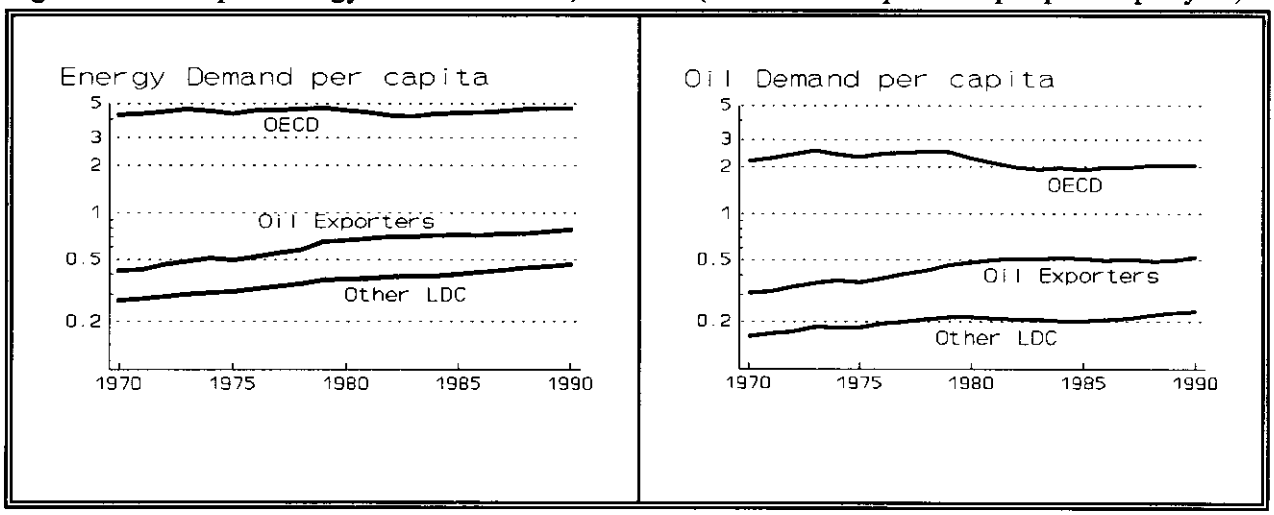
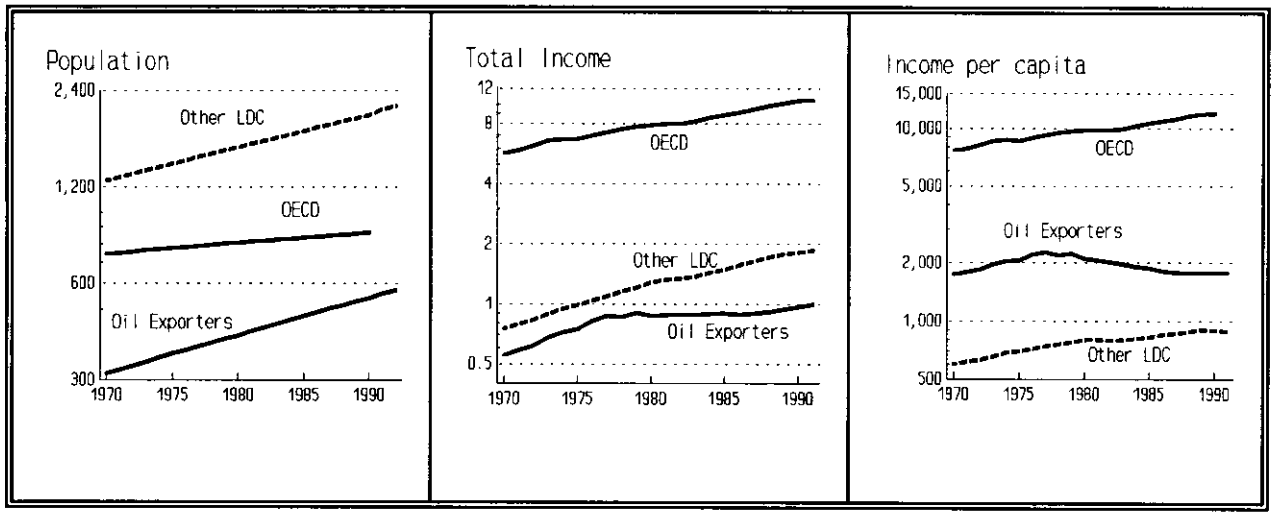



Figure 3. Population (millions), Total Income (Trillions 1980$) and Per-capita Income (1980$), 1970-91



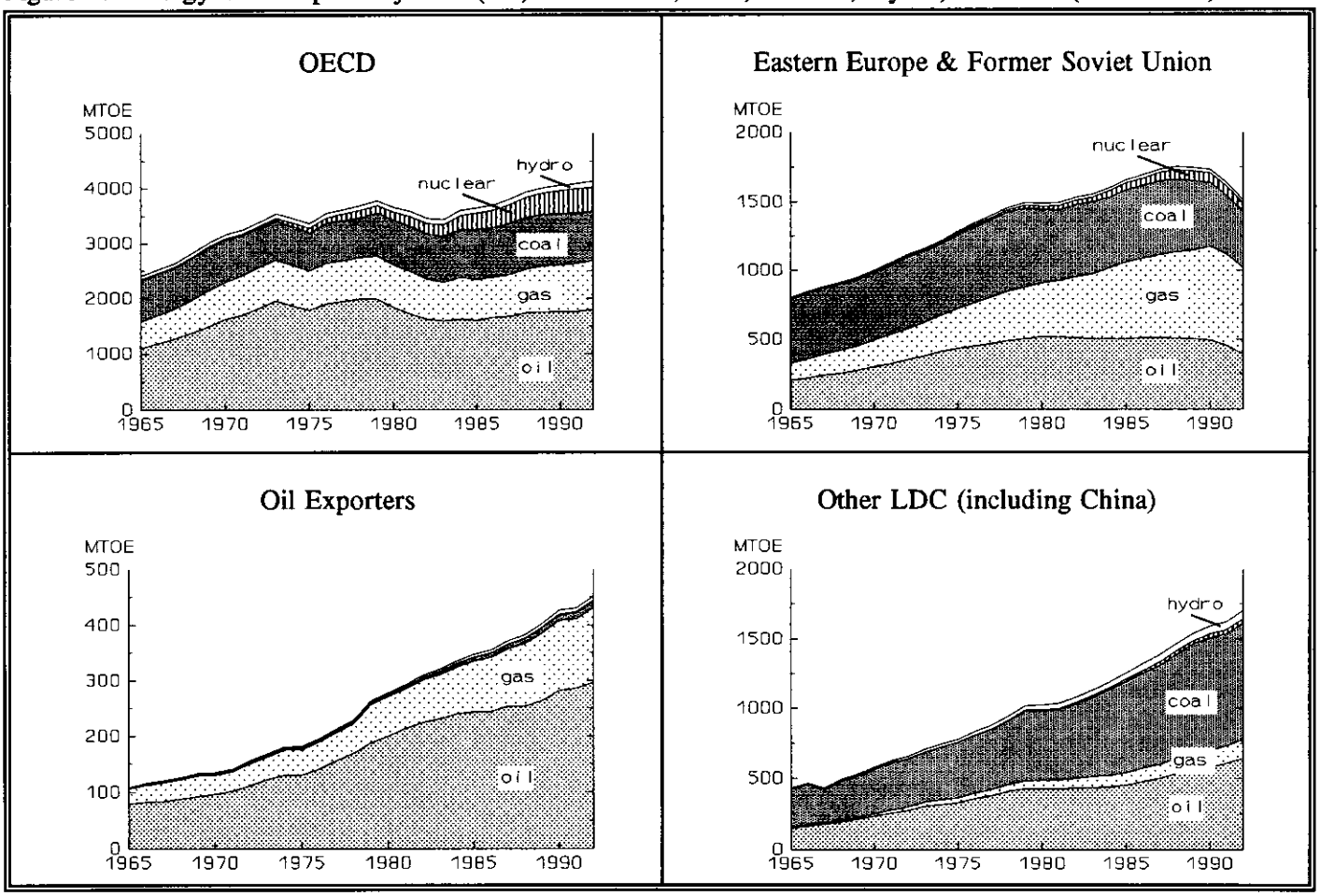
## 1. Energy and Oil Demand since 1965: by region, by fuel, by sector

### 1.1 Energy Demand

Figure 4 summarizes the recent history of energy consumption, from 1965-92, disaggregated by fuel: oil, natural gas, coal, nuclear, hydro. Four regions are shown separately: in addition to the three mentioned above, we also show Eastern Europe and the Former Soviet Union. Several observations can be made:

1. *Total energy* demand has been relatively flat since 1973 in the OECD, but it has continued to grow in the other regions. Total energy demand grew similarly in all regions from 1965 to 1973, at an average annual rate greater than 2%. But during the high-price era from 1973 to 1985, demand remained flat in the OECD and to a lesser extent in Eastern Europe and the Former Soviet Union; but it continued to grow as rapidly as before in the other regions. Since the 1986 oil-price collapse, energy demand has begun to grow again in the OECD, but at a rate half the pre-1973 growth rate. In Eastern Europe and the Former Soviet Union, however, it flattened out and declined in the late 1980's, a time of both political and economic transition.
2. Similarly for *total oil* demand: since 1973 it has been relatively flat in the OECD, and in Eastern Europe and the Former Soviet Union. But it has been increasing in the other regions. The renewed growth in energy demand since the mid 1980's in the OECD was not accompanied by a comparable growth in oil demand. Even in the LDC regions, oil demand grew less rapidly than total energy demand.
3. Oil's share of total energy is higher in the OECD than in other regions, except for the Oil Exporters. However, there is a large variation in oil dependency within the Other LDC, but this is hidden in the aggregate figures. The Other LDC's low oil share is primarily a reflection of its two largest economies, China and India, which are also large coal producers. They constitute half of the total energy consumption in the Other LDC region. Eluding these two countries, the oil share of total energy for the rest of the LDC's is 55% in 1993, which is significantly higher than the 43% share in the OECD. The shares for China and India are 20% and 31% respectively.
4. Oil's share of total energy demand has declined in most regions: world-wide from 50% in 1973 to 40% in 1993. Although the OECD is responsible for the larger part of this reduction, almost all countries have reduced their oil dependency.

Figure 4. Energy Consumption by Fuel (Oil, Natural Gas, Coal, Nuclear, Hydro): 1965-92 (Source: BP)



In Figures 5 and 6 we show energy use, disaggregated by fuel, in two of the most important energy-using sectors[2]: in electric power (Figure 5) and in industrial uses (Figure 6).

