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The rapid growth of domestic oil consumption in Saudi Arabia and the opportunity cost of oil exports foregone

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ABSTRACT

We analyze the rapid growth of Saudi Arabia's domestic oil consumption, a nine-fold increase in 40 years, to nearly 3 million barrels per day, about one-fourth of production. Such rapid growth in consumption – 5.7% annually, which is 37% faster than its income growth of 4.2% – will challenge Saudi Arabia's ability to increase its oil exports, which are relied upon in long-term world oil projections by the International Energy Agency (IEA), US Department of Energy (DOE) and British Petroleum (BP). However, these institutions assume unprecedented slowdowns in Saudi oil consumption – from 5.7% annual growth historically to less than 2% in the future – allowing them to project increases in Saudi oil exports. Using 1971–2010 data, we estimate that the income responsiveness (elasticity) of oil consumption is at least 1.5—using both Ordinary Least Squares regression and Cointegration methods. We believe that continued high growth rates for domestic oil consumption are more likely than the dramatic slowdowns projected by IEA, DOE and BP. This will have major implications for Saudi production and export levels.

1. Introduction

Saudi Arabia's domestic oil consumption has grown rapidly in the past four decades, a nine-fold increase in 40 years, averaging 5.7% annually, to nearly 3 million barrels per day[3] (mbd). Saudi Arabia is now the 6th largest oil consumer in the world, trailing only the US, China, India, Japan, and Russia. Saudi domestic consumption is now more than one-fourth of production; see Fig. 1. If this growth continues, which we believe to be likely, it will have major implications for Saudi oil production and exports.

The outline of this paper is as follows. In Section 2, we summarize the factors that lead to increasing oil consumption: the growth in income and population. We analyze the demand for different oil products – transport oil, residual oil, and other oil – and summarize the effect of income on the demand for each product and on the total. Our focus is the ratio of total oil consumption growth to income growth, which has been 1.37 over the period 1971–2010. That is, total oil consumption has increased 37% faster than income. Section 3 presents econometric evidence on the income responsiveness (elasticity) of demand, using both ordinary least squares and cointegration methods. Section 4 discusses the projections of Saudi oil consumption made by the IEA, DOE, and BP. Their projected growth rates of demand are extremely low, less than 2% annually – *much* slower than the historical growth rate (5%) and only one-third as fast as projected income growth (rather than 37% faster, as in the past). We contrast these extremely low projections with what we believe are more likely projections of consumption growth – say at the 1995–2010 rate of 5% annually – and the implications for Saudi oil production and exports. Section 5 summarizes our conclusions.

2. Background

As in most countries, oil demand growth is driven by increases in real income and population: see Fig. 2. In Saudi Arabia's case, demand is also stimulated by very low end-user prices, made possible by the country's abundant oil reserves.

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[3] There are different published estimates of Saudi oil consumption. Disaggregated product consumption estimates are published by the Saudi Arabia Ministry of Petroleum and Mineral Resources and also by the IEA, in *Energy Balances of Non-OECD Countries*; British petroleum BP (2011a) publishes total oil consumption. The similarities and differences are discussed in Appendix A, where the data are listed. In this paper we rely primarily upon IEA estimates.

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Given the importance of the oil sector in total income, we show in Fig. 3 the composition of oil income and non-oil income. Non-oil income has been growing steadily since 1971, except for the early 1980s. Oil income fell sharply in the early 1980s and has been fairly steady for the past two decades.

The ratio of oil consumption to income (also known as "oil intensity") is shown in Fig. 4, together with the ratios of natural gas and energy to income. (Unlike most countries, Saudi Arabia's only primary sources of energy are oil and gas; there is no consumption of coal, hydroelectric or nuclear power.) These ratios – oil/income, gas/income, and energy/income – have all risen steadily since the mid-1970s; this indicates that oil, gas, and energy consumption have grown faster than income. By contrast, in the early 1970s the quadrupling of oil prices and income outstripped the growth of oil and energy consumption, causing the ratios of oil/income and energy/income to fall sharply.

In order to understand the growth of total oil consumption, it is important to distinguish the growth of different oil products: see Fig. 5. Residual Oil (Heavy Fuel Oil) was a significant part of Total Oil consumption in the early 1970s, but its use has not changed much since then. Used primarily in electricity generation, Residual Oil can be easily substituted for, with natural gas. In contrast, Transport Oil (gasoline, jet fuel, and light fuel oil including diesel oil) has grown faster than income for forty years, as has Other Oil (LPG, naphtha, and all other oil products).

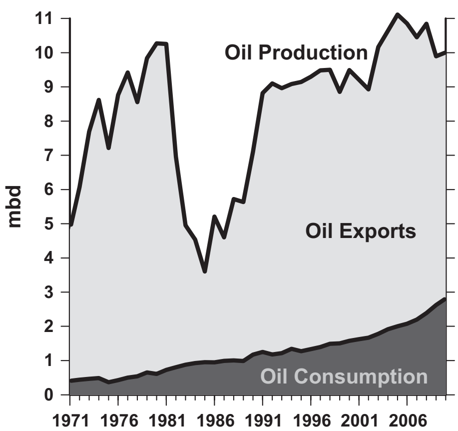

Fig. 1. Saudi Arabia: oil production, consumption and exports, 1971–2010.
Source: BP, 2011a.

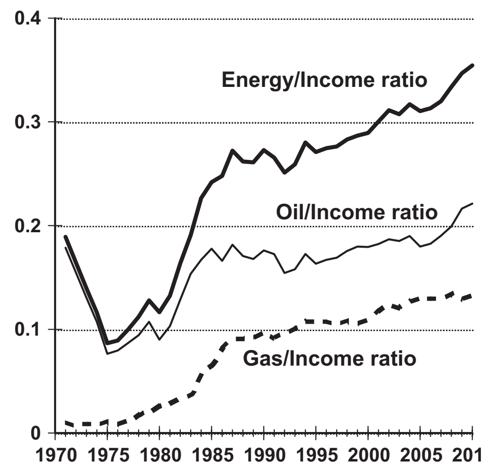

Fig. 4. Energy, oil, and gas intensity in Saudi Arabia, 1971–2010: the ratios of consumption to income (tons of oil equivalent per thousand $ income).

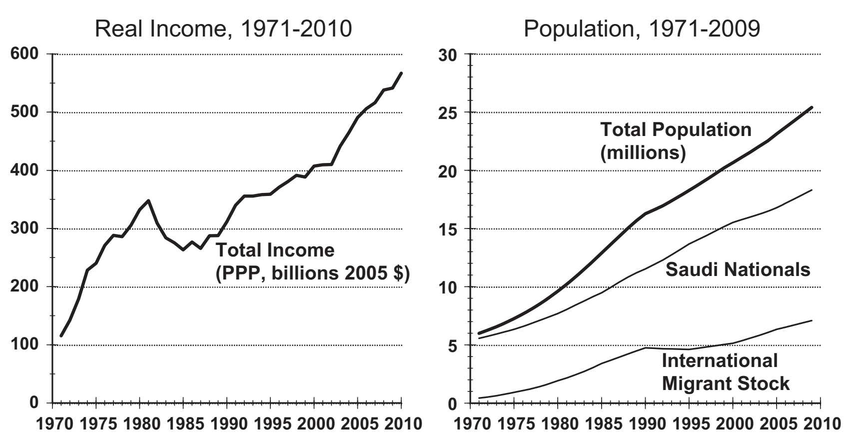

Fig. 2. Saudi Arabia: real income and population, 1971–2010. (a) Real income, 1971–2010; (b) Population, 1971–2009.

