Oil Demand and Technical Progress

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Abstract: This analysis provides an empirical perspective on the role of technical progress in *OECD* oil demand since 1971. It differentiates the role of price-induced and exogenous technical progress from other time-related factors that may influence oil demand growth. Results confirm that both sources of technical progress operate, but that price-induced improvements appear to be substantially larger.

Oil Demand and Technical Progress

I. Introduction

Technical progress in energy demand relationships can operate exogenously over time. It can also unfold endogenously from a mixture of sharp energy price shocks or learning by doing and other similar cost-reductions associated with increased experience with a particular process. Both sources are critically important for analyzing the impact and preferred timing of constraints on greenhouse gas (GHG) emissions (Clarke and Weyant 2002).

This analysis provides an empirical perspective on the role of technical progress in *OECD* oil demand since 1971. It differentiates the role of price-induced and exogenous technical progress from other time-related factors that may influence oil demand growth. These findings improve our understanding of the relative importance of these trends in shaping the long-run growth in oil consumption patterns.

The next section reviews some important previous research related to this topic. After the data and their properties are discussed in section III, specification issues are considered in section IV. Section V overviews the main results and key conclusions are summarized in section VI.

II. Previous Studies

Oil price shocks retarded oil demand growth during the 1970s and early 1980s. Oil demand did not spurt after oil prices declined in 1983 or collapsed in 1987. These unbalanced responses between price escalations and collapses gave rise to the asymmetric response argument related to oil consumption. For example, see Walker and Wirl (1993), Dargay and Gately (1994, 1995), Gately and Huntington (2002), Ryan and Plourde (2002), and Dargay, Gately and Huntington (2007) among others. Asymmetric long-run responses could be evidence of price-induced technical change, as suggested by Nordhaus (2002).

Price declines appeared to have much smaller effects on petroleum use than did comparable price increases. Griffin-Schulman (2005) argued that exogenous technical progress was not properly controlled in estimates based upon pooled country data. They recommended that the pooled estimates should include fixed yearly as well as fixed country effects. Without fixed yearly effects, the estimates were assigning the technical progress effects to the apparent asymmetric responses. Hunt et al (2003a, 2003b) raises similar concerns about single-country studies that fail to include a stochastic trend effect.

Several studies have tested whether asymmetric responses were a separate effect from time-related technical progress. Huntington (2006) concluded that the correct specification for the Griffin-Schulman data set should be the inclusion of both asymmetric responses and time-related technical progress. F-tests on either set of variables rejected a constrained estimation that excluded either effect. Adeyemi and Hunt (2007) revised this approach to use a set of nested tests on a similar but different OECD data set. They found that these two effects, asymmetric responses and time-related technical progress, were complements rather than substitutes. Although these two studies suggest that both effects are relevant, conditions may vary across different countries and time periods. Hence, there is a need to test these restrictions routinely.

III. Data Sources and Properties

The estimates explain per-capita oil consumption excluding residual fuel oil as a function of prices (see below) and per-capita real GDP measured in purchasing power parity terms.[1] Non-residual oil products combine both short- and long-run responses that will be important in evaluating technical progress and asymmetric responses. In contrast, residual fuel oil displays primarily short-run responses.

High-quality data for end-use oil product prices is available for only seven of the more than 30 industrialized OECD countries before 1978. The experience for the entire decade of the 1970s is critical for testing the asymmetric-response hypothesis. Restricting the data set to these few countries rather than using all OECD countries has some serious limitations. These seven major countries experienced considerably slower oil demand growth over the 1971-2005 period, the sample used for this study. Demand increased by 0.5% annually while real GDP rose by 2.0% between 1971 and 2005; the simple ratio of the two increases was only 0.25. In contrast, demand in all OECD countries grew by 1.6% per year, while real GDP grew by 2.2%; the simple ratio for the wider set of countries was 0.73.

A wider data set on all OECD 30 countries that report oil consumption since 1971 avoids the selection bias of considering only the few countries that report product prices. The main drawback is that world crude oil prices rather than country-specific product prices must be used. Fortunately, Griffin-Schulman (2005) show that estimation results

[1] Data sources include International Energy Agency, *Energy Statistics of OECD Countries*, Paris, 2007, for OECD oil consumption. Real GDP (billion 2000 US$ using PPPs) and population are derived from SourceOECD dataset, maintained by the Organization for Economic Co-operation and Development.

based upon product prices are similar to those based upon crude oil prices for industrialized countries, presumably because crude oil prices are highly fungible. The country-panel data set focuses on these countries in order to draw inferences from a wide range of country experiences.