In each of these two sectors, substitution away from oil is easier than in most other sectors of the economy -- especially compared with transportation, where fuel substitution away from oil is most difficult. In electric power generation, several points should be noted regarding Figure 5:

1. There has been growing demand for electric power in all regions.
2. Oil use in electric power generation declined sharply in the OECD after the 1979-80 price increase, and this decline was not reversed by the oil price declines of the 1980's.
3. In the non-OECD regions, oil use in electric power generation has been flat since the early 1980's, and oil's fuel-share declining. This demand reduction has not been reversed by the price cuts of the 1980's, except in a few countries such as South Korea (to be discussed below).
4. Growth has come from coal in all regions except the Oil Exporters, nuclear in the OECD and a few LDC (Taiwan, South Korea), and some expansion of natural gas in virtually all regions.

[2] The country-coverage for the Oil Exporters and Other LDC does not correspond exactly to that shown in Figure 4. Figures 5 and 6 cover about sixty of those non-OECD countries whose data is provided by the IEA; fortunately, these include the largest and most important. The IEA data is more detailed for specific countries, but it is not as comprehensive geographically as the BP data in Figure 4.

Figure 5. Energy Sources for Electric Power, 1971-91:

Oil, Natural Gas, Coal, Nuclear, Hydro (Source: IEA)

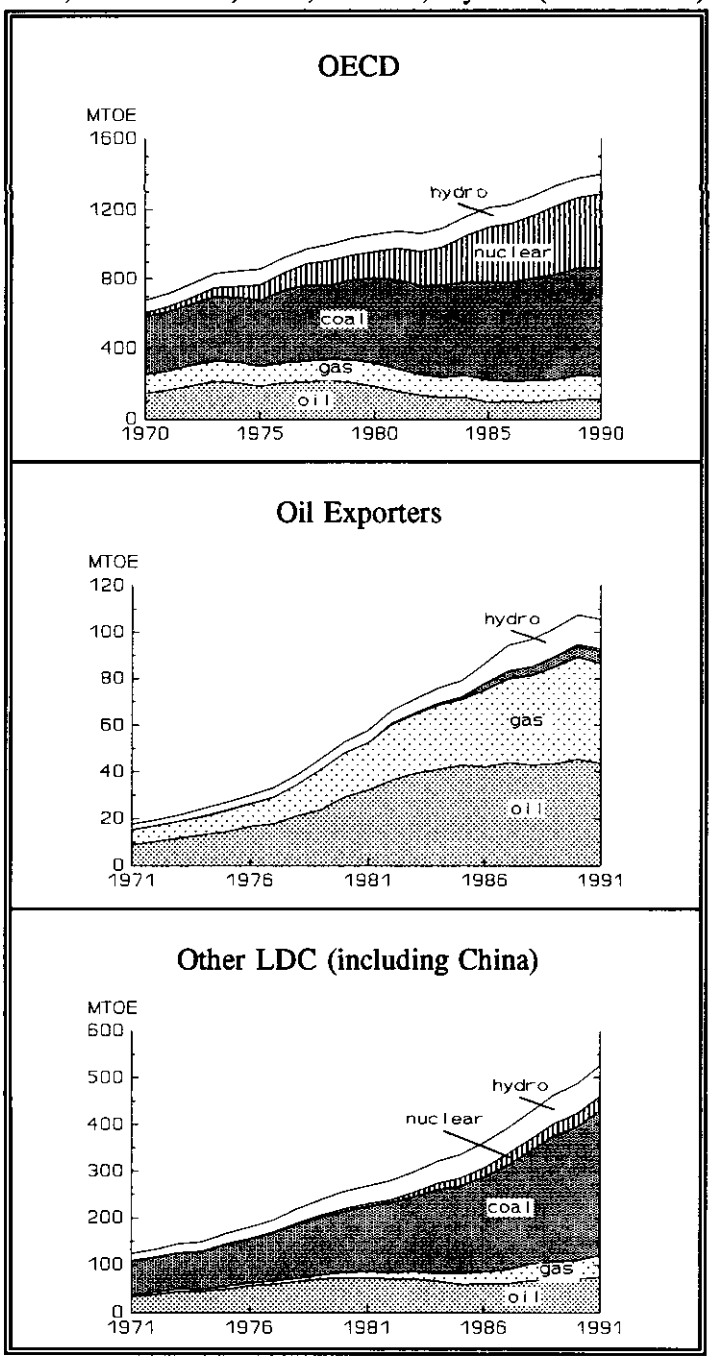
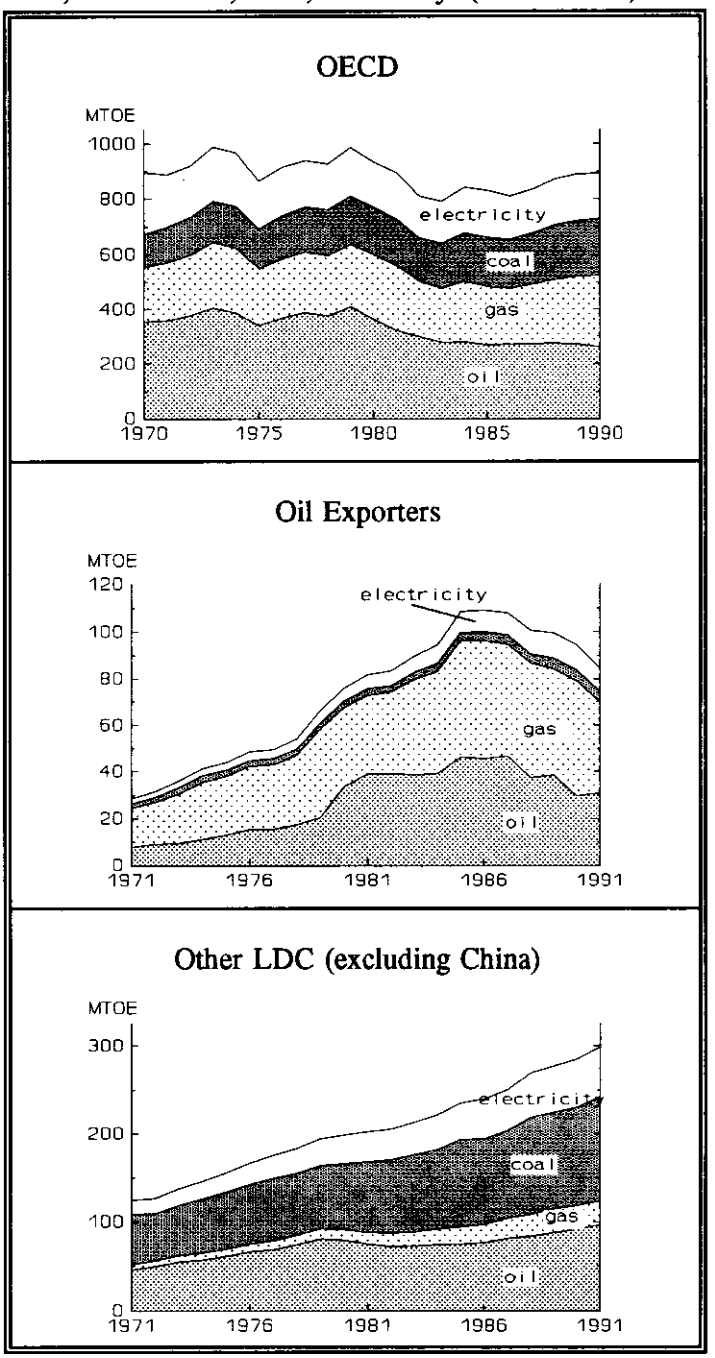


Figure 6. Energy Sources for the Industrial Sector, 1971-91:
Oil, Natural Gas, Coal, Electricity (Source: IEA)



Although sharing some similarities, energy use in the industrial sector[3] is somewhat different from that in electric power generation.

1. Total *energy* use in the industrial sector has actually fallen in the OECD since the early 1970's, but has continued to rise in the Other LDC. Growth has been most rapid in those parts of the Other LDC that have had the most growth in both income and industrial production -- primarily Asia. For the Oil Exporters, industrial energy consumption grew rapidly until the mid-1980's but has declined since then.
2. Industrial use of *oil* has been relatively flat in most regions. In the OECD there were substantial declines in oil use in response to the price increases, which were not reversed by the oil price decreases. Since the 1986 oil price collapse, only in the Pacific Rim has there been a substantial increase in industrial use of oil, primarily in South Korea.
3. Industrial use of oil has been reduced through overall energy conservation and some fuel-switching to natural gas. Oil's share of industrial energy use has declined since the early 1970's in all regions. In both the OECD and the Other LDC, oil's share was reduced from 40% to 30% (approximately). But there is significant variation within the Other LDC. In India (and also in China, which is not shown in Figure 6), coal predominates in the industrial sector, and oil's share is only 15%. On the other hand, in the Pacific Rim, oil is still the dominant energy source in industry, accounting for nearly 55% of total consumption.

The difference between the OECD and LDC in growth in industrial energy consumption over the past two decades is the result of several factors. Firstly, the rate of growth of industrial production has been much lower in the OECD than in the LDC. During the 1970's and 1980's, OECD industrial production rose by an average annual rate just above 1%. By contrast, in the fastest growing economies of the Pacific Rim, industrial production rose by more than 8% annually. The low growth in OECD industrial production partially reflects the slowing of aggregate economic growth experienced during this period. But it was also due to structural changes; industrial production grew less rapidly than many other sectors of the economy.

The second explanation lies in changes in industrial energy intensity: the ratio of industrial energy use to industrial output. During the last two decades, this ratio has been reduced by nearly 50% in the OECD. Although many LDC countries have also experienced substantial improvements, for example South Korea, others have shown only minor reductions.

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[3] Energy use in the residential and in the commercial sectors (not shown) has followed patterns similar to those of the industrial sector.

The decline in industrial energy intensity in the OECD is due partly to energy efficiency improvements in all industries and partly to a structural shift away from energy-intensive products such as iron and steel to less energy-intensive, higher technology products. On an aggregate level, it is difficult to decompose the decline into efficiency and structural components, and to determine the impact of energy prices on either component, relative to the effects of autonomous technological change. The best work addressing these issues is contained in Schipper and Meyers (1992).

### 1.2 Oil Demand

To understand the determinants of oil demand, it is important to distinguish (at least) between oil's two main uses: transportation oil demand and non-transportation oil demand. Fuel substitution away from oil is far easier in most non-transportation uses: in space heating, in water heating, and as inputs for industrial processes and electric power generation. This disaggregation is shown in Figure 7.

Transportation oil use has continued to grow, in all regions. On the other hand, at least in the OECD, non-transportation oil demand has declined over the past two decades, especially after the 1979-80 price increase. But in the LDC, non-transportation oil demand has continued to grow, although at a slower rate than transportation oil.