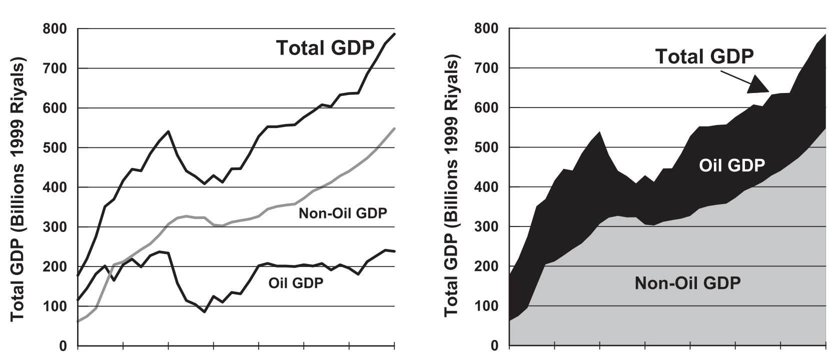

Fig. 3. Total income, oil income and non-oil Income, 1971–2009.

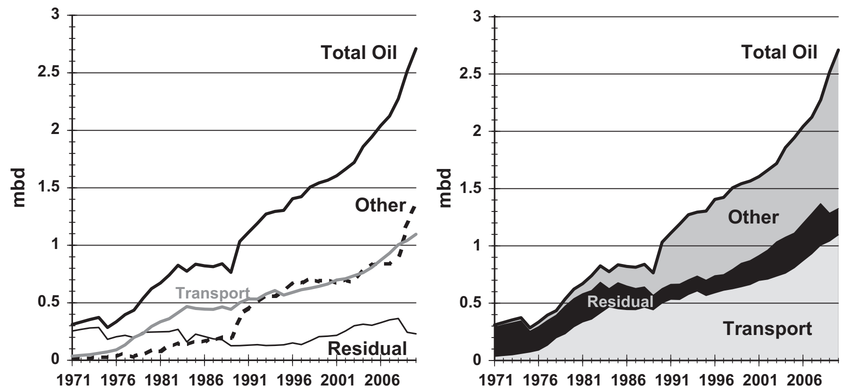

Fig. 5. Saudi Arabia: oil consumption by product, 1971–2010.
Source: IEA.

Table 1
Average annual growth rates and ratio of total oil consumption growth to income growth (Oil data from IEA, energy and natural gas data from BP.).

	Average Annual Growth Rates		
	1971–2010	1971–1985	1985–2010
Total oil consumption	**5.7%**	**7.3%**	**4.8%**
Transport oil	9.2%	19.9%	3.6%
Residual oil	−0.3%	−0.8%	0.1%
Other oil	11.4%	15.5%	9.1%
Natural gas consumption	11.2%	20.7%	6.2%
Total energy consumption	5.9%	8.0%	4.7%
Real income	**4.2%**	**6.1%**	**3.1%**
Population	3.8%	5.6%	2.8%
Ratio: total oil growth rate to income growth rate	**1.37**	**1.21**	**1.55**

Table 1 shows the average annual growth rates for the main variables. For the period 1971–2010, Total Oil has grown at an average annual rate of 5.7%, much faster than the 4.2% annual growth of Income. Transport Oil and Other Oil have grown almost twice as fast as Income, while Residual Oil (80% of the total in 1971) has been stagnant. We also show the growth rates before and after 1985; that was the year that ended the 1981–85 income declines and marked the start of 25 years of steady income growth. Since 1985 Total Oil has grown 4.8% annually, much faster than the 3.1% rate of income growth. This ratio of the growth rate of oil demand to the growth rate of income is the central concern of the paper.

Fig. 6 compares the relative growth of oil consumption and real income over time. The axes are logarithmic; the diagonal lines indicate equi-proportional growth of oil consumption and income. Movement parallel to these lines indicates that oil consumption is growing as rapidly as income (income elasticity=1); steeper [less steep] movement indicates income elasticity greater than [less than] 1. In the upper-left graph of Fig. 6, we see the following changes in Total Oil demand:

- 1971–74: Total Oil grows slower than income (due to stagnant Residual Oil demand)
- 1974–75: Total Oil declines
- 1975–81: Total Oil increases faster than income (due to surging Transport and Other Oil)
- 1981–85: Total Oil increases despite income declines
- 1985–2010: Total Oil increases faster than income

Similar graphs show the relationship to income for each of 3 oil products: Transport, Residual, and Other Oil. For Transport Oil, the upper-right graph shows the following:

- 1971–74: Transport demand grows about as fast as income;
- 1974–81: Transport demand grows much faster than income;
- 1981–85: Transport demand continues to grow despite declining income;
- 1985–2010: Transport demand grows slightly faster than income

The lower-right graph for Other Oil shows a similar pattern to that of Transport Oil, except that the growth of Other Oil has been more sporadic, with spurts experienced in 1982 and 1990. In contrast, the lower-left graph for Residual Oil depicts relatively small, and uneven, changes over time and relative to income.

On a per-capita basis, the relationship between oil demand and income growth is complicated. Although total income has grown steadily, except in the early 1980s, per-capita income has been relatively flat for the past three decades, as income growth was matched by population growth. Per-capita oil consumption has grown steadily for the past two decades, after significant declines in the 1980s. See Fig. 7.

Compared with other countries at similar levels of per-capita income, Saudi Arabia's per-capita oil consumption is quite high – twice the average for the OECD countries. To put this in context, however, Saudi per-capita *energy* consumption is similar to that of OECD countries, who use substantial amounts of coal, nuclear and hydro power. Europe's oil share of energy consumption is only half that of Saudi Arabia, which uses only oil (62%) and natural gas.

Demand analyses are often done in per-capita terms, especially in panel analyses when time series for various countries are pooled together. See, for example, Gately and Huntington (2002) and Dargay and Gately (2010). These papers' analyses found that oil exporting countries' per-capita oil demand increased when per-capita income increased but did not decline when income fell—indicating an asymmetric responsiveness of demand to income changes. This was certainly the experience of Saudi Arabia, especially for Transport and Other Oil demand.

To analyze Saudi Arabia's growth in oil consumption, we believe that it is easier to understand the relationship of total demand to total income, as in Fig. 6, rather than on a per-capita basis. We do this econometrically in the following section.

3. Econometric analysis

We are interested in the relationship between oil demand and current and past levels of income. In particular, we estimate the long-run responsiveness of oil demand to changes in income: the long-run "income elasticity" of demand.

