ENERGY DEMAND AND ECONOMIC DEVELOPMENT: RELATIONSHIPS AND IMPLICATIONS

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Overview

This study analyzes the relationship between economic development and the demand for commercial energy. To capture the evolving structure of production and consumption throughout the development process, end-use energy demand per capita is modeled by sector for 60 countries spanning all levels of development. The sectors are defined as industrial, transportation, and "other" which includes residential, commercial and agricultural energy consumption. Because the share of electricity in total end-use energy consumption tends to increase with economic development, we have also chosen to disaggregate demand by energy source in the industrial and other sectors. The energy source is defined as either electricity or the sum of all other "direct-use" fuels such as petroleum products and natural gas. For the transportation sector, we model total energy consumption.

Authors such as Kuznets (1971) and Chenergy and Syrquin (1975) first described the pattern of economic development in relation to the relative shares of output by sector. Benardini and Riccardo (1993) extended this pattern of development to describe energy demand and energy intensity, defined as energy use per unit output. In particular, a predominately agrarian society neither requires large quantities of energy nor has significant levels of disposable income. However, as the nation transitions into an industrialized economy, the growth rate of energy demand is higher than the growth rate of aggregate production. Thus, energy *intensity*, defined as energy use per unit GDP, increases rapidly throughout this period. As disposable income increases, however, industrial production transitions from heavy to light industry to accommodate increasing consumer demand for light manufactured goods. Furthermore, the share of services in total output increases. This process of *dematerialization* decreases energy intensity.

A model describing energy demand as a function of aggregate output must allow energy intensity to increase rapidly during the early stages of production, to peak and then decline with output. Aggregate energy consumption will therefore correspond to the evolving structure of production and consumption. In particular, income elasticity of demand should decrease with economic development. Three notable studies allowing income elasticity of total energy consumption per capita to decline with economic growth include Judson, Schmalensee, and Stoker (1997), Galli (1998) and Medlock and Soligo (2001).

Our study is unique in two respects. First, we model energy demand per capita by energy source. Second, the data set created for this study is unique in its depth and inclusion of energy price statistics by energy source. We have collected data for 60 countries from 1980 to 2004. It should be noted that these 60 countries account for 80% of all commercial energy consumption in the world from 1980 to 2004.

Methods

Consider a model where the long-run equilibrium level of energy consumption per capita, ec_t^*, is a function of per capita output, y_t, and energy prices, p_t. To allow income elasticity of demand to be non-constant, we adopt the long-run equilibrium energy demand function specified by Medlock and Soligo (2001). This function is

$$\ln ec^*_{i,j,k,t} = a_{i,j,k} + b_{1,j,k} \ln p_{i,j,k,t} + b_{2,j,k} \ln y_{i,t} + b_{3,j,k} (\ln y_{i,t})^2 \tag{1}$$

where *i* denotes a specified country, *j* denotes a specified sector, and *k* denotes the energy source**.**

The Koyck (1954) partial adjustment mechanism describes the partial adjustment to the long-run equilibrium level of per capita energy use, $\ln ec^*_{i,j,k,t}$. Specifically,

$$\left(\ln ec_{i,j,k,t} - \ln ec_{i,j,k,t-1}\right) = \gamma_{j,k} \left(\ln ec^*_{i,j,k,t} - \ln ec_{i,j,k,t-1}\right) \tag{2}$$

where the speed of adjustment factor, $\gamma_{j,k}$, is between 0 and 1. Eliminating $\ln ec^*_{i,j,k,t}$ by substitution of (2) into (1), and allowing for time specific effects, $\theta_{j,k,t}$, and country-specific effects, $\alpha_{i,j,k}$, yields the dynamic model of energy consumption per capita to be estimated

$$\ln ec_{i,j,k,t} = \alpha_{i,j,k} + \theta_{j,k,t} + \beta_{1,j,k} \ln p_{i,j,k,t} + \beta_{2,j,k} \ln y_{i,t} + \beta_{3,j,k} (\ln y_{i,t})^2 + (1-\gamma_{j,k}) \ln ec_{i,j,k,t-1} + u_t \tag{3}$$

Where $\gamma_{j,k} a_{i,j,k} = \alpha_{i,j,k}$ and $\gamma_{j,k} b_{n,j,k} = \beta_{n,j,k}$ for $n = 1, 2, 3$. Note that the time-specific effects may capture the presence of technological innovations, and the country-specific effects may be treated as fixed or random.