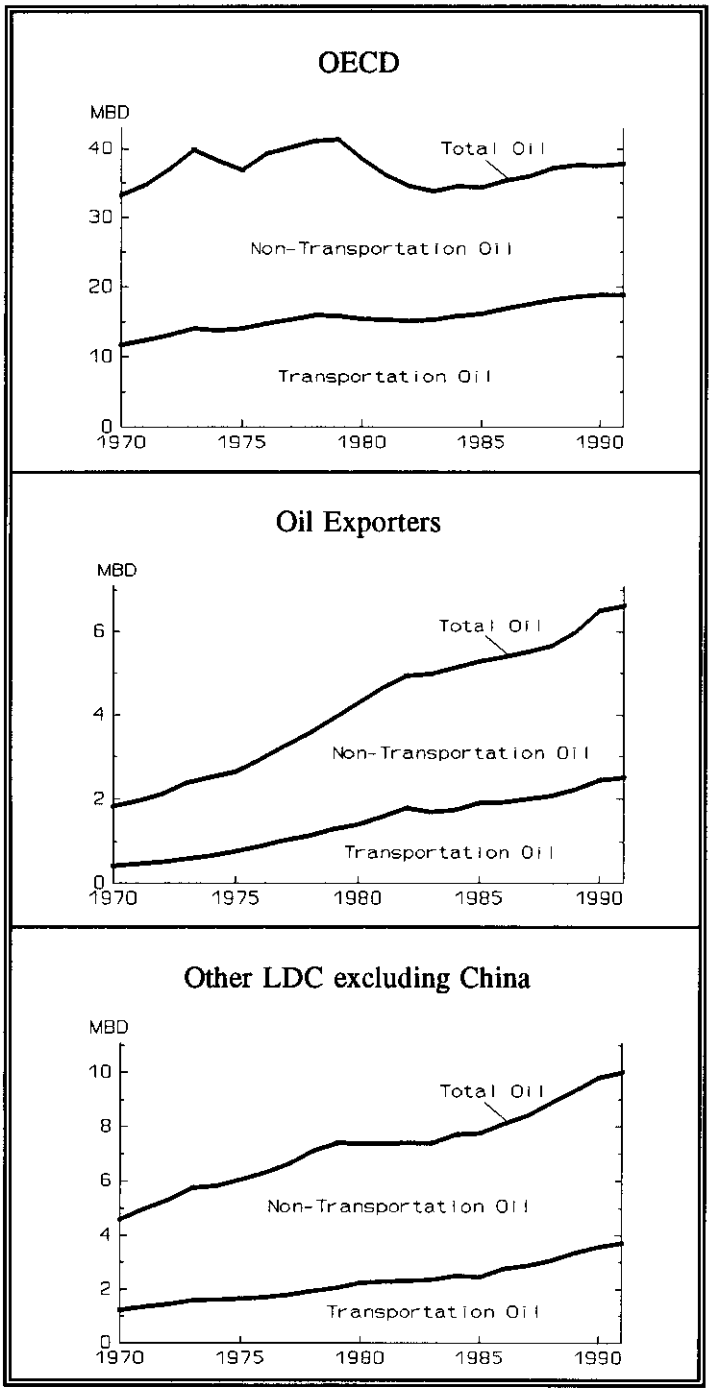
Transportation oil's share of total oil demand is higher in the OECD than in the other regions, and it has now grown to equal the share of non-transportation oil. It has also increased in the LDC -- both in the Oil Exporters and the Other LDC -- from about 25% in 1970 to nearly 40% by 1991.

With respect to non-transportation oil demand, in the OECD it has declined over the past two decades, especially since the 1979-80 price increase. But in the Other LDC and the Oil Exporters, it has continued to grow, at about the same rate as transportation oil demand.

Thus, since 1970, *total* oil demand has increased significantly in all regions except the OECD: quadrupling within the Oil Exporters, and doubling in the Other LDC. Within the OECD, the decline in non-transportation oil has been almost matched by the continued growth of transportation oil demand, so that by 1991 total oil demand was close to its 1973 level.

Figure 7. Oil Consumption, 1970-91:

Transportation Oil & Non-Transportation Oil (Source: DOE)



## 2. Demand and the Effects of Income Growth

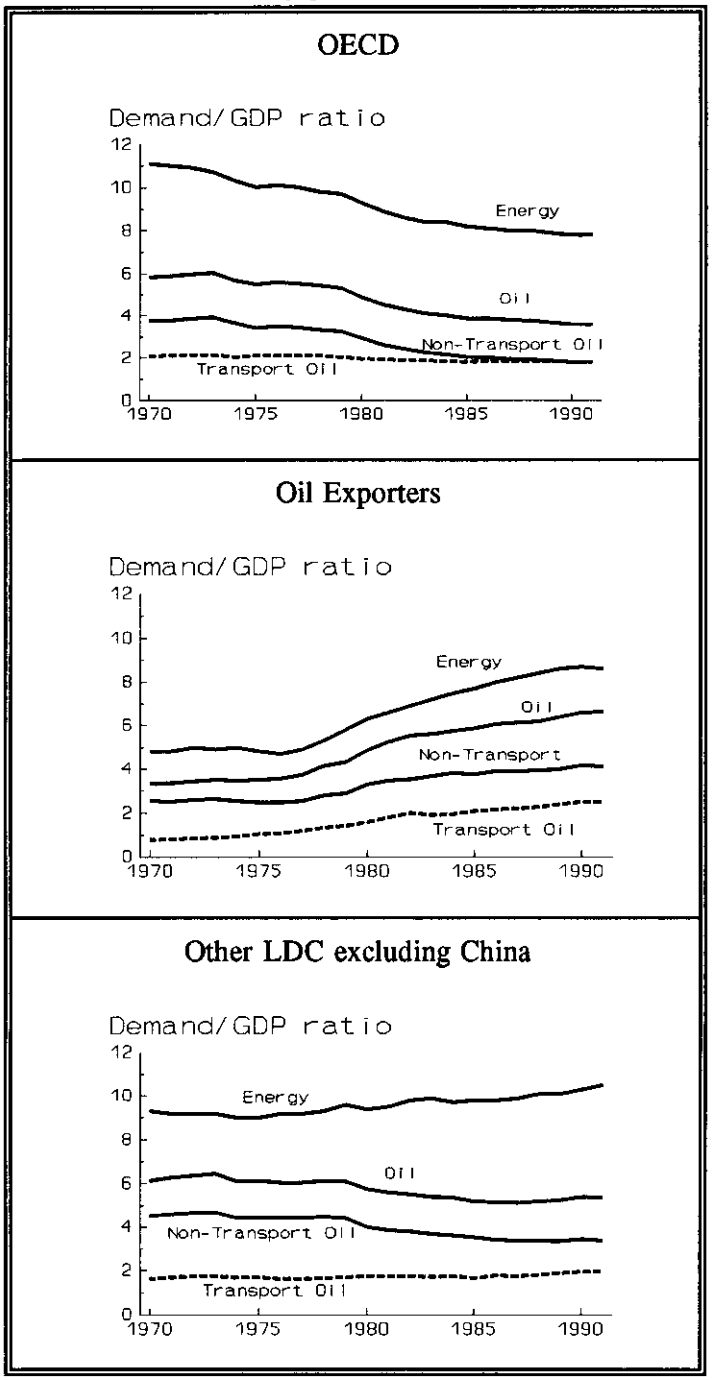
In addition to showing energy and oil demand over time, both in absolute and per-capita terms, it is useful to examine demand relative to real income growth. A standard way of doing this is to show the ratio of demand to income, the "demand/GDP ratio" (GDP: Gross Domestic Product). See Figure 8.

Within the OECD, demand/GDP ratios have been declining over time -- except for transportation oil, which has remained roughly constant relative to GDP.

Among the Oil Exporters, on the other hand, these ratios have increased. Initially, in the 1970's, the increases reflected demand growing even more rapidly than the Oil Exporters' income. Since the late 1970's, however, their income has been flat, while demand has continued to rise (although more slowly than previously), so that the demand/GDP ratio has increased.

Within the Other LDC, the demand/GDP ratio for both energy and transportation oil have increased slowly, while this ratio has decreased moderately for non-transportation oil, and declined slightly for total oil.

Figure 8. Ratio of Demand to GDP, 1970-91
Thousand Barrels Day per Billion $ Income (1980 $) (Sources: BP, DOE)



Another way of viewing these data is presented in Figure 9: for each of the four demands respectively (total energy, total oil, transportation oil, and non-transportation oil), each figure shows how demand has changed relative to total income from 1970 to 1991. The left column shows total demand vs. total income, and the right column shows per-capita demand vs. per-capita income. The scales are logarithmic, so that absolute distances (horizontally and vertically) measure *percentage* changes, not *absolute* changes as they normally would. Thus we see that the Other LDC experienced the greatest total income growth in percentage terms -- the greatest horizontal movement.

Also shown are dashed, diagonal lines indicating "equi-proportional growth". Movement along or parallel to these lines indicate demand growing in equal proportion to income: for example, total transportation oil in the OECD and Other LDC. Ignoring the effects on demand of any price changes, this would be equivalent to an unitary income elasticity. Steeper movement indicates demand growing faster than income (an income elasticity greater than one, ignoring price changes). Less steep, but positive movement indicates demand growing less rapidly than income (an income elasticity less than one, ignoring price changes): for example, total energy demand in the OECD.

We can also observe examples of demand declines, and examples of demand being flat while income continues to grow: total OECD non-transportation Oil in 1979-83 and 1983-91, respectively. Finally, for the Oil Exporters we observe in the left graphs total income growth (rightward movement) until the late 1970's, followed by stagnant total income but continued total demand growth (vertical movement).

Values in per-capita terms move similarly to the totals, but higher population growth rates in the Oil Exporters and Other LDC (Figure 3) slow their increase in per-capita income more than in the OECD. In fact, for the Oil Exporters, when total income remains roughly constant in the 1980's (vertical movement in the left graphs), we see per-capita income declining (bending back in the right graphs). But despite this decline in per-capita income, their demand continues to increase, especially for transportation oil.

Shown separately in Figure 10 are analogous graphs for China. They show the significant growth in income over this period, both total income and in per-capita terms. Although starting at a low level of per-capita income, China managed to sustain one of the highest rates of growth of per-capita income in the world. Although transportation oil increased as rapidly as income, overall energy and oil demand did not increase nearly as rapidly. Energy demand has increased only half as rapidly as income. Non-transportation oil was relatively flat, so that total oil increased much less rapidly than income.