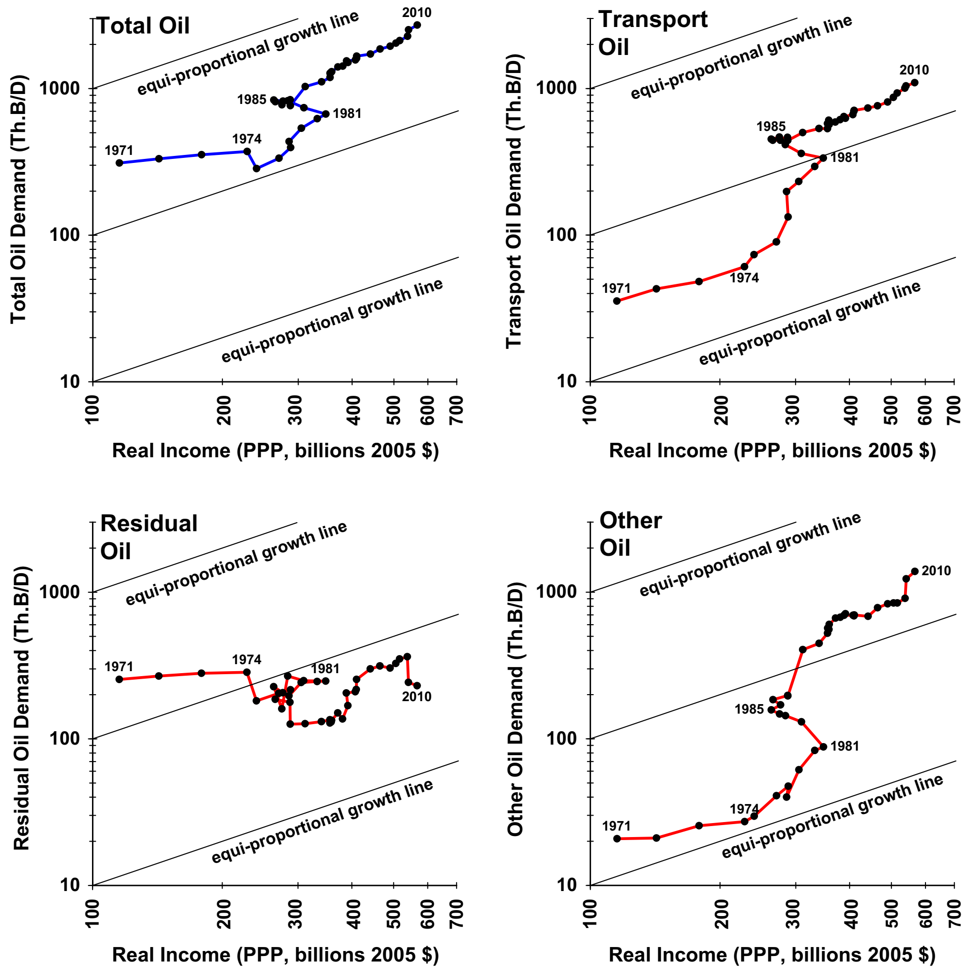

Fig. 6. Oil demand and income, 1971–2010: total oil, transport oil, residual oil, and other oil. (Oil data: IEA).

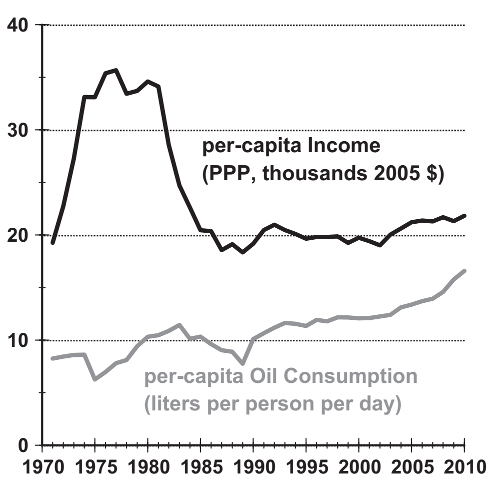

Fig. 7. Per-capita income and oil consumption, 1971–2010.

We examined two alternative approaches to this relationship: Ordinary Least Squares Regression, and Cointegration Analysis. Table 2 presents a summary of the estimated long-run income elasticities, for total oil and for each of the three oil products – using oil data both from the IEA and from the Saudi Arabia Ministry of Petroleum and Mineral Resources. The two econometric approaches and the two sources of data all provide similar estimates, which are consistent with what would be expected by the graphs of Fig. 6 above: that total oil demand increases at least as fast as income, as does transport oil and other oil, but residual oil demand has no clear relationship with income.

3.1. Ordinary least Squares regression.

We examined ordinary least squares regressions of the logarithm of demand on the logarithm of income using a partial-adjustment equation[4] – for total oil, transport oil,[5] residual oil, and other oil:

$$D_t = k_0 + k_1{}^{*}D_{t-1} + k_2{}^{*}Y_t \quad (1)$$

[4] This is the most common specification in the literature; see Gately and Huntington (2002) and Dargay and Gately (2010). Other specifications are possible, of course: see Dahl (1993, 1994). Non-linear specifications (such as the logistic) that assume saturation are not appropriate for a developing country like Saudi Arabia, although they may be appropriate for OECD countries. As noted below, Saudi Arabia's vehicle ownership is still only half the levels in Europe.

[5] For transport oil, we also examined equations using Vehicle Registration in addition to Income, and instead of Income. Although it had the expected positive sign, it was not statistically significant. Vehicle registrations were estimated from government data on cumulative New Vehicle Plates issued in a given year. This data, which start in 1970, does not reflect scrapping of vehicles, so we made assumptions about vehicle longevity for each cohort of new vehicles, and about the size of new vehicle cohorts for years before 1970. We estimated the current level of Vehicle Registrations to be about 5.8 million vehicles in 2010. Vehicle ownership (vehicles per 1000 people) has increased from about 60 in 1971 to 228 in 2010, which is about half the levels of Europe, despite comparable levels of per-capita income; see Dargay et al., (2007).

Table 2
Long-run income elasticity of oil demand, using annual data 1971–2010.

Ordinary least squares		Cointegration	
Using IEA data	Using SA Ministry data	Using IEA data	Using SA Ministry data
Total oil			
2.06	1.88	2.02	1.73
Transport oil			
1.74	1.80	1.76	1.84
Residual oil			
0.42	0.97	1.67 Not cointegrated	1.27 Not cointegrated
Other oil			
3.19	2.81	1.98 Not cointegrated	2.60 Not cointegrated

where D_t represents the log of Oil Demand in year t and Y_t the log of Income in year t.

In addition, we also included price as an explanatory variable but it was never statistically significant.[6] This does not imply, of course, that increasing domestic end-user product prices would have no effect on restraining demand. It only means that historical prices have been so *consistently* low that we cannot detect their effect on oil demand in Saudi Arabia. However, comparisons with other countries, in which end-user prices are ten to twenty times higher than in Saudi Arabia, suggest that per-capita consumption can certainly be reduced by higher prices.

We also estimated demand equations in which we replaced income by its two components: oil income and non-oil income. In all equations the two income components had the expected positive sign but were never statistically significant, except for non-oil income in the transport oil equation.

Improvements in technology might also affect demand. However, lacking data to measure this variable, we did not include its possible effect.[7]

The resulting long-run elasticities of demand with respect to income are presented in Table 2. Details of the OLS regressions using the IEA demand data are presented in Appendix B; results using demand data from the Saudi Ministry were very similar.

3.2. Cointegration analysis.

We also examined the stationarity of the different variables, and performed a cointegration analysis of the relationship between demand and income. The details of the statistical tests and of the results for the IEA data are presented in Appendix C; results for data from the Saudi Ministry were very similar. The long-run elasticities of demand, also presented in Table 2, are similar to those resulting from OLS regression.

$$D_t = k_0 + k_1{}^* Y_t \quad (2)$$

These long-run income elasticities of oil demand indicate that total oil demand grows about twice as fast as income. Transport Oil and Other Oil also grow faster than income, while Residual Oil grows more slowly.[8]

As with the OLS results, we also examined replacing income with its components: oil income and non-oil income. Cointegration was found only for Transport Oil, indicating the existence of a long-run relationship, but was not found for Total Oil or the other two products. For Transport Oil, the long-run elasticity was estimated to be 1.43 with respect to oil income and 1.28 with respect to non-oil income.

Even if the effect of the rapid growth of the 1970s is removed, by eliminating those years from our regression analysis (as discussed in Appendix B), the income elasticity remains relatively high for total oil, at about 1.5 – meaning that oil demand is likely to grow significantly faster than income. This is an important result, because it indicates the challenges that Saudi Arabia will face in maintaining its oil export levels.