Results

The dynamic model described in equation (3) is estimated assuming the country-specific effects are fixed and that time effects can reasonably be omitted using the two-stage least squares procedure. Testing procedures verify this approach. The instruments are the lagged and current values of population and the regressors. The parameter estimates of equation (3) and the implied long-run coefficients from equation (1) are presented in the following table. All parameter estimates have the anticipated sign are significant at the 5% level except the coefficient on squared income in the regressions for transportation and direct-use energy in the "other" sector. Accordingly, the results reported for equation (3) drops the variable on squared income.

Parameter estimates using a two-stage least squares, fixed effects model

	Transportation	**Industrial**		**Other**	
	Total	Direct-Use	Electricity	Direct-Use	Electricity
Estimated Coefficient					
β_1	-0.0793	-0.0411	-0.0498	-0.0350	-0.0234
β_2	0.1468	0.4618	0.7437	0.0481	0.3791
β_3	---	-0.0201	-0.0304	---	-0.0159
$1-\gamma$	0.8442	0.8441	0.8175	0.9054	0.9245
R^2	0.9930	0.9902	0.9927	0.9957	0.9978
Long-Run Coefficient					
b_1	-0.0793	-0.0411	-0.0498	-0.0350	-0.0234
b_2	0.1468	0.4618	0.7437	0.0481	0.3791
b_3	---	-0.0201	-0.0304	---	-0.0159

Conclusions

Our preliminary results indicate that a model of the relationship between energy demand and the impact of economic development may be improved by modeling energy demand per capita by sector and energy source as a function of prices and income per capita where income elasticity of demand may be non-constant. In particular, the parameter estimates for electricity demand in both the industrial sector and the residential, commercial, and agricultural sector suggest that there is some level of income per capita at which per capita energy demand begins to decrease, or at least cease to grow, with per capita income growth. Using GDP per capita denominated in 2000 PPP dollars, energy demand per capita peaks at an income level of $97,496 per capita in the industrial sector for direct-use fuels, at $205,234 per capita in the industrial sector for electricity, and $150,450 per capita in the other sector for electricity. However, the per capita demand for transportation energy and direct-use fuels in the residential, commercial, and agriculture sector will capture an increasing share ot total end-use consumption of commercial energy. This will likely translate into increasing demand for crude oil, especially for developing nations.

References

Bernardini, O. and G. Riccardo (1993). "Dematerialization: Long-Term Trends in the Intensity of Use of Materials and Energy." *Futures*, (May): 431-448.

Chenergy, H. B. and M. Syrquin (1975). *Patterns of Development, 1950-1970*. London: Oxford Press.

Galli, R. (1988). "The Relationship between Energy Intensity and Income Levels: Forecasting Long Term Energy Demand in Asian Emerging Countries." *The Energy Journal*, (19)4: 85-105.

Judson, R.A., R. Schmalensee and T.M. Stoker (1999). "Economic Development and the Structure of the Demand for Commercial Energy." *The Energy Journal*, (20)2: 29-57.

Koyck, L.M. (1954). *Distributed Lags and Investment Analysis*. Amsterdam: North Holland Publishing.

Kuznets, S. (1971). *Economic Growth of Nations: Total Output and Production Structure*. Cambridge, MA: The Belnapp Press of Harvard University.

Medlock III, K.B. and R. Soligo (2001). "Economic Development and End-Use Energy Demand." *The Energy Journal*, (22)2: 77-105.