Figure 9. Energy and Oil Demand (MBD) vs. Real Income (Trillions of 1980 $), 1970-91; per-capita Demand (Tons) vs. per-capita Income; logarithmic scales (Sources: BP, DOE, UN)

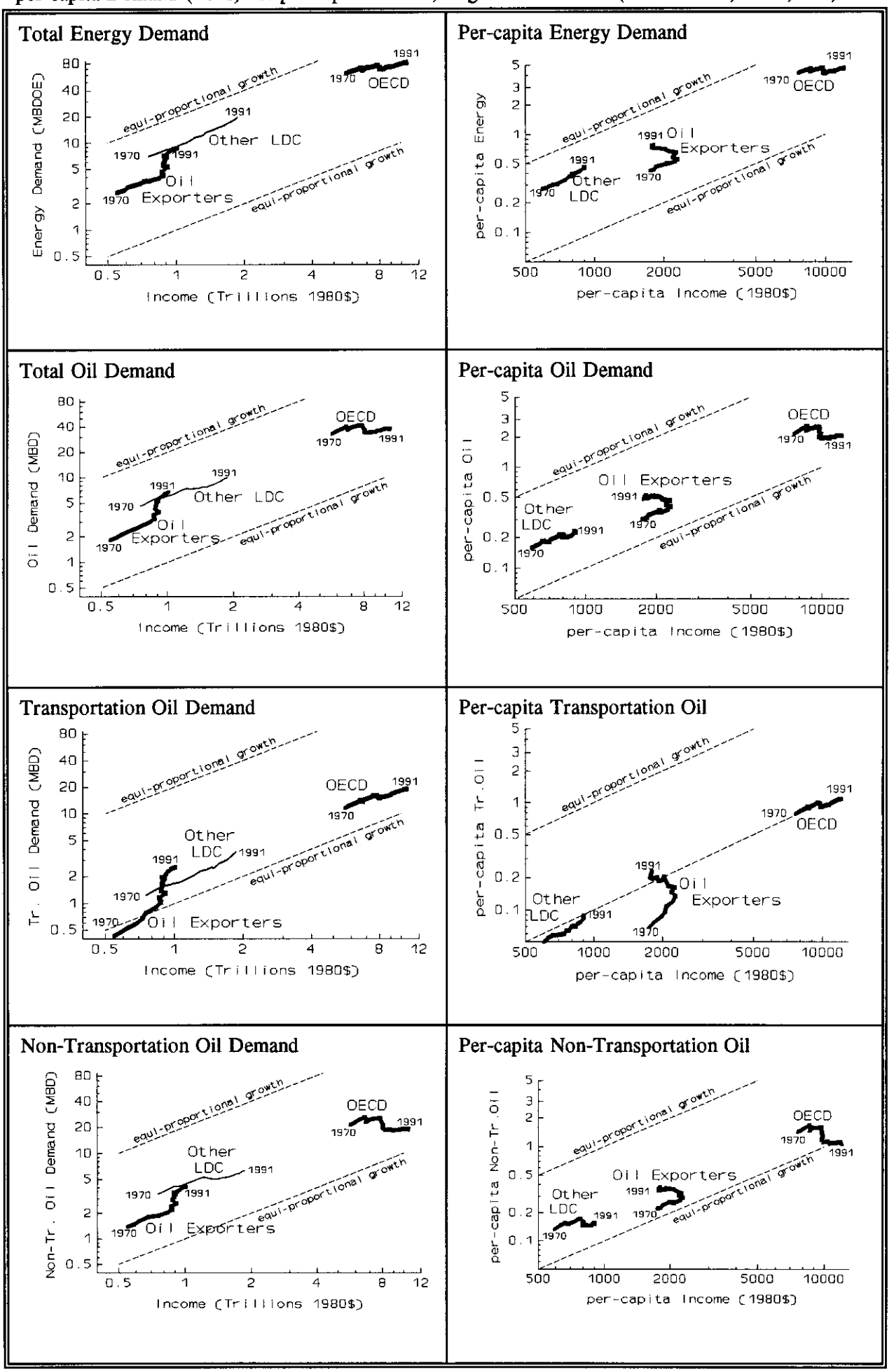
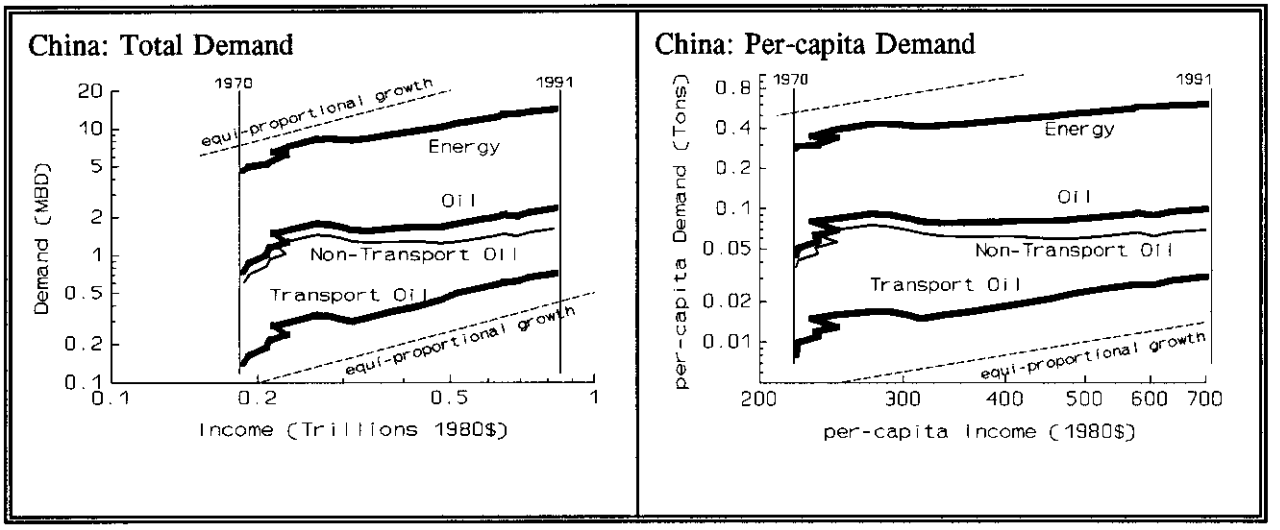


Figure 10. China: Energy and Oil Demand (MBD) vs. Real Income (Trillions of 1980 $), 1970-91; per-capita Demand (Tons) vs. per-capita Income; logarithmic scales (Sources: IEA, DOE, UN)




In general, the relationship between energy demand and income growth for any individual country is determined by a number of factors: the stage of economic development, the state of technology, energy endowments and energy pricing policy. All of these can, and will, change over time. Economic development theory suggests that there are phases in the development process which have implications for energy consumption, and particularly on the relationship between energy and income growth. Economic development is initially accompanied by an increasing energy/income ratio, which at some point reaches a maximum, and then declines as incomes continue to increase. In the initial stage, the mechanization of agriculture and the shift from an agrarian economy to an industrial economy will require larger inputs of energy per unit output. At the same time, larger and larger segments of the society are replacing non-commercial with commercial energy supplies, especially with growing urbanization. During this phase, energy demand increases more rapidly than income. However, as the economy continues to grow, the relative importance of heavy industry diminishes, the sectoral share of services increases, and household energy consumption reaches saturation limits. The energy requirements of increasing income will diminish, so that energy consumption will increase less rapidly than GDP.

These ideas are consistent with Figures 8 and 9: total energy consumption has not increased as rapidly as income in the OECD, but has increased more than proportionately to income in the LDC. The income elasticity declines from greater than unity in the developing countries to less than unity in the mature economies of the OECD.

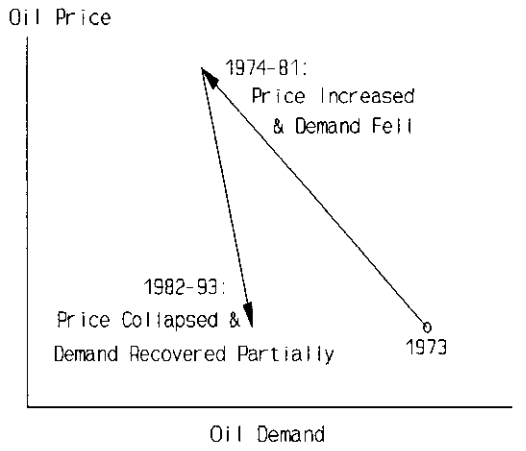
### 3. Demand and the Effects of Oil Price Increases and Decreases

Next we address the question of how energy and oil demand have been affected by the oil price increases of the 1970's and by the oil price declines of the 1980's. As we have argued in other articles, this relationship has not been symmetric: see Dargay-Gately(1994a, 1994b). The oil demand reductions caused by the oil price increases have not been reversed by the oil price decreases. This is most obvious in data for OECD oil demand, especially non-transportation oil demand.

Such a view of demand being imperfectly price-reversible, or of demand not responding symmetrically to price increases and price decreases, contrasts with conventional demand analysis. In particular, a conventional demand relationship between price and quantity demanded is symmetric with respect to price increases and decreases. That is, demand is perfectly price-reversible: demand reductions caused by a price increase would be reversed by an equal price decrease.

In contrast, we argue that demand need not respond symmetrically, that demand can be imperfectly price-reversible: demand reductions caused by a price increase need *not* be completely reversed by an equal price decrease. A simple way of summarizing this idea graphically is Figure 11.