These estimated income elasticities of Saudi oil demand can be compared with those in the literature. Dargay and Gately (2010) estimated per-capita demand equations for different groups of countries around the world. For the group of Oil Exporters, they found an asymmetric response to income changes: oil demand (except for Residual Oil) increased as fast as income for increases to maximum historical levels, and nearly as fast for income recoveries. In the most recent summary of demand elasticities, Dahl (2007) reports median estimates for income elasticities for oil products in *all* Non-OECD countries to be about 1 for most oil products; similarly for Dahl (1993, 1994).

4. Projections of oil consumption

Our econometric analysis indicates that the income elasticity of Saudi oil consumption is certainly greater than 1 and could be as large as 2. This means that domestic oil demand will grow faster than income, as it has for the past 40 years. Since 1971, annual demand growth has averaged 5.7% with income growth 4.2%. Since 1985, demand has grown 4.8% annually and income 3.1%.

Moreover, there is an uncertainty about income growth in the future, which in the past has averaged 4.2% annually since 1971 and 3.1% annually since 1985. Most long-term projections of income growth are in the range of 3.5%–3.9% annually.[9]

For illustrative purposes, we project to year 2030 an oil demand growth rate of 5% annually.[10] Such a growth rate would result from projecting an income growth rate of 3.6% annually (which is slightly lower than what are assumed by IEA and DOE), combined with an income elasticity of oil demand equal to 1.4, which is at the low end of the range we estimate. This yields substantially higher projections than those made by IEA and DOE, who for the last 15 years have persisted in oil demand growth projections of only 2% or less, despite actual growth of 5% annually.[11]

[6] We used the world price of crude oil (BP Statistical Review of World Energy 2011), in lieu of domestic end-user product prices which were not available except for a few years (Metschies, 2005). Domestic prices for oil products are very low and almost constant; there are no plans to change these prices in the near future.

[7] Such data on technological improvements are not available, even for OECD countries. For example, Griffin and Schulman (2005) used simple time-trend variables when attempting to capture the effects on OECD oil demand of energy-saving technical change.

[8] However, for Other Oil and Residual Oil, the income coefficient is not statistically significant in the OLS regression. Income is not cointegrated with Other Oil and Residual Oil. Details are discussed in Appendix B (OLS) and Appendix C (Cointegration). The elasticities are shown only for comparison.

[9] Income projections to 2016 for Saudi Arabia in the latest IMF World Economic Outlook (2011) have growth rates that average greater than 6% annually. Long-term income growth projections to 2030 for the Middle East by DOE (2010) and IEA (2010) are, respectively, 3.8% and 3.9% annually. IEA (2005) projected 3.5% annual income growth for Saudi Arabia over the period 2003–2030.

[10] This is similar to the 5.36% growth rate for Saudi oil consumption that is assumed by Lahn and Stevens (2011) in their Business-As-Usual scenario. They also consider two alternative scenarios: (1) higher production and consumption of natural gas, which substitutes for oil consumption and slows oil growth to 3.7% annually; (2) nuclear power development combined with increasing energy efficiency, which slows oil growth to 2.6% annually.

[11] The IEA (2010) provides the detailed assumptions that underlie their oil demand projections but they do not provide the basis for those assumptions. They

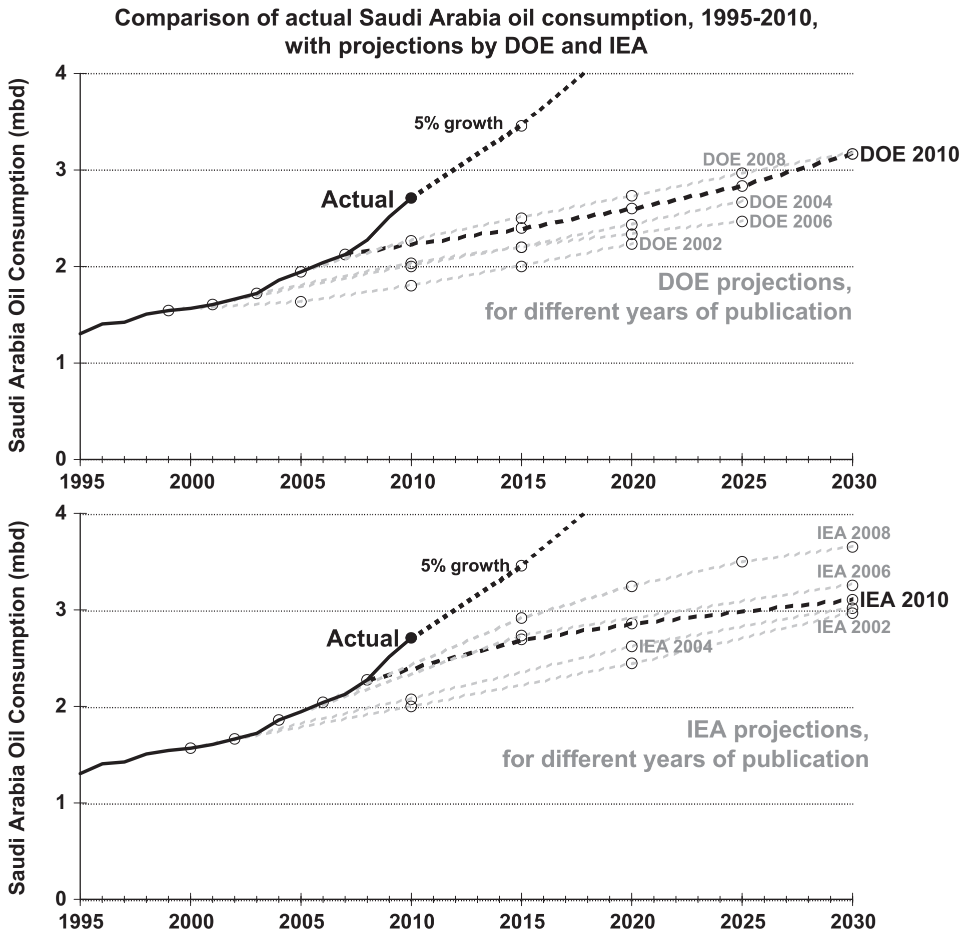

Fig. 8. Comparison of actual Saudi Arabian oil consumption 1995–2010 with projections by DOE and IEA published from 2002 through 2010.

Fig. 8 compares actual oil consumption for 1995–2010 with projections made by DOE and IEA,[12] shown as several dashed lines. Also shown, as a dotted line, is our projected growth rate of 5% annually. The DOE and IEA projections have consistently underestimated the growth of actual consumption. For example, the DOE and IEA projections published in 2002 were much too low, underestimating the actual 2010 consumption by 30%. The actual 2010 consumption level of 2.7 mbd was not projected to occur until 2020 or 2025. Subsequent projections, published in 2004 through 2010, persisted with a low projected growth rate of about 2% annually. Each year's new publication merely increased the starting year's consumption value but did not modify the projected growth rate. For example, the DOE 2002 publication used 1999 consumption as its starting historical value and projected a growth rate of 1.8% annually. The DOE, 2010 publication updated the starting historical value to that of 2007 (to a level that, in the 2002 projection, had not been expected to be reached until nearly 2020), but again continued to use the same projected growth rate of 1.8%.

Recent projections to 2030 by BP (2011b) of Middle East oil liquids are similar to those of DOE (2010) and IEA (2010): 1.79% annual growth in consumption, 1.70% in production, and 1.66% in exports.

