ENERGY DEMAND AND SUPPLY ELASTICITIES

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Summary

Energy demand and supply equations are useful ways to represent consumers and producers in a competitive market. They indicate how the quantities demanded and supplied are affected when other relevant variables change. They also incorporate energy demand and supply elasticities, which indicate how responsive the quantity demanded and supplied is to other relevant variables. Elasticities are useful for forecasting and policy analysis. Demand price elasticities determine whether price increases will increase or decrease total expenditures in a market, while income elasticities will determine how the budget share of a product changes as a nation gets richer. Cross-price elasticities indicate how other related prices influence the quantity demanded or supplied of a good. Demand and supply elasticities can be used to compute the incidence of a tax or subsidy. The more inelastic side of the market pays more of a tax and receives more of a subsidy. Demand elasticities can help in forecasting the effect of an energy supply disruption on the price of an energy product. Numerous energy demand and supply elasticities have been estimated using econometric techniques. Such elasticities are unit free and can be used to create demand and supply equations. Although supply equations and supply elasticities may not be

relevant for monopoly markets, the demand side of the market may be competitive, and demand elasticities may help indicate the degree of monopoly power in a market or help forecast demand for rate of return regulation.

1. Introduction

The responsiveness of fuel demands and supplies to various economic variables are important inputs into energy planning and policy design. For example, if fuel consumption is very responsive to income growth, then high-income growth areas, such as the Asia Pacific regions prior to 1997, will have increased needs for fuel production and imports and the infrastructure that accompanies such fuel growth. Also, if production is very price responsive, only a small increase in price may be necessary to elicit the necessary production to satisfy consumption growth. Such responsiveness on both the demand and supply side of the market also influences the effects that taxes, subsidies, and a variety of energy policies, have on the price and consumption of energy products.

2. Competitive Markets

One way, that economists measure such responsiveness of production and consumption, is through demand and supply elasticities. To develop such elasticities, we must first consider demand and supply equations in a competitive market. A competitive market is a stylized market that satisfies a number of properties. First there are so many buyers and sellers that no one of them can influence the price. Second the product sold is homogenous, such as electricity, in which each kilowatt hour sold is like any other one. Third, there is free entry and exit. Thus, if the market is very profitable, firms will enter, but if firms are losing money, they will exit. Fourth in perfect competition, there is perfect information as well. If the above four properties hold, we can represent consumers by a demand equation and producers by a supply equation.

Although there are very few perfectly competitive energy markets, many might be workably competitive. Coal is not homogenous but varies by energy, ash, and sulfur, content. Nevertheless, the different grades are very close substitutes and one still might be able to estimate a reasonable demand curve for coal. Very large firms such as ExxonMobil produce and sell gasoline and may have some pricing power. Nor is all gasoline perceived as being exactly the same. However, again, the various gasolines are very good substitutes and ExxonMobil must compete against other very large firms, such as BP Amoco and TotalFinaElf, which limits its pricing power. Also, firms can and do enter and exit gasoline refining as the market changes. Certainly no market has perfect information, but in capitalist energy markets, there is a large of amount of information published and readily available.

Thus, many energy markets are workably competitive, and supply and demand equations and the resulting elasticities provide a reasonable approximation of how the two sides of the market will behave. Such equations can be estimated and will provide valuable information that can be used for forecasting and policy analysis. In markets where governments intervene and allow or require supply monopoly, supply equations will not be meaningful. This has often been the case for electricity generation, or where very large suppliers have monopoly power and can influence price, such as OPEC in the world oil market. Alternatively, where a large buyer has monopsony power and is able to influence the price, demand equations would not be meaningful. This would be the case for Eskom, the South African electrical utility, which buys all the coal from certain mines. These markets would not be workably competitive, and supply and demand equations and their resulting elasticities would be difficult to develop.

3. Supply Functions

In a workably competitive market, the quantity of energy supplied to a competitive market is a function of its price along with economic and technological variables that determine costs. For example, in a competitive market the quantity of gasoline, Q_s, supplied will be a function of the price received for the gasoline, P, the price paid for the resource inputs such as crude oil and catalysts, P_i, the price of the capital for the refinery necessary to produce the gasoline, P_k, the price of labor, which includes wages, salaries, and indirect labor costs, such as employment taxes, P_l, the price of using land or any other natural resource or other factor of production, P_n, and technological change that improves the production process for this fuel, T. Although the supplier responds to the market prices that they have to pay, if there are market externalities, such as environmental damage, that are not reflected in the market price. Then the market will under price the good and too much of the good will be produced.

Prices of other related goods will also influence quantity supplied. For example, when heavier fuels are cracked, both gasoline and lighter products are formed. These lighter products produced with gasoline are called complementary goods in production. Increasing their price, P_c, will make gasoline production more attractive. Alternatively, goods may be substitutes in production. A refiner may crack heavier products and produce more gasoline when these heavier substitute product prices, P_s, increase.