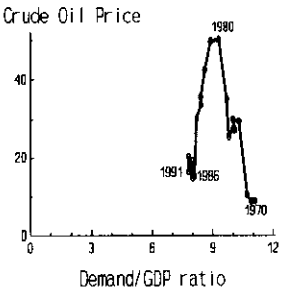
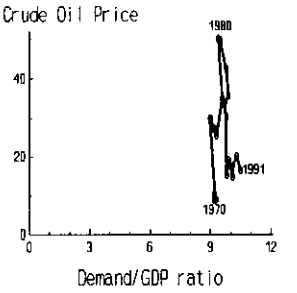
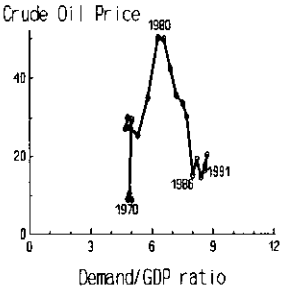
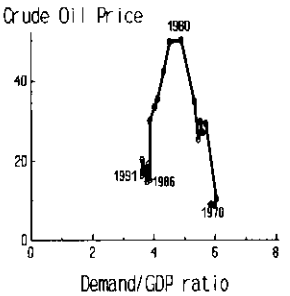
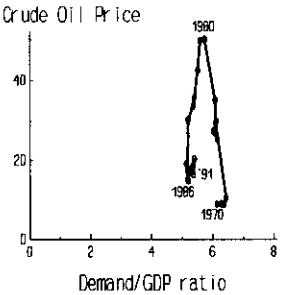
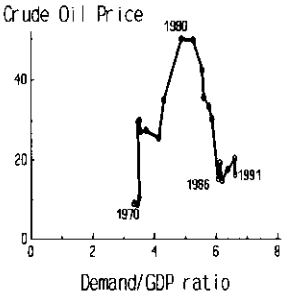
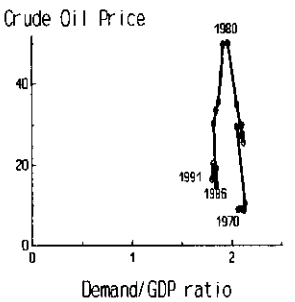
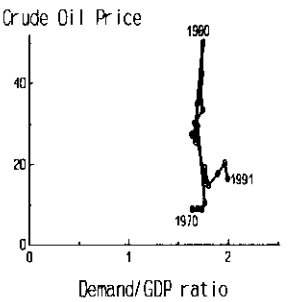
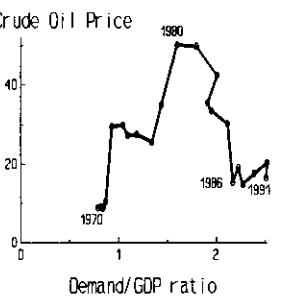
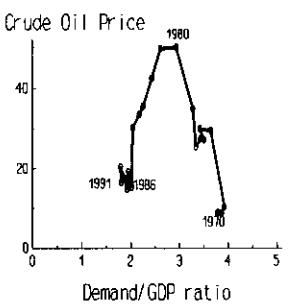
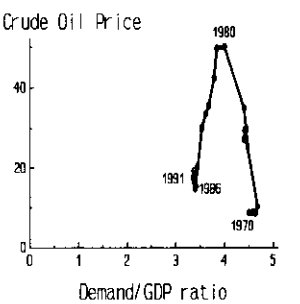
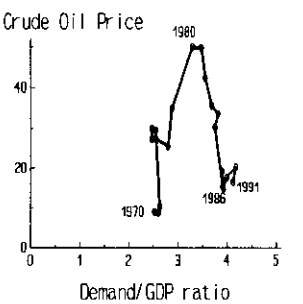
**Figure 11**
Imperfectly Price-Reversible Demand




For evidence of this imperfect price-reversibility -- especially for the OECD and for non-transportation oil in particular -- see Figure 12. This shows the time-path, from 1970 to 1991, of price vs. the demand/GDP ratio in each of the three regions for each of four demands: total energy, total oil, transportation oil, and non-transportation oil. Although we could have shown instead the *absolute level of demand*, we chose to show the *demand/GDP ratio* in order to simplify the interpretation of the graphs, which would be complicated by natural demand growth due to income growth.

Figure 12. Crude Oil Price (1985$/barrel) vs. Demand/GDP ratio (Th.BD/Billion$), 1970-91

(Source: DOE)

| | OECD | Other LDC | Oil Exporters |
|---|---|---|---|
| Energy/GDP |   |   |   |
| Oil/GDP |   |   |   |
| Transport Oil/GDP |   |   |   |
| Non-Transport Oil/GDP |   |   |   |

As shown in Figure 12, there are important *regional* differences in the movement of the demand/GDP ratios. In the OECD these demand/GDP ratios have all declined since the first oil price increases of 1973-74. The greatest decline was for the ratio of non-transportation oil to GDP; it fell by half since 1973-74, and that reduction was not reversed by the price cuts of the 1980's -- although the decline slowed after the 1986 oil price collapse. Smaller reductions have occurred in the OECD demand/GDP ratios for transportation oil, total oil, and total energy. In general, the inverted U pattern, typical of imperfect price-reversibility is apparent in the data for the OECD.

The Other LDC has also experienced a decline in its demand/GDP ratio for non-transportation oil, even though the absolute level of non-transportation oil has risen. This decline followed the price increases of the 1970's and it has not been reversed by the price cuts of the 1980's. But for transportation oil and for total energy, the demand/GDP ratios have *increased* over time: demand increased faster than income. Either demand has not responded much to the price increases, or the response has been outweighed by an income elasticity substantially greater than unity.

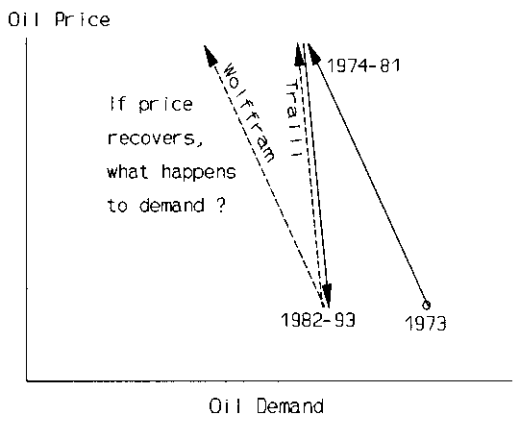
For the Oil Exporters -- in contrast to the OECD and the Other LDC -- all these ratios have *risen* over time, especially after the late 1970's when their real income had flattened out but their energy and oil demand continued to increase.

## 4. Econometric Estimation of Demand Responses to Changes in Prices and Income

The graphical evidence suggests that -- at least in the OECD -- the demand response to price cuts in the 1980's has not reversed the demand reductions caused by the price increases of the 1970's. However, there is another important question, concerning the effect on demand of future price recoveries -- that is, price increases which do not exceed the historic maximum levels of the early 1980's. Will the demand response to a future price recovery be as great as it was to the price increases of the 1970's? Or will a price recovery only reverse the small demand increase caused by the price cuts? Or will it be somewhere in between?

These possibilities are depicted in Figure 13. The greatest demand reduction from a price recovery, equal to that for the price increases of the 1970's, is labelled "Wolffram". It assumes that all price increases have the same effect -- both increases in the maximum historical price and (sub-maximum) price recoveries. The smallest demand reduction from a price recovery is labelled "Traill"; it merely reverses the small, partial reversal of the 1980's demand increase. It assumes the response to a price recovery is equal to the (small) response to a price cut. The third alternative would lie somewhere in between: demand responds more strongly to price rises than to price falls, but not quite as much to price recoveries as to increases in the maximum historical price.

**Figure 13** Effect on Demand of a Price Recovery



In order to allow for the possibility of an asymmetric response between price increases and decreases, we need to be able to measure separately the effects upon oil demand of oil price increases and price decreases. To do this, we have adapted a technique from the literature on agricultural supply: see Wolffram (1971), and Traill, Colman, and Young (1978). It involves the decomposition of the price series $P_t$ into three component series, each of which is monotonic: maximum historical price $P_{max,t}$ (positive and non-decreasing), the cumulating series of price cuts $P_{cut,t}$ (non-positive and non-increasing), and the cumulating series of price recoveries $P_{rec,t}$ (non-negative and non-decreasing):

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

(1a) $P_{max,t} \equiv \max (P_0,\ldots,P_t)$

(1b) $P_{cut,t} \equiv \Sigma^t_{i=0} \min \{0, (P_{max,i-1}-P_{i-1})-(P_{max,i}-P_i)\}$

(1c) $P_{rec,t} \equiv \Sigma^t_{i=0} \max \{0, (P_{max,i-1}-P_{i-1})-(P_{max,i}-P_i)\}$

**Figure 14** Decomposing Price into 3 Series

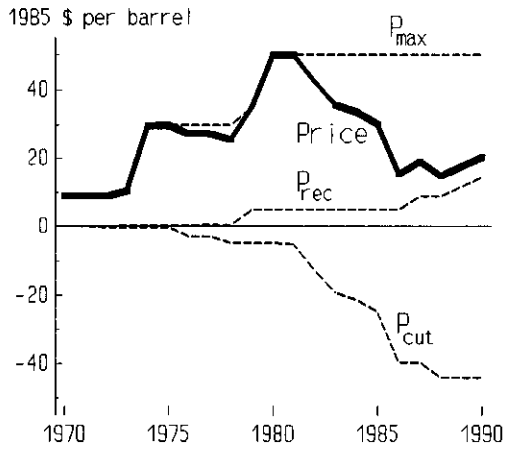



Figure 14 shows the real price of crude oil, together with its three-way decomposition. We see the jump in $P_{max}$ in 1973-74 and 1979-80; it is always positive and non-decreasing. The cumulating series of price cuts, $P_{cut}$, is negative and non-increasing; it shows the dramatic price declines of the 1980's. Also shown is the cumulating series of price recoveries, $P_{rec}$, which is positive and non-decreasing; but such price increases have been relatively few, and small.

We specify per-capita demand in its simplest form as a log-linear function of real per-capita income, the real price of crude oil, and lagged demand. There are two different demand specifications, depending upon whether we assume that demand is perfectly price-reversible or whether it estimated as being imperfectly price-reversible:

Perfectly Price-Reversible:

(2a) $\log \text{Demand/Pop.}_t = \alpha + \gamma \log \text{Income/Pop.}_t + \beta \log \text{Price}_t + \phi \log \text{Demand/Pop.}_{t-1}$

Imperfectly Price-Reversible:

(2b) $\log \text{Demand/Pop.}_t = \alpha + \gamma \log \text{Income/Pop.}_t + \beta_m \log P_{max,t} + \beta_c \log P_{cut,t} + \beta_r \log P_{rec,t} + \phi \log \text{Demand/Pop.}_{t-1}$

Alternatively, we could estimate total demand as a function of total income and price.

### 4.1 Econometric Estimation: Demand in Industrialized Countries

Our econometric results for OECD oil demand have been recently summarized in Dargay-Gately(1994a); some of this work is shown below in Table 1, along with estimates for total energy consumption. Among our conclusions regarding OECD demand are the following.

There has been an asymmetric, smaller demand response to the price decreases of the 1980's than to the price increases of the 1970's. This is true for both transportation and non-transportation oil, as well as for total energy. The irreversibility of gasoline demand resulted primarily from automobile fuel-efficiency improvements not being reversed by the price cuts; these were due both to irreversible improvements in technology and to the non-reversal of government policies such as fuel-efficiency standards. Although more fuel-efficient vehicles in combination with cheaper fuel have lowered the per-mile costs of transportation, neither greater vehicle use nor a partial return to less fuel-efficient vehicles has fully reversed the demand reductions caused by the price increases. For non-transportation oil, on the other hand, the irreversibility is better explained by fuel-switching not being reversed by the price cuts, but efficiency improvements have also played a role.