Such demand projections are inconsistent with the historical relationship between demand and income growth, which are plotted in Fig. 9, together with the IEA (2010) projection to 2030 (1.4% demand growth, 3.9% income growth). Also plotted is an alternative demand projection that would continue the 1995–2010 growth of 5% annually. The IEA projects very slow demand growth, only 1.4% annually, to a level of only 3.5 mbd in 2030. This represents a sharp break with the historical relationship between the growth of demand and income, where demand grew 1.5 times as fast as income. The IEA projection's kink at 2010 is evident in the graph—an extreme example of "bending the curve downward": they project demand growth only one-third as fast as income. Projections by DOE and BP are similar, but are not shown.

The alternative projection shown, which we believe is more likely, continues historical growth of consumption at 5% annually. This increases consumption to 7.2 mbd in 2030, which is *twice* the level projected by IEA.

The implications of these projections for oil intensity (the oil/income ratio) are the following. The IEA projection implies a sharp

(*footnote continued*)
rely upon the wisdom of experts rather than econometric analysis. DOE (2010, Appendix L) mentions the models on which some of their demand projections are based. These are sectoral end-use demand models for various fuels in 16 regions or countries of the world, not including the Middle East, about whose demand projections they provide no details.

[12] Projections of oil consumption for the Middle East region (but not specifically for Saudi Arabia) are published each year, by DOE in their *International Energy Outlook*, and by IEA in their *World Energy Outlook*. Recently, BP has also published such projections (British petroleum BP, 2011b): see *BP Energy Outlook 2030*. In all cases, the Middle East region includes Iran, Iraq, Syria, Lebanon, Israel, Jordan and the entire Arabian peninsula. We assume that Saudi Arabia's regional share of these projections for the Middle East remains constant at its average historical level of 33%. (Only in the 2005 edition of the IEA *World Energy Outlook* has there been an explicit projection for Saudi Arabia itself, with 2.55% annual growth, which is virtually identical to assuming a constant share for Saudi Arabia in Middle East projections.)

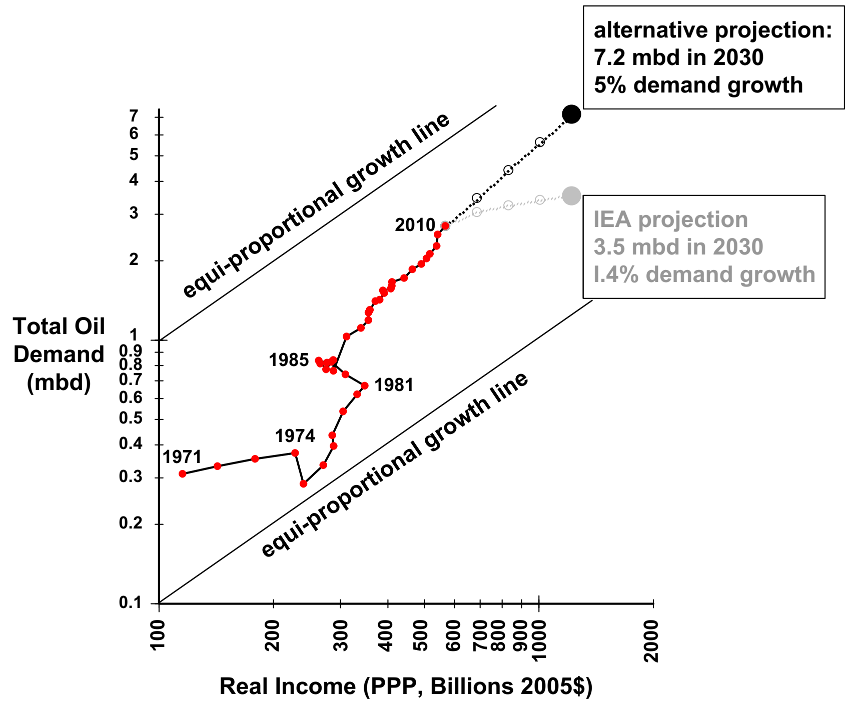

Fig. 9. Oil demand and income: 1971–2010, with the IEA projection and an alternative projection to 2030, with 3.9% income growth (logarithmic axes).

Table 3
Projections of Saudi Arabia's oil consumption, production and exports in 2030 (mbd).

	Oil consumption	Oil production	Oil exports
History: year 2010 (mbd)	2.7	10.0	7.3
Projections for year 2030 (mbd):			
IEA	3.6	11.8	8.2
DOE	3.8	13.0	9.2
BP	3.8	14.1	10.2
Our consumption projections (combined with 3 alternative	7.2	12.2 (1% growth)	5.0
annual growth rates for production)	7.2	14.9 (2% growth)	7.7
	7.2	18.1 (3% growth)	10.9

decline in oil intensity, to a level in 2030 that has not been experienced since the early 1980s. In contrast, our projection implies a continuing increase in oil intensity, growing at about the rate of the past three decades. See Fig. 4 for historical levels.

Continuing growth in world oil consumption and OPEC oil exports are common features in projections made by IEA (2010), DOE (2010), OPEC (2010), Exxon-Mobil (2010), and BP (2011b). All five institutions project that world oil consumption will continue to grow, from 85 mbd in 2008 to levels in 2030 that range from 103 to 106 mbd. Similarly, all project that OPEC oil exports will continue to increase, from 28 mbd in 2008 to levels in 2030 that range from 33 mbd (DOE) to 41 mbd (IEA).

However, the rapid growth of domestic oil consumption will make it difficult for Saudi Arabia to increase oil exports without substantial increases in production. Table 3 shows the latest projections to 2030 by IEA, DOE, and BP, compared with three projections using our annual consumption growth with three alternative rates of production growth. IEA, DOE and BP project only modest increases in Saudi oil consumption—less than 2% annually.[13] This allows them to project increases in Saudi oil exports[14] to 2030 with only small increases in Saudi oil production.

In contrast, if Saudi oil consumption were to grow at the rate we project, there would be major implications for production and export levels.[15] If Saudi production were to increase slowly, by only 1% annually, similar to what IEA and DOE assume, then Saudi oil exports would decline sharply. Faster production growth of 2% annually, to 15 mbd in 2030, would be required just to *maintain* oil export levels. Even faster growth in production of 3% annually, to 18 mbd in 2030, would be required to increase oil exports significantly, to 11 mbd.

Of course, comparison of only two sets of oil demand projections as in Fig. 9 – between the IEA's projected 1.4% growth rate and our 5% growth projection – does not fully reflect the range of uncertainty about the growth of Saudi income and oil demand. Shown in Table 4 are the implied growth rates of oil demand that would result from the two main sources of uncertainty: future income growth rates and the income elasticity of oil demand. We assume that average annual income growth is likely to be in the range of 3%–4%, and that the income elasticity of total oil demand is between 1 and 2. This implies an oil demand growth ranging from 3% to 8%. Even the low end of this range (3% growth) is much faster than the assumed growth rates used by IEA (1.42%), by BP (1.79%) and by DOE (1.88%).

[13] For the Middle East region, IEA (2010) New Policies scenario assumes 1.42% annual growth in oil consumption, DOE (2010) Reference Case assumes 1.88% annual growth, and BP Energy Outlook 2030 (2011b) has 1.79% growth. All three project substitution of natural gas for oil, but all assume *significant* slowdowns from the 1985–2010 annual growth rates of both total energy and natural gas consumption. The annual growth rates for total energy projected by IEA, DOE and BP respectively are 2.2%, 2.1%, and 3.0%—about half the 1985–2010 growth rate of 5%. For natural gas, the projected growth rates are respectively 2.7%, 2.5%, and 3.9%—also about half the 1985–2010 growth rate of 7%.

[14] Annual % growth in Saudi oil exports: 0.57% for IEA, 1.17% for DOE, 1.66% for BP.