Governments may interfere in energy markets and their policies may influence quantity supplied. For example, environmental regulations, E_r, that require less pollution or more safety when producing fuels, will decrease the quantity of fuel supplied. Such regulations include the removal of sulfur from fuels, restrictions on the use of lead in gasoline in many countries in the world, and health and safety requirements in the workplace. Increasing environmental regulation increases production cost and should decrease quantity supplied. The market supply also depends on the number of suppliers in the industry #S.

Using the above variables, we can write a supply function for any energy source in a competitive market as

$$Q_s = f(\overset{+}{P}, \overset{-}{P_i}, \overset{+}{P_c}, \overset{-}{P_s}, \overset{-}{P_l}, \overset{-}{P_k}, \overset{-}{P_n}, \overset{+}{T}, \overset{-}{E_r}, \overset{+}{\#S}) \tag{1}$$

Where P = the own price, P_i = the price of resource inputs, P_c = the price of complementary goods, P_s = the price of substitutes, P_l = the price of labor, P_k = the price of capital, P_n = the price of land or other natural resources, T = technical change, E_r = environmental regulation and policy, and #S = number of suppliers.

The signs above the variables indicate whether the variable is inversely (−) or directly related (+) to gasoline production. If inversely related, the variables move in the opposite direction. When the variable goes up, production goes down. If directly related, the variable and production both increase or both decrease together. Thus, increasing costs of production, the price of substitute goods, and environmental regulations (P_i, P_l, P_k, P_n, P_s, E_r) will all decrease production, while increasing the price of complements in production, improvement in technology, and increasing the number of suppliers, (P, P_c, T, #S) will all increase production.

4. Supply Elasticities

The responsiveness of quantity supplied to a variable is called the elasticity of supply with respect to that variable. It is the percentage change in quantity divided by the percentage change in the variable. We can write the elasticity of supply with respect to price P as

$$\varepsilon_s = \frac{\%changeQ_s}{\%changeP} = \frac{\Delta Q_s / Q_s}{\Delta P / P} \qquad (2)$$

where Δ represents a discrete change in the variable. If the supply price elasticity of coal is 0.89, then when the price of coal increases by 1%, the quantity of coal supplied increases by 0.89%. The cross-elasticity of supply indicates how quantity supplied is related to price of another good. For example, if the cross-elasticity of gasoline supply with respect to the price of distillate is –0.2, then if the price of distillate increases by 1%, the quantity of gasoline produced decreases by 0.2%.

The time period over which we measure the supply elasticity influences the size of the elasticity. In the short run, say one year, if the price of coal goes up, coal mines may only be able to increase production by a small amount. Since coal mining is very capital intensive, using specialized equipment, it takes time to buy new equipment and typically takes 4-7 years to open a new mine. Thus, the short run elasticity may be quite low. However, in the long run, or in the amount of time required to totally adjust to a price change, production may change much more and the long run elasticity is likely to be much larger than the short run elasticity. The more capital intensive the industry and the longer-lived the capital stock, the greater the difference between the long and the short run elasticities.

Although the long run may vary from product to product, it is fairly well defined. It is simply the time it takes for total adjustment to take place. The short run is less well defined and typically depends on the period of interest, and is most often a year or less. If carrying out statistical analysis using actual data, the short run is often the periodicity of the data. (For example, periodicities include daily or weekly energy prices, monthly data for natural gas in storage, quarterly data on economic indicators, or annual data for oil consumption). If the analysis were on monthly data for coal supply, the short run would be a month. If the analysis were on annual data, the short run would be a year and one would expect the annual response to be larger than the monthly response. The long run elasticities in both cases should be the same but would be more elastic. For example, it has been found that the underground supply of US coal has a short run annual elasticity of 0.61 and a long run elasticity of 1.31. Thus, with time to adapt, coal producers are over twice as price responsive as they would be in a year.

5. Using Elasticities to Forecast Supply

Supply elasticities are quite useful for policy and planning as shown in the following examples. Suppose the world price of coal goes up. Government planners in Australia will want to know what will happen to domestic coal production. Because Australia is a large coal exporter, coal production will have implications for employment, GNP, tax revenues, balance of payments, and demand for mining equipment. Likewise, competitors in South Africa and the US will want such information for both their own and their competitor's production. For example, let the coal price go from US$20 per metric tonne to US$22 per metric tonne. Suppose that the short run (one year) supply elasticity is 0.10 and the long run supply elasticity is 1.1. Since

$$\varepsilon_s = \frac{\Delta Q_s / Q_s}{\Delta P / P} \tag{3}$$

then in the short run

$$\Delta Q_s / Q_s \;=\; \varepsilon_s(\Delta P / P) \;=\; 0.10 \text{x} 2/20 \;=\; 0.01 \tag{4}$$

Thus, Australian production would go up 0.01 or 1 percent. Australian production was 345.664 million metric tons in 1998, thus production would increase 0.01×345.664 = 3.456 million metric tonnes.