There has been -- at least for non-transportation oil -- a greater response to price rises above the previous maximum price than there has been to price recoveries. We would therefore expect a smaller demand response to future price recoveries than we saw to the price increases of the 1970's. For the OECD countries, this result is a mixed blessing. On the one hand, they may be comforted by now having both low oil prices and lessened oil-import dependence; they need not fear a full reversal of the demand reductions achieved in the past two decades. On the other hand, in the event of an oil price recovery (due either to OPEC or to domestic tax increases) they may not be able to rely upon the same demand reductions in the future as they experienced in the past. Fuel-switching or conservation measures, which had been done in response to the price increases of the 1970's but not *un-done* by the price declines of the 1980's, cannot be *re-done* if price recovers in the 1990's. The possibilities for demand reduction may be smaller than in the 1970's, because the uses of oil which remain significant today are probably those less amenable to switching to other energy sources, and for which further efficiency improvements are more costly. The only cases in which non-transportation oil demand might be sharply reduced by a price recovery would be those where there is still a substantial amount of demand, and where fuel-switching is relatively easy.

The demand response to future income growth will be not substantially smaller than in the past. As was shown in Gately (1993b) and in Dargay-Gately (1994a, 1994b), if demand were wrongly assumed to be perfectly price-reversible, then the successive-year inclusion of post-1986 data -- with moderate income growth and very low prices but little demand growth -- causes the estimate

of income elasticity to be reduced, and sometimes to become negative! With the imperfectly price-reversible specification, however, no such error is caused: the estimated income elasticity is relatively unaffected by the inclusion of the post-1986 data.

Table 1. OECD: Elasticity Estimates from Imperfectly Price-Reversible Demand Specifications

| Oil Product | Region | long-run demand elasticities | | | |
|---|---|---|---|---|---|
| | | Income[a] | Changes in Price | | |
| | | | Increases in $P_{max}$ | Price Cuts $P_{cut}$ | Price Recoveries[b] $P_{rec}$ |
| Per-capita Energy Demand equation (2b) above | OECD | 0.81 | -.3 | -.2 | -.3 (Wolffram) |
| Total Non-Transportation Oil Dargay-Gately(1994b) | OECD | 1.09 | -.76 | -.03 | -.54 |
| Total Transportation Oil Gately(1993a) | US | .70 | -.21 | -.04 | -.21 (Wolffram) |
| Gasoline (per driver) Gately(1992) | US | .79 | -1.08 | -.46 | -1.08 (Wolffram) |
| Road Transportation Oil Dargay(1992a) | France<br>Germany<br>U.K. | 1.29<br>1.71<br>1.49 | -0.80<br>-0.44<br>-1.50 | -0.45<br>-0.02<br>-0.10 | -0.80 (Wolffram)<br>-0.44 (Wolffram)<br>-0.10 (Traill) |

Notes:

a. Anthony Finizza and James Wallace have suggested to us that the surprisingly high income-elasticities in some of our earlier papers could be the result of a specification error in our implicit assumption that income changes are independent of changes in price. Specifically, the recession-induced declines in demand in 1974-75 and 1980-82 were the indirect result of the price increases of 1973-74 and 1979-80: Mory(1993) showed that US income growth was negatively affected by the two oil-price shocks. Using a two-stage least squares approach for US non-transportation oil demand, we estimated the determinants of US income growth, following the specification in Mory(1993), and then estimated the determinants of oil demand. This has the effect of reducing the estimated income-elasticity of oil demand by about half (results not shown in this Table).

b. If the results employed a specification in which the decomposed price coefficients were constrained, they are so indicated: Wolffram ($\beta_m=\beta_r$), or Traill ($\beta_c=\beta_r$). Otherwise, the three price coefficients were estimated separately.

## 4.2 Econometric Estimation: Demand in Less Developed Countries

In this section we examine the demand behavior of the LDC, both the Oil Exporters and the Other LDC; good surveys can be found in Dahl(1993, 1994). Actually, in this section we should say "Most Other LDC" because we use IEA data for about sixty non-OECD countries, rather than the more complete (but less detailed) coverage of BP or DOE statistics. Fortunately, these sixty countries include the largest and most important of the LDC.

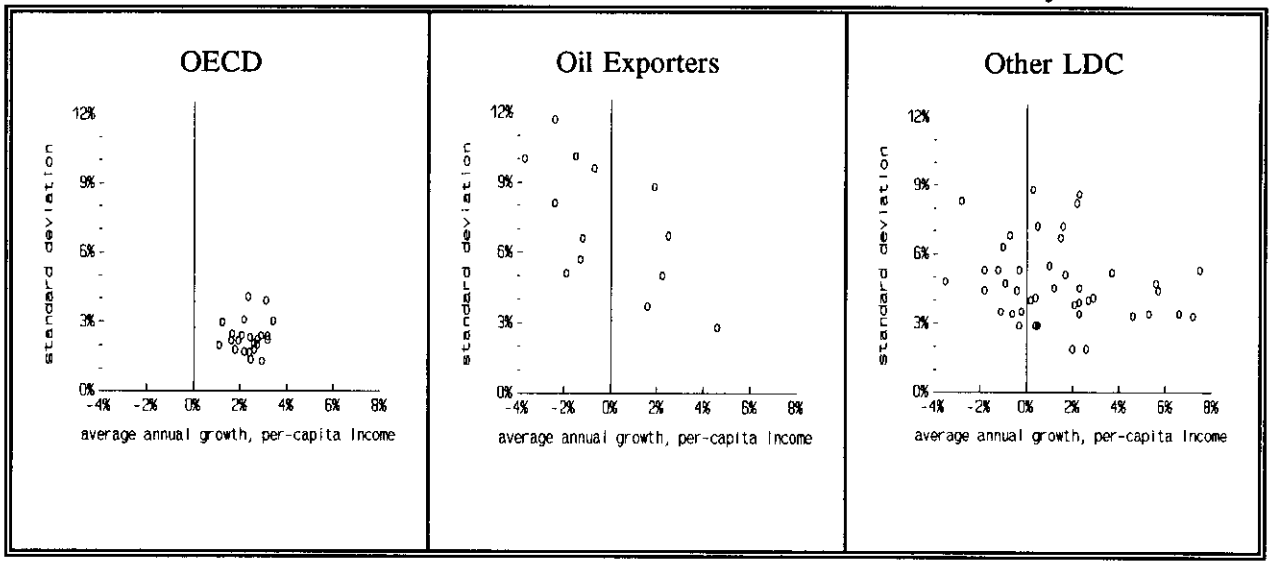
In contrast to the steady income growth of the OECD countries, the performance of the LDC countries has been very mixed. One-third of these sixty LDC countries have experienced average annual growth in per-capita income that is *negative*: their total income grew less rapidly than population.

A simple way of contrasting the heterogeneous income-growth performance of these countries with that for the OECD countries is presented in Figure 15. Each circular marker graphs a single country's average annual growth rate of per-capita income from 1970-91 and the standard deviation of its annual growth rate of per-capita income.

The OECD countries are clustered together. They have each experienced steady growth in per-capita income: average annual growth of about 2-3%, and a standard deviation of the annual growth rate of 1-3%. In contrast, both the Oil Exporters and the Other LDC groups are widely dispersed. One-third of them have *negative* growth in per-capita income, and the standard deviation of their annual growth rates ranges widely, from 2% to 10%.

Figure 15. Heterogeneity within Groups in Per-capita Income Growth Rates, 1970-91

Average Annual Growth and Standard Deviation of Annual Growth for each country

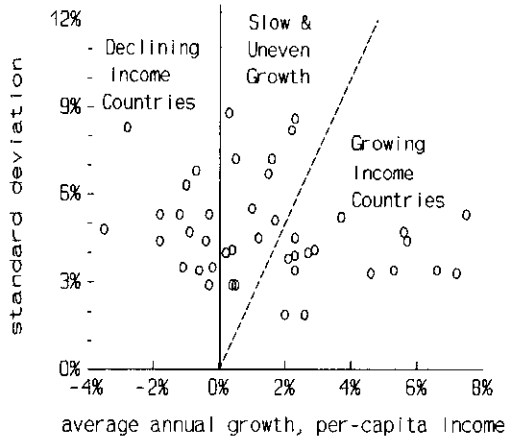


Given the heterogeneous experience of these LDC with respect to per-capita income growth, and given that one of our primary interests is to understand the effect of income growth on LDC energy demand, we want to focus on those countries which have experienced income growth most consistently.

We draw upon the work on LDC patterns of development by Chenery, Robinson, and Syrquin (1986). They found it useful to examine the behavior of different countries rather than aggregates. In particular they examined common patterns of behavior within clusters of countries.

This is what we shall do. We examine separately each of three clusters of countries within the Other LDC, based on the idea that an understanding of the effects of income growth on demand requires that we cluster the countries according to their performance in per-capita income growth. It would only cloud the analysis to consider all these countries as an aggregate. These clusters are indicated in Figure 16:

**Figure 16** Disaggregating Other LDC into 3 sub-groups




1) Other LDC, Growing Income:
those with relatively high average annual growth rate in per-capita Income and relatively low standard deviation in the annual growth rate of per-capita Income (less than 2.5 times the average growth rate) --

Brazil, Colombia, Egypt, Hong Kong, India, Malaysia, Morocco, Pakistan, Paraguay, Singapore, South Korea, Sri Lanka, Taiwan, Thailand, Tunisia.

2) Other LDC, Declining (Per-capita) Income:
those with negative average annual growth rate in per-capita Income --

Angola, Argentina, Benin, Bolivia, Ethiopia, Ghana, Ivory Coast, Jamaica, Mozambique, Peru, Senegal, South Africa, Tanzania, Zaire, Zambia, Zimbabwe.

3) Other LDC, Slow and Uneven Income Growth:
those with relatively low (but positive) average annual growth rate in per-capita Income and relatively high standard deviation --

Bangladesh, Cameroon, Chile, Congo, Guatemala, Kenya, Myanmar, Nepal, Panama, Philippines, Sudan, Trinidad, Uruguay.

Although the three sub-groups within the Other LDC have roughly the same number of countries, the Growing Income cluster comprises a disproportionately large share (two-thirds) of the total population.

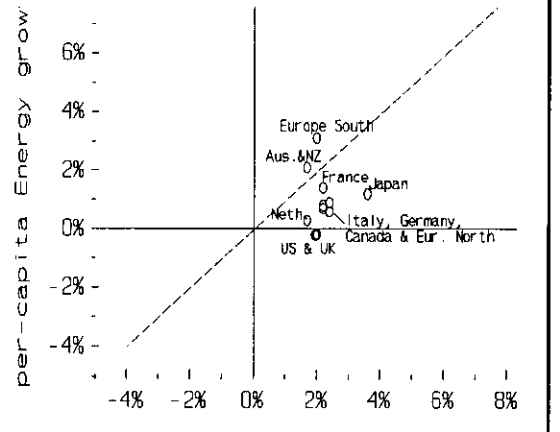
China, although it would be within the cluster of Growing Income countries in Figure 16, is analyzed separately, given its size and its different historical experience. We also analyze the Oil Exporters separately:

Algeria, Bahrain, Ecuador, Gabon, Indonesia, Iran, Iraq, Kuwait, Libya, Mexico, Nigeria, Oman, Qatar, Saudi Arabia, United Arab Emirates, Venezuela.