[15] This is a central theme of Lahn and Stevens (2011). They project Saudi oil consumption growing to 7.7 mbd by 2030 under their Business-As-Usual scenario, with slower growth under two alternative scenarios: to 5.6 mbd (higher natural gas) or 4.5 mbd (energy efficiency plus nuclear power).

Table 4
Implied annual rates of Saudi oil demand growth to 2030, as a function of assumptions about future income growth rates and the income elasticity of oil demand.

Alternative annual income growth rates to 2030		Alternative assumptions about income elasticity of total oil demand			
		Lowest plausible income elasticity of total oil	Ratio of oil demand growth to income growth		Our estimated income elasticity of total oil
			1971–2010	1985–2010	
		1.0	1.37	1.55	2.0
Lower bound of likely income growth to 2030	3%	3.0%	4.1%	4.7%	6.0%
Average % income growth 1985–2010	3.1%	3.1%	4.2%	4.8%	6.2%
IEA (2005) projected for Saudi Arabia, 2003–2030	3.5%	3.5%	4.8%	5.4%	7.0%
DOE, Middle East region, projected to 2030	3.8%	3.8%	5.2%	5.9%	7.6%
IEA, Middle East region, projected to 2030	3.9%	3.9%	5.3%	6.0%	7.8%
Upper bound of likely income growth to 2030	4%	4.0%	5.5%	6.2%	8.0%

Table A1
Data.

Source	IEA				SA Ministry of Petroleum and Mineral Resources				Penn world tables	
Units	Total Oil	Transport Oil	Residual Oil	Other Oil	Total Oil	Transport Oil	Residual Oil	Other Oil	Population	Real Income, PPP
	Thousand Barrels per day				Thousand Barrels per day				millions	billions 2005 $
1971	311	35	254	21					5.99	115
1972	332	43	268	21					6.26	142
1973	354	48	280	26					6.56	179
1974	373	61	285	27					6.89	228
1975	285	73	182	30					7.25	240
1976	335	90	204	41					7.65	271
1977	396	133	216	47					8.08	288
1978	435	198	197	40					8.54	286
1979	536	232	242	61					9.05	305
1980	623	294	246	83	493	266	162	65	9.60	332
1981	671	335	248	88	495	325	97	73	10.20	348
1982	740	361	249	130	597	388	112	97	10.83	309
1983	826	414	268	143	694	432	135	127	11.49	284
1984	774	467	160	147	734	463	147	123	12.17	275
1985	835	451	227	157	794	454	212	128	12.87	263
1986	821	444	206	170	752	436	188	128	13.58	277
1987	814	443	186	185	743	444	160	139	14.31	266
1988	839	464	178	198	770	466	146	158	15.03	287
1989	764	442	126	196	724	478	96	150	15.68	288
1990	1032	500	127	405	782	498	94	189	16.26	312
1991	1112	533	131	448	844	536	93	215	16.60	340
1992	1191	532	135	524	864	552	104	208	16.95	356
1993	1271	576	128	567	931	597	97	238	17.38	356
1994	1294	607	130	557	961	612	95	254	17.82	358
1995	1303	567	134	602	925	570	98	256	18.27	359
1996	1405	590	150	665	1006	598	93	315	18.74	371
1997	1423	613	137	674	1039	621	102	317	19.21	381
1998	1507	626	168	712	1117	634	131	352	19.70	391
1999	1543	643	205	695	1153	647	166	341	20.20	388
2000	1567	663	209	695	1176	670	171	335	20.64	407
2001	1605	698	217	689	1214	701	183	330	21.10	410
2002	1662	709	254	698	1223	715	217	291	21.57	410
2003	1720	735	300	685	1277	747	264	266	22.04	442
2004	1858	761	314	782	1323	775	275	274	22.53	465
2005	1944	808	304	832	1387	818	269	299	23.12	491
2006	2041	870	327	844	1466	877	280	309	23.68	506
2007	2124	931	351	842	1586	949	306	330	24.24	516
2008	2275	1005	364	906	1715	1024	313	378	24.81	538
2009	2515	1041	243	1231	1890	1067	237	586	25.39	541
2010	2709	1096	230	1383	2037	1118	238	681	25.98	567

5. Conclusions

Saudi Arabia's domestic oil consumption is likely to grow in the future at least twice as fast as the projections made by IEA, DOE and BP. Those institutions project dramatic slowdowns in annual growth rates—from 5.7% since 1971 to less than 2% in the future. Their projections imply an income elasticity that is only 1/3 of what we have estimated. Instead of consumption increasing much faster than income, as it has in the past, they project that it will increase less than half as fast as income.

If Saudi oil consumption grows 5% annually, then Saudi Arabia will need to increase production 2% annually just to maintain oil export levels. By 2030, production would have to increase to nearly 15 mbd, and domestic consumption would be almost as large as oil exports. For oil exports to increase to 11 mbd by 2030, production would have to grow at 3% annually to 18 mbd.

Such rapid growth in domestic oil production, when combined with domestic end-user prices that are much lower than world oil prices, implies rapid growth in the costs of subsidizing domestic consumption. Such subsidies are not explicit costs that appear as budgetary items. Instead, they are the opportunity costs of oil exports foregone, now or in the future.

Restraining the growth of domestic oil consumption will be a challenge, both economically and politically. Saudi Arabia uses relatively little residual oil, which limits the possibilities of fuel-switching to natural gas. Vehicle ownership, currently at 230 vehicles per 1000 people, is only half the levels in Europe and Japan, and only 30% of that in the USA, and hence far from saturation. Increasing the end-user prices for domestic oil products, making them closer to the opportunity cost of exports foregone, would be an important component of a longer-term strategy. Although the immediate effects on demand would be limited by low price-elasticities in the short run, the longer-run effects on slowing demand growth would be substantial.

Appendix A. Data

Data are shown in Table A1. There are two published estimates of Saudi Arabia's consumption of oil products, the IEA and the Saudi Arabian Ministry of Petroleum and Mineral Resources. We used primarily the IEA data:

1971–2008: IEA, Energy Balances of Non-OECD Countries, Paris, 2010

2009–2010: Joint Organizations Data Initiative, www.JodiData.org

We calculated Transport Oil as the sum of Motor Gasoline, Aviation Fuels, and GasOil (which includes not only diesel oil but also light fuel oil used for heating and other purposes; these are disaggregated by the IEA only for the OECD countries). Other Oil is calculated as Total Oil minus Transport Oil and Residual Oil; it includes LPG, naphtha, non-jet kerosene, and other products. For 2009–2010, we used oil product data from JodiDATA by assuming the following: (1) JodiDATA "kerosene" was disaggregated into jet-fuel kerosene and other kerosene in the same proportion as the 2008 IEA data, and then aggregated gasoline, gas oil, and jet-fuel kerosene into "transport oil"; (2) the IEA total increased from 2008 to 2009 and 2010 by the same percentage as the totals from JodiDATA; (3) Other Oil in 2009 and 2010 was calculated as the difference between the total demand calculated in (2) minus transport oil calculated in (1) and the JodiData values for Residual Oil in 2009–2010.

Demand data from the Saudi Ministry are similar to the IEA data, with one important exception. The IEA classifies ethane (feedstock to petrochemicals) within Other Oil, while the Ministry reports it as natural gas consumption, because it comes from natural gas plants, unlike other liquids consumption from oil refineries. The two data sources are compared in Fig. A1. As noted in the text, the econometric results are similar, as summarized in Table 2.