Both the Im, Pesaran and Shin W-stat and the ADF–Fisher Chi-square tests rejected unit roots for logged levels of oil consumption, real GDP and oil prices. These tests are preferred in this application because they allow the autoregressive parameter to be panel specific rather than global, as in the Levin, Lin & Chu t test. Hence, we conclude from these unit root tests that the logged variables are stationary and can be estimated directly.

IV. Specification Issues

An autoregressive-distributed-lag (ADL) specification was selected to emphasize both short- and long-run oil consumption responses to prices and GDP, along with the technology trend and other unmeasured variables.

$$dQ_{it} = \beta_1(dP_{it}) + \beta_2(dY_{it}) + \alpha_1 Q_{i,t-1} + \alpha_2 P_{i,t-1} + \alpha_3 Y_{i,t-1} + \alpha_4 t + \lambda Z_t + \sum \lambda_i C_i + \mu_{it} \qquad (1)$$

where *Q* is per-capita oil consumption (excluding residual fuel oil), *P* is a vector of inflation-adjusted oil prices (to be discussed below), *Y* represents real per-capita country GDP in purchasing power dollars, t denotes the time trend, *Z* incorporates all other global time effects that cannot be directly measured, *C* is a vector of fixed country effects, and *u* is the disturbance term. The β coefficients are short-run price (income) elasticities, while the α coefficients capture the long-run price (income) responses.[2]

Asymmetric demand responses to price increases and decreases are represented initially in the traditional approach by decomposing the logarithm of the price variable into three series:

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

Price maximums capture major shocks that move consumers into new regions of their consumption frontiers. Price recoveries/cuts track price levels that have already been experienced. In this decomposition, price increases rise continuously over time and price decreases decline over time (e.g., see Gately and Huntington, 2002). This assumption will be revisited below.

This specification in equation (1) contains a serious problem. There are three factors that are strongly correlated with time: world price dynamics, exogenous technical progress and other time-related factors. Previous tests (Griffin and Schulman, 2005, and Huntington, 2007) suffer from this problem, because yearly dummy variables incorporate all three effects. Significant coefficients for these dummy terms do not allow one to test whether these variables' explanatory power are derived from technical change,

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[2] The response to price is $\alpha_2/(-\alpha_1)$ and that to income is $\alpha_3/(-\alpha_1)$.

asymmetric responses, or any other common, time-related factors influencing oil consumption.

This analysis adopts an approach that separates price and trend factors from other unmeasured effects. Plümper and Troeger (2007) used a three-stage decomposition approach to disaggregate fixed regional effects into effects that could be measured and effects that were not measurable. In a study of offshore U.S. natural gas reserves, Forbes and Zampelli (2009) adopted this approach to measure effects of well size and other field characteristics separately from other regional effects for which no explicit variables were available. Our problem is different but requires a similar decomposition approach. In our case, we want to disaggregate fixed yearly effects rather than fixed country effects.

V. Results

Initially, equation (1) is estimated by replacing dP_t, P_{t-1}, t and Z_t with simple fixed yearly effects that incorporate all of these factors. This initial stage provides estimated coefficients for the fixed time effects, one for each year regardless of the country. This technique is essentially the Griffin-Schulman approach but excluding all prices. These coefficients for the fixed yearly effects are regressed in the second step as functions of the price components and the time trend. When the analysis uses the cumulative price components (price maximums, cuts and recoveries), only the price maximums are significant. Table 1 shows in the first column that the time trend as well as the recoveries and cuts are insignificant. Inspection of the correlation matrix for the independent variables confirms that the time trend and these submaximum price components are highly collinear (>90%) with time. Their cumulative nature makes them increase or decrease over time.

A different approach to the second step would be to replace the cumulative price components with price levels for the years. If price maximums are again separated from reported oil prices, the remaining component is the extent to which actual prices remain below the maximum level. In other words, it is the actual price level as a ratio of the maximum price, ranging between zero and unity.[3] Additional tests supported the conclusion that the responses to these submaximum price movements are more likely symmetric than asymmetric. For this reason, only one submaximum price is included.

The second-step estimation on these revised price components now clearly shows that each variable is significant, except for the short-run effect of submaximum price changes. These coefficients, however, are not the essence of this second step. Instead, the purpose of this step is to provide residuals from the fitted and actual data. Since the equation explains how much of the fixed yearly coefficients are due to the price components and the trend, the residuals indicate the influence of other unmeasured factors that could not be directly included.

The third step involves estimation of equation (1) where the second-stage residuals are the Z variable. Results for estimated coefficients are summarized in Table 2. The coefficient on the unmeasured time factors is unity, in accordance with the discussion in Plümper and Troeger (2007).