Another contrast between the homogeneity of the OECD countries' energy-income experience and the heterogeneity of the LDC countries' experience can be found in Figures 17 and 18. These show, for the OECD and for the four LDC sub-groups respectively, the average annual rate of per-capita energy demand growth vs. per-capita income growth over the period 1971-92.

The OECD countries and country-groups[4] have exhibited relatively homogeneous performance not only in income growth but also in energy demand growth: from 0% to 2%. See Figure 17. In most of the OECD countries, demand grew more slowly than income, and in the US and UK it actually declined slightly. The most obvious exception is in Europe South -- the group of countries with the lowest per capita incomes in the OECD -- where energy demand increased more rapidly than income.

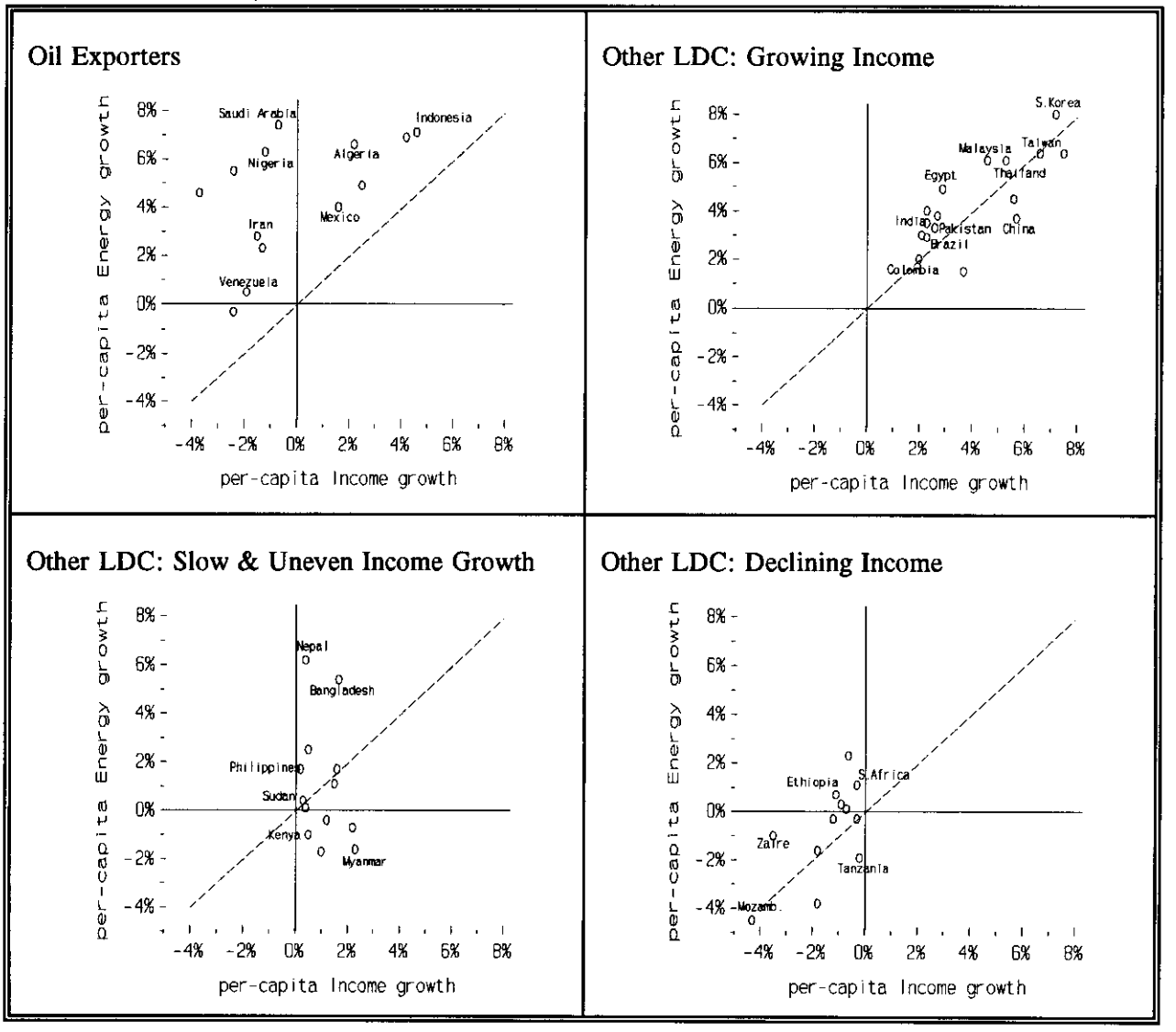
**Figure 17** OECD Average Annual Growth Rates, 1971-92: per-capita Energy & per-capita Income




[4] This analysis is based upon work published in Dargay-Gately(1994b), in which we analyzed the OECD as consisting of eleven "regions": countries or groups of countries. These eleven consisted of the 8 largest OECD countries -- US, Japan, Germany, France, Italy, UK, Canada, Netherlands -- and 3 aggregated regional groups: Europe North (Norway, Sweden, Finland, Denmark, Belgium, Luxembourg, Iceland, Ireland, Austria, Switzerland); Europe South (Spain, Portugal, Greece, Turkey); and Australia - New Zealand.

Figure 18. LDC Average Annual Growth Rates, 1971-92,

for per-capita Energy Demand & per-capita Income




The four graphs in Figure 18 show the heterogeneity among the LDC, both in their per-capita income growth and also in its relationship to per-capita demand growth. Although not shown, there is similar heterogeneity for per-capita *oil* demand. Only the most heavily populated countries are labeled in each graph.

Most of the Oil Exporters experienced negative growth in per-capita income over this period. Their income growth of the 1970's was more than reversed by the oil price declines of the 1980's. Some of them, however, did experience growing per-capita income; among these were Indonesia, Algeria, and Mexico. But regardless of whether their per-capita income grew or declined, they all had one thing in common: their growth in per-capita energy (and oil) demand exceeded their income

growth. In fact, most had positive growth in energy demand together with declining income.

In contrast, the Growing Income LDC experienced not only growth in per-capita income but also growth in per-capita energy (and oil) demand that was in rough proportion to income growth. Some experienced faster growth in energy demand than in income: Egypt, India, Malaysia, South Korea. But of the largest countries, only China (which is analyzed separately) had slower than equi-proportional growth.

The Declining Income countries include many that are less heavily populated. But several have populations in excess of 20 million: Zaire, Tanzania, Mozambique, Ethiopia, and South Africa. For these countries, the relationship between per-capita energy demand growth and per-capita income growth was not very close. Some experienced growing per-capita energy demand (South Africa, Ethiopia), some had per-capita energy demand declining but more slowly than per-capita income (Zaire), and some had per-capita energy demand decline more rapidly than per-capita income (Tanzania).

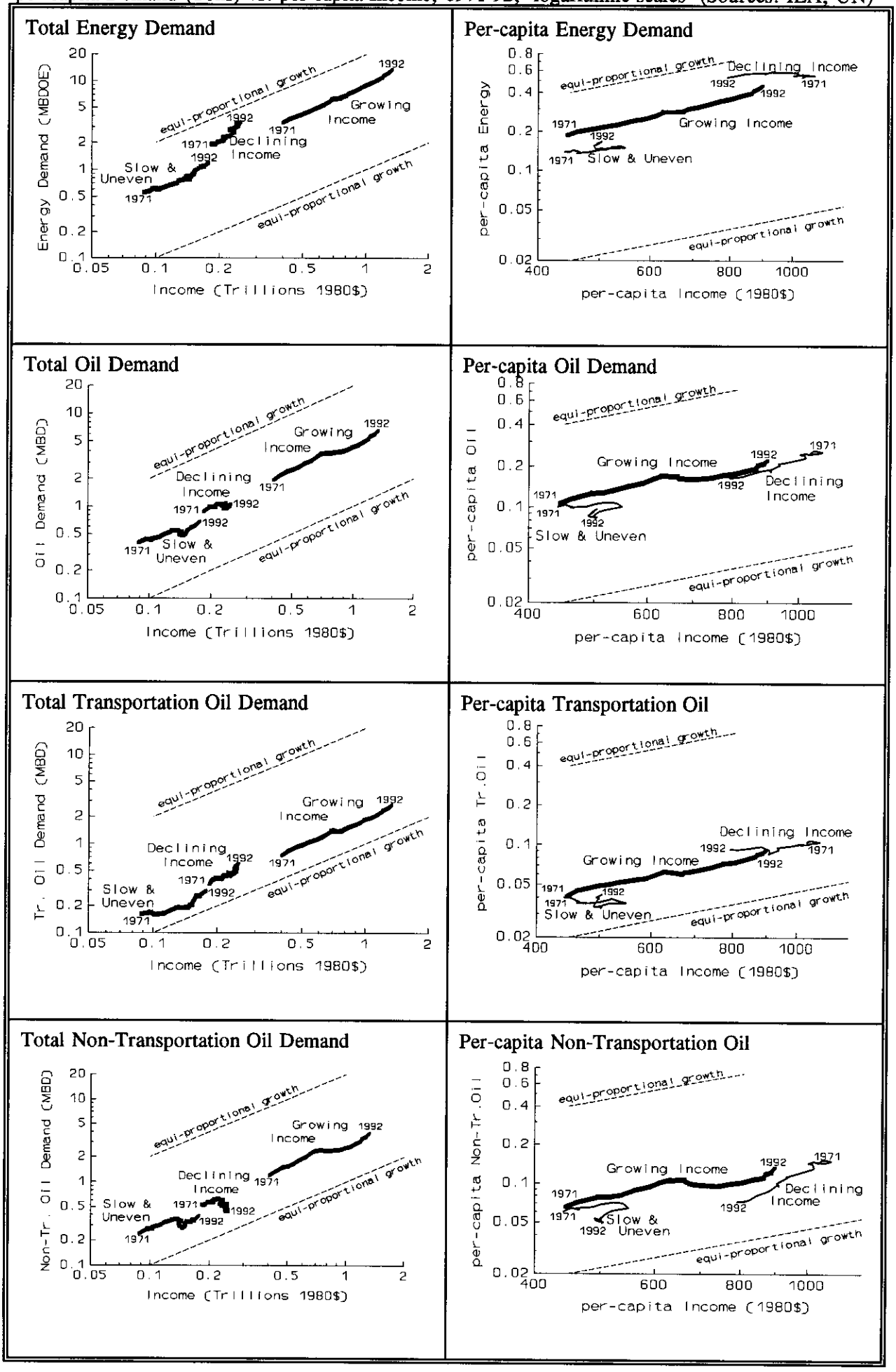
The third sub-group, Slow and Uneven Income Growth, had a similarly low correlation between per-capita growth in energy demand and income. Some had energy demand growing much more rapidly than their slow income growth: Nepal, Bangladesh, Philippines. Others experienced modest declines in energy demand together with slow growth in income: Kenya, Myanmar.