Other data used were the following:

- Real GDP, PPP (constant 2005 international $): Penn World Tables
- Real GDP, Oil and Non-Oil (1999 Riyals): National Account Statistics, Saudi Arabian Monetary Agency—46th Annual Report
- Population: Penn World Tables
- World crude oil prices (2010 $ per barrel), 1971–2010: BP Statistical Review (2011a)
- Natural Gas consumption: BP Statistical Review (2011a).

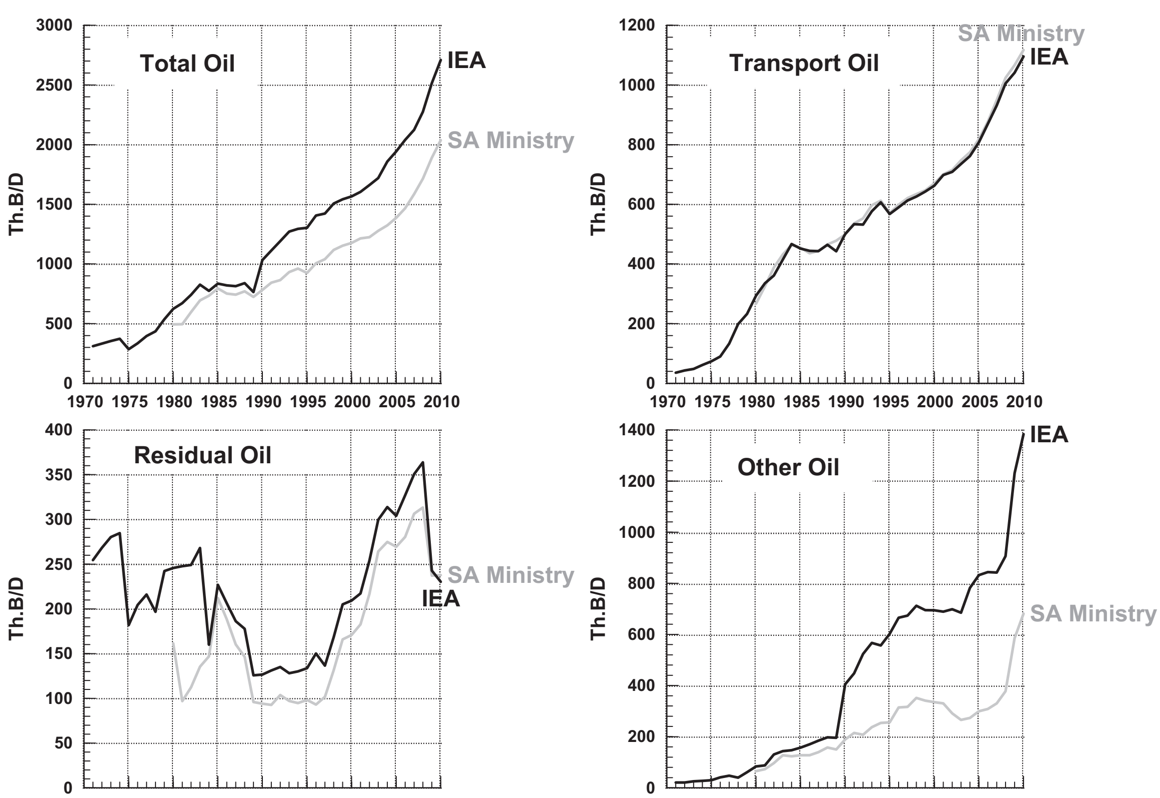

Fig. A1. Comparison of demand data from IEA and from Saudi Arabian Ministry of Petroleum and Mineral Resources, 1971–2010 .

Appendix B. Ordinary Least Squares Regression Analysis

Table B1 shows the results for several least-squares regressions of demand on income: for total oil, transport oil, residual oil, and other oil. We use a log-linear, partial adjustment demand equation:

$$D_t = k_0 + k_1{}^{*}D_{t-1} + k_2{}^{*}Y_t \quad \text{(a1)}$$

Table B1
Ordinary least squares results, annual data 1971–2010.

	Ordinary least squares		
	Equation coefficients		
	Speed of adjustment 1−k1	Income k2	Long-run income elasticity k2/(1−k1)
Total oil	0.11 t=19.9	0.23 t=2.5	**2.06**
Transport oil	0.15 t=41.0	0.25 t=3.9	**1.74**
Other oil	0.08 t=24.4	0.27 t=1.6	**3.19**
Residual oil	0.17 t=9.4	0.07 t=0.7	**0.42**

where D_t represents the log of Oil Demand in year t and Y_t the log of Real Income in year t.

All the coefficients have the expected sign and magnitude. All are statistically significant, except income for Residual Oil and for Other Oil. For each equation the Adjusted R^2 was 0.98 or higher, except Residual Oil for which it was 0.70.

One important question is whether these econometric estimates are stable, over different time periods of data. In particular, might the estimates be highly dependent upon the rapid demand growth experienced in the 1970s, which might not be relevant for the future relationship between demand and income? To address this, we re-ran the equations multiple times, successively dropping the initial years of the data sample. Thus, instead of starting our data in 1971, we also estimated the long-run income elasticities for the data sample 1972–2010, then 1973–2008, and so forth, with our final estimation using only relatively recent data 1994–2008. These results are shown in Fig. B2.

The estimate for Transport Oil is the most stable – once the first few years of data are dropped, the elasticity is fairly steady at about 1.3. For Total Oil, the income elasticity estimate is almost as stable as that for Transport Oil: as the early years are dropped from the data sample, the income elasticity declines slowly, to about 1.5. In contrast, the estimated elasticities for Other Oil and especially for Residual Oil are relatively sensitive to dropping of additional years of data.

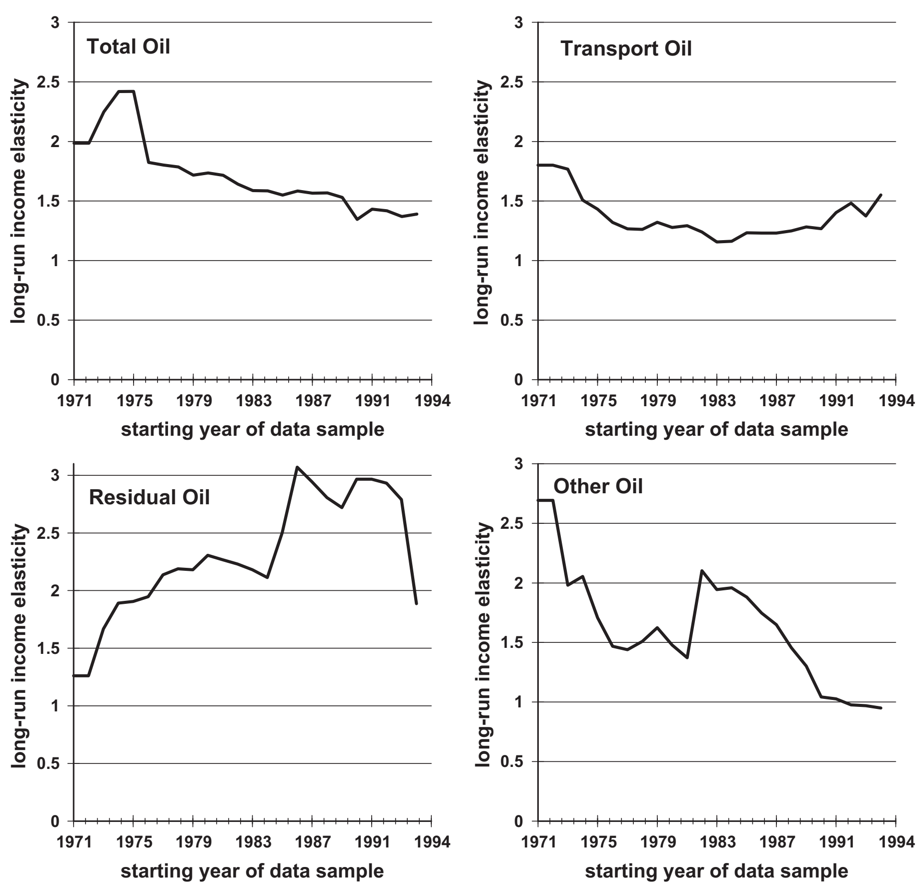

Fig. B2. Sensitivity of long-run income elasticity to starting year of data.
The estimate for Transport Oil is the most stable – once the first few years of data are dropped, the elasticity is fairly steady at about 1.3. For Total Oil, the income elasticity estimate is almost as stable as that for Transport Oil: as the early years are dropped from the data sample, the income elasticity declines slowly, to about 1.5. In contrast, the estimated elasticities for Other Oil and especially for Residual Oil are relatively sensitive to dropping of additional years of data.