Is there any support for considering the two price components as variables with separate effects on oil consumption? A Wald test on the joint restriction that the two

[3] Since the variables are in logarithms, this variable is constructed as the log(price) – log(maximum price).

short-run effects are equal and the two long-run responses are equal can be rejected ($\chi2$= 34.2; p-value=0.0%). Decomposing prices adds value to these estimates.

A 10% price increase beyond previous levels reduces demand by 0.7% in the short run. This response exceeds that for submaximum prices where the short-run effect is only 0.1%. The same maximum price increase reduces demand by 4.5% in the long run, considerably above the 3.4% decline related to submaximum prices. These effects for maximum price increases are not undone by subsequent price declines. Their asymmetric nature is consistent with technical progress that has been induced by sharp and sudden oil price changes.

Technical progress also operates with an exogenous trend as well. Each year, it reduces demand by 0.16% and operates against the effect of rising income. Oil demand rises more rapidly than economic growth in the long run (abstracting from trend). The time trend for exogenous technical change causes oil demand to increase somewhat more slowly over time. For an economy growing 2.2% per year (the OECD average), demand will grow 2.6% per year (incorporating the trend effect). This relatively strong income effect may be reasonable, given that residual fuel oil consumption has been excluded from these estimates. Residual fuel oil has been steadily replaced by other energy sources in virtually all OECD countries.

Quantitatively, price-induced improvements appear to dominate exogenous improvements in the long-run OECD oil demand patterns. The 2005 price maximum (achieved in 1980) is about 62 percent higher than its 1971 counterpart. When multiplied by the long-run elasticity of -0.45, the effect alone would set oil demand in 2005 about 75.5 percent of its 1971 level. This 24.5 percent decline in oil consumption is equivalent to 0.82 percent per year on an annual basis, considerably larger than the annual 0.16 percent decline for the exogenous trend.[4] Together, these two sources amount to almost a 1.0 percent decline in aggregate OECD oil demand per year.

VI. Conclusions

Technical change can be both exogenous and induced by prices and other economic variables. Although understanding the relative importance of each trend can be important, their separation can be challenging because multiple factors that could drive energy demand may change with time. This paper provides a tractable method for identifying these factors from panel data representing different country experiences. The results suggest strongly that neither the induced or exogenous trend dominates the other source of technical progress. We conclude that asymmetric price responses, exogenous technical progress trends, and unobserved time-related factors all contribute to the observed changes in oil consumption across 30 different OECD nations.

[4] Due to the large price change, these computations were done as logarithmic deviations. Thus, the price-induced reduction in demand equals exp[-0.45 x (.622)] = 0.755. Annualized, each demand level is 0.9918 times its previous year's level.

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Table 1. Dependent Variable: Fixed Time Effects from First Stage

	(1)		(2)	
Time Trend	-0.0017		-0.0016	**
	(0.0034)		(0.0005)	
Δ Price Maximum	-0.0715	**	-0.0717	**
	(0.0161)		(0.0148)	
Δ Price Recovery	-0.0127			
	(0.0312)			
Δ Price Cut	-0.0093			
	(0.0259)			
Δ Submaximum Price			-0.0104	
			(0.0135)	
Price Maximum (t-1)	-0.0291	*	-0.0297	**
	(0.0134)		(0.0072)	
Price Recovery (t-1)	-0.0215			
	(0.0185)			
Price Cut (t-1)	-0.0232			
	(0.0205)			
Submaximum Price (t-1)			-0.0222	**
			(0.0077)	
Sum of squared residuals	0.0068		0.0068	
F (zero slopes)	7.72	**	11.60	**
Adjusted R^2	0.581		0.609	

Coefficients (standard errors).
** Indicates 1 percent significance.
* Indicates 5 percent significance.

Table 2. Dependent Variable: Non-Residual Oil Demand

Δ GDP	0.8017	**
	(0.0484)	
Δ Price Maximum	-0.0717	**
	(0.0071)	
Δ Submaximum Price	-0.0104	
	(0.0065)	
Demand (t-1)	-0.0659	**
	(0.0081)	
GDP (t-1)	0.0857	**
	(0.0148)	
Price Maximum (t-1)	-0.0297	**
	(0.0035)	
Submaximum Price (t-1)	-0.0222	**
	(0.0037)	
Time Trend	-0.0016	**
	(0.0003)	
Other Time Effects	1.0000	**
	(0.0887)	
Sum of squared residuals	1.626	
Adjusted R-squared	0.459	
F (zero slopes)	24.39	**

Note: Unreported fixed country effects were also included.
Coefficients (standard errors).
** Indicates 1 percent significance.