Figure 19, virtually identical in structure to Figure 9, shows for each of the 3 sub-groups of the Other LDC, their 1970-91 time-paths of demand vs. income, for energy, oil, transportation oil, and non-transportation oil -- both totals (left column) and per-capita (right column).

To avoid confusion, two points should be made about the "Declining Income" sub-group. First, the sub-group's name refers to its declining *per-capita* income; its total income is rising over time, but less rapidly than population growth. Second, its 1970 level of per-capita income (above $1000) is more than double that of the other two sub-groups. This is due to the presence of two moderate-income countries (Argentina and South Africa), without whom the sub-group's per-capita income in 1970 would be comparable to that of the other two sub-groups.

The income-growth experience of the Growing Income sub-group is impressive. Its total income tripled over this period, from about 0.4 trillion in 1970 to above 1.3 in 1991. Its per-capita income doubled, from about $450 in 1970 to about $900 in 1991. Its energy and oil demand growth is the most easily understood of any of the sub-groups. We describe it in per-capita terms. Energy demand grew slightly faster than income, and transportation oil demand grew about as fast as income. Non-transportation oil demand, which grew about as fast as income until the 1979-80 price increases,

Figure 19. Other LDC, 3 sub-groups: Energy and Oil Demand (MBD) vs. Real Income (Trillions 1980$) per-capita Demand (Tons) vs. per-capita Income, 1971-92; logarithmic scales (Sources: IEA, UN)



declined until 1985, but has increased since the 1986 oil price collapse even faster than income growth. Compared with the OECD countries, they experienced faster economic growth, and their energy demand and transportation oil demand grew more rapidly. They responded less to the oil price increases than did the OECD, and there was little evidence of imperfect price-reversibility: the price collapse of the 1980's stimulated demand growth, especially for non-transportation oil.

The Declining (Per-capita) Income countries were in some ways the opposite of the Growing Income sub-group. Their per-capita income declined substantially: from above $1000 in 1970 to below $800 in 1991. Their total income grew slowly (less rapidly than population): from about .18 Trillion in 1970 to .25 Trillion in 1991. In per-capita terms (moving right to left in the per-capita graphs), their transportation oil demand remained relatively unchanged, but non-transportation oil fell more than twice as rapidly as income.

The third sub-group, Slow and Uneven Income Growth, experienced both increases and decreases in per-capita income: it increased until 1981 but declined and stagnated thereafter. Its per-capita demand experience was similar in some ways to each of the other two sub-groups. When its per-capita income was increasing, its energy and oil demand increased, although much more slowly than in the Growing Income countries. And when its per-capita income declined, it cut back more on non-transportation oil than on transportation oil, as in the Declining Income countries.

It is useful to compare the Other LDC sub-group behavior in Figure 19 with the aggregated Other LDC behavior in Figure 9. For per-capita non-transportation demand, the reversal of the 1980-85 demand reduction by the Growing Income countries after the 1986 price collapse is masked when the Other LDC is aggregated in Figure 9. There it appears that Other LDC per-capita non-transportation oil demand is imperfectly price-reversible after the 1986 price collapse. This is due to the fact that in the 1980's per-capita income declined not only in the Declining Income countries but also in Slow & Uneven Growth countries, and they responded by reducing non-transportation oil even faster than their income declined. Thus, after the 1986 oil price collapse, the two sub-groups whose per-capita income was declining were reducing non-transportation demand faster than their income declined, while the Growing Income countries were increasing their demand faster than their income growth. The aggregation of the three sub-groups masks what is happening to them separately. In particular, it masks the Growing Income countries' (partial) reversal of the non-transportation oil demand reductions of the early 1980's.

The effect of aggregation is different for transportation oil than for non-transportation oil, because the demand behavior is different. For transportation oil, declining-income countries reduce their demand less than proportionately to income declines, while the Growing Income countries increase demand about as rapidly as income. Combining countries with declining per-capita incomes with the Growing Income countries will reduce the average per-capita income growth, but it will not reduce per-capita transportation oil demand growth proportionately. Hence the ratio of transportation oil growth to income growth will be higher for the aggregate than for the Growing Income countries. Thus, for transportation oil, aggregating declining per-capita-income countries with growing per-capita-income countries will cause an overestimate of the true effects of income growth.

Having viewed the graphs, we can also examine the LDC data econometrically, using the two demand specifications: the perfectly price-reversible (2a) and the imperfectly price-reversible (2b). However, having tried both specifications, we present only the results for the former, because there was little evidence of imperfect price-reversibility for the LDC. The econometric results are shown in Table 2 for energy, transportation oil, and non-transportation oil, for various groups estimated separately: each of the three Other LDC sub-groups, the total of all three Other LDC sub-groups, the Oil Exporters, and the total of all LDC groups including the Oil Exporters, and China.

Table 2. Long-run Elasticities of Per-Capita Demand, for different groups of LDC's
Perfectly Price-Reversible:
$\log \text{Demand/Pop.}_t = \alpha + \gamma \log \text{Income/Pop.}_t + \beta \log \text{Price}_t + \phi \log \text{Demand/Pop.}_{t-1}$

| Groups of LDC's | Energy per capita | | Transport Oil per capita | | Non-Transport Oil per capita | |
|---|---|---|---|---|---|---|
| | Price elas. | Income elas. | Price elas. | Income elas. | Price elas. | Income elas. |
| Other LDC: Growing Income | -.12 | 1.2 | -.18 | 0.95 | -.09 | 1.04 |
| Other LDC: Declining Income | .05[a] | 1.5[b] | -.07 | 0.73 | -.07[b] | 3.6 |
| Other LDC: Slow, Uneven Income Growth | -.32 | 2.9 | -.29 | 2.0 | c | c |
| All Other LDC excluding Oil Exporters | -.08 | 1.4 | -.19 | 1.0 | c | c |
| Oil Exporters | c | c | -.23[b] | 3.5 | .1[a] | 2.5 |
| All LDC including Oil Exporters | -.14 | 3.0 | -.18 | 2.5 | -.03[b] | 2.0 |
| China | .03[a] | 0.5[b] | -.18[b] | .7[b] | c | c |

Notes:
a. coefficient had the wrong sign but was not statistically significant
b. coefficient had the correct sign but was not statistically significant
c. The standard specification failed to yield meaningful results.

The results are best for the Growing Income countries. This is not surprising, given their relatively close correlation between income and demand growth. For both energy and transportation oil demand, price and income have the expected sign and are statistically significant. Unlike for the OECD, there was little or no evidence of imperfect price-reversibility (the tests are not shown). The income elasticity was 1.2 for energy and .95 for transportation oil, and 1.04 for non-transportation oil.

For the other groups -- Declining Income, and Slow & Uneven Growth, and the Oil Exporters -- the results were not nearly as good as for the Growing Income countries. In particular, the income elasticities were implausibly high, often indicating that per-capita demand rises twice as rapidly as per-capita income. This would suggest that their response to income growth would be to increase demand perhaps twice as rapidly as in the Growing Income countries.

The results were least satisfactory for the Declining Income countries, which is perhaps not surprising. In the energy demand equation, price had the wrong sign and income was statistically insignificant. Results for transportation and non-transportation oil were similarly unsatisfactory.

For the Slow & Uneven Growth countries, the results were also unsatisfactory. The income elasticity was surprisingly and misleadingly high.

If all three of these Other LDC sub-groups were aggregated, the results would be largely determined by the experience of the Growing Income countries: they constitute a disproportionately large share of the total, two-thirds of population. However, such aggregated results would be contaminated by the irregular behavior of the other two sub-groups: their declining income was not matched by proportional declines in transportation oil demand, and non-transportation oil declined more than proportionately.

Also unsatisfactory are the econometric results for the Oil Exporters, or for an LDC aggregate that includes both the Oil Exporters and the Other LDC.

For China, the econometric results were reasonable, but not completely satisfactory. The low income-elasticity is certainly consistent with Figure 11 above.

## 5. Conclusions

The responsiveness of energy demand to income growth is higher in the LDC than in the OECD: energy demand grows faster than income in the LDC, but slower than income in the OECD.

Transportation oil has grown consistently, in all regions of the world, about as rapidly as income growth, and it is less price-responsive than non-transportation oil demand.

The effect of the oil price increases of the 1970's on LDC energy and oil demand was not as great as its effect on OECD energy and oil demand. In the past two decades, OECD energy demand has grown much more slowly than income, as has OECD oil demand. OECD non-transportation oil fell sharply after the 1979-80 oil price increase, but it has not reversed that decline after the oil price increases were reversed in the 1980's.

There is much less evidence of imperfect price reversibility in the Other LDC than in the OECD. A substantial part of the decline in Other LDC non-transportation demand in the early 1980's -- for the Growing Income sub-group especially -- was reversed by the 1986 oil price collapse. Since then, non-transportation oil demand has risen faster than income, and oil's share of energy has partially recovered.

Finally, the aggregation of the three sub-groups of the Other LDC will distort the effects of true income growth on energy and transportation oil demand, and the effects of the oil price reductions of the 1980's on non-transportation oil demand. For transportation oil and energy, aggregating declining per-capita-income countries (who reduced demand less than proportionately to their income decline) with growing per-capita-income countries will cause an overestimate of the effects of true income growth. For non-transportation oil, the aggregation will mask the Growing Income countries' post-1986 reversal of the demand reductions of the early 1980's. This is due to the fact that the declining income countries reduced their non-transportation oil demand twice as fast as their income declined, while Growing Income countries increased it much faster than their income grew.

## Appendix A:
## Data Sources

Real Income (GDP): *OECD Main Economic Indicators*
and United Nations statistics

Real Price of Crude Oil: British Petroleum, *Energy Statistics*

Energy and Oil Demand: *Energy Statistics of OECD Countries* (Paris: International Energy Agency).
*Energy Statistics of Non-OECD Countries* (Paris: International Energy Agency).
*Energy Balances of Non-OECD Countries* (Paris: International Energy Agency).
DOE: US Department of Energy
BP: British Petroleum, *Energy Statistics*

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