Table C1
Unit root test results.

	Intercept only				Intercept and trend			
	Level		First difference		Level		First difference	
	ADF	PP	ADF	PP	ADF	PP	ADF	PP
Critical value	−2.94	−2.94	−2.94	−2.94	−3.53	−3.53	−3.53	−3.53
Total oil	3.20	3.08	−4.54	−4.68	0.38	0.38	−5.56	−5.60
Transport oil	1.28	0.75	−4.37	−3.18	−0.42	−1.30	−4.45	−3.16
Residual oil	−1.88	−1.83	−7.06	−7.08	−1.95	−1.88	−7.01	−7.02
Other oil	2.31	2.31	−4.05	−4.04	−1.22	−0.30	−4.56	−4.56
GDP	−0.78	−0.90	−4.05	−3.98	−1.64	−2.19	−5.19	−3.96

Notes: For each variable, one lag was included in the estimation to eliminate the possibility of autocorrelation of residuals. The lag was determined according to the minimum value of the Akaike Information Criterion (AIC).
Critical value indicates 5% level of significance.
Types of test: Augmented Dickey-Fuller (ADF) test and Phillips–Perron (PP).

Table C2
F-statistics for cointegration relationship with income.

Critical values		
Lower bound	5.27	
Upper bound	6.16	
Total oil	7.09	Cointegrated
Transport oil	37.20	Cointegrated
Residual oil	2.19	Not cointegrated
Other oil	2.00	Not cointegrated

Appendix C. Stationarity Tests and Cointegration Analysis

Following the work of Engle and Granger (1987), which focused attention on whether the variables in a regression are stationary, we performed stationarity (unit root) tests, whose results are shown in Table C1.

The results indicate that, for all variables, the null hypothesis of non-stationarity (of unit root) *in levels* cannot be rejected at 5 percent level of significance. This casts doubts on the validity of the OLS results. However, *in first differences*, for all variables we can reject the null hypothesis of non-stationarity (of unit root) at 5 percent level of significance. It appears that all variables are integrated of order one Table C2.

We then utilized the autoregressive distributed lag (ARDL) approach to analyze the relationship between oil demand and income.[16] One of the reasons for preferring the ARDL approach is that it is applicable irrespective of whether the underlying regressors are purely I(0), purely I(1) or mutually cointegrated. Another reason for using the ARDL approach is that it is more robust and performs better for small sample sizes than other cointegration techniques. Table C3

The ARDL approach involves two steps for estimating the long-run relationship (Pesaran et al., 2001). The first step is to examine the existence of a long-run relationship among all variables in the equations under estimation. The second step is to estimate the long-run and the short-run coefficients.

F-tests are used to determine the existence of a long-run cointegration relationship. If the computed F-statistic is greater than the upper-bound critical value (see Pesaran and Pesaran (2010)), then we reject the null hypothesis of no cointegration,

[16] See Pesaran and Shin (1998); Pesaran et al., (1996); Pesaran et al. (2001). Recent studies have indicated that the ARDL approach to cointegration is preferable to other conventional cointegration approaches, such as Engle and Granger (1987), Johansen (1988), Johansen and Juselius (1990) and Gregory and Hansen (1996).

Table C3
Cointegration results.

	Cointegration		
	Speed of adjustment	Short-run income elasticity	Long-run income elasticity
Total oil	0.16 t=19.9	0.82 t=3.58	**2.05**
Transport oil	0.19 t=5.5	0.04 t=0.43 Not significant	**1.71**

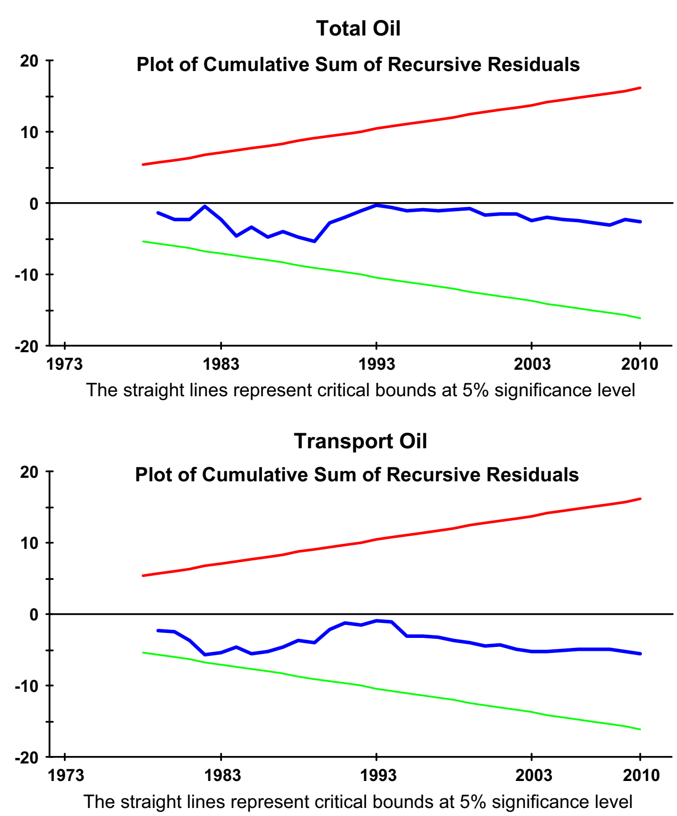

Fig. C4. Cumulative sum of recursive residuals..

and we conclude that there exists a steady-state equilibrium between the variables. If the computed F-statistic is less than the lower-bound critical value, then we cannot reject the null hypothesis of no cointegration. If the computed F-statistic falls within the lower- and upper-bound critical values, then the result is inconclusive. In our analyses, the results of the bounds tests for cointegration indicate that the null hypothesis of no cointegration can be rejected for Total Oil and Transport Oil; see Fig. C4. However, for Other Oil and for Residual Oil, the null hypothesis of no cointegration cannot be rejected, indicating no significant relationship.

Following the establishment of the existence of cointegration for Total Oil and Transport Oil, we move to the second stage, where we retain the lagged level of variables and estimate an error-correction model (ECM) equation based on the ARDL model selected by the Schwarz-Bayesian Criterion (SBC).

These results are generally similar to those from OLS regression, especially the long-run income elasticities of demand.Finally, the CUSUM and CUSUMSQ tests were applied to the residuals of the estimated error-correction model, to test for the stability of both the short-run and long-run coefficient estimates. The two graphs of these two tests (Fig. C4) reveal the estimated coefficients are stable because neither statistic crosses the critical values represented by the two straight lines. The diagnostic tests and the stability tests indicate that the models are good and can be used for forecasting.

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