In the long run, the increase would be

$$\Delta Q_s / Q_s \;=\; \varepsilon_s(\Delta P / P) \;=\; 1.1 \text{ x } 2/20 \;=\; 11\% \tag{5}$$

for an increase of 0.11×345.664 = 38.023 million metric tonnes.

The same computations could be done for any policy that changed right hand side variables in the supply equation for any market that is considered competitive. For example, Israel has the largest density of solar hot water heaters supplying around 80 percent of the Israeli market for hot water. If interest rates lowered capital costs for Israeli solar hot water equipment by 22 percent, we can compute what would happen to the short run production of such hot water heaters. Suppose the short run cross price elasticity of supply with respect to the price of capital is −0.15. We can again use the same procedure but substituting the proportionate change in capital price for the proportionate change in own price or:

$$\Delta Q_s / Q_s \;=\; \varepsilon_s(\Delta P_k / P_k) = (\ 0.15) \text{ x } (-0.22) = 0.033 \tag{6}$$

If production of water heaters had been 100,000, then new production would be (1 + 0.033) ×100,000 = 103,300.

Supply elasticities for products are derived by using econometric estimations based on historical data, or by using engineering estimates of costs of production. Studies using simple models for the US have found the following long run own price elasticities of supply: ε (natural gas) = 0.41, ε (uranium) = 0.74 to 3.08, ε (Appalachian coal) = 0.41 to 7.90.

6. Energy Demand

On the other side of the market are all the consumers of energy. In a workably competitive market, we can represent their consumption with a demand function. To illustrate such a function, take the demand for natural gas in the largest gas consumer in Europe - the Netherlands. It has large reserves of natural gas, which supply over half of its energy needs. For household or personal consumption, let the quantity demanded of natural gas be a function of the natural gas price, P. As gas prices increase, households will economize and buy less gas.

Disposable income, Y, is also likely to influence Dutch gas consumption. As disposable income increases, consumers are likely to buy larger houses and more appliances, which is likely to increase their demand for natural gas. Their natural gas consumption is also a function of other related prices. Suppose the price for electricity, P_s, a substitute for natural gas, increases. This price change may cause consumers to shift away from electric water heaters, clothes driers, and furnaces, to ones that use natural gas, thus decreasing the quantity of natural gas demanded. With increasing prices for gas appliances, P_c, which are complements to natural gas, consumers may buy fewer gas appliances and, hence, use less natural gas.

Other variables, O, may also influence the demand for natural gas and other energy products. Such variables include personal preferences, lifestyle, demographic variables, and weather. Some people prefer cooking with gas, others feel safer with electricity and use it despite the fact it is typically more expensive to use than gas. Preferences also influence the demand for other energy products. A family that travels a lot may prefer a larger more comfortable vehicle that consumes more fuel. A family where all members work out of the home may use less fuel for heating. In hot climates, more electricity may be used for air conditioning in the summer, whereas in cold climates, more electricity may be used for heating in the winter. Thus, electricity flows from Canada to the United Stated in the summer, but from the United States to Canada in the winter.
If we have total demand, we also add the number of consumers, #C, and write a general household energy demand function as follows:

$$Q_d = f(\overset{-}{P}, \overset{-}{P_c}, \overset{+}{P_s}, \overset{+/-}{Y}, \overset{+/-}{O}, \overset{+}{\#C}) \tag{7}$$

where P = the own price, P_c = the price of complements, P_s = the price of substitutes, Y = income, O = other variables, and #C = the number of consumers.

The signs again indicate whether the variables are directly or inversely related to energy consumption. For income, the sign would be (+) for a normal and (–) for an inferior good. For the other variables, O, the sign depends on the product and the other variable.

For example, it might be plus if the demand is for solar collectors and the variable is hours of sunshine, or it might be minus if the demand is for gasoline and the variable is the percent of the population over 50 years old.

Energy is not only demanded by households but is also a factor of production. Coal, oil products, gas, and uranium, are used to produce electricity and process heat. Gasoline and diesel are used in transporting goods to market. Electricity runs motors, cools and lights our factories and businesses. To illustrate factor demand, take the demand for coal for electricity generation in India, a major world coal producer. If Indian electricity generators behave in a competitive fashion, their demand would depend on the price paid for coal, P, the prices paid for the other factors of production—land, labor, and capital—that are complements to coal in producing electricity, P_c, and the price of other fuels—gas and oil—which are substitutes for coal in the production of electricity, P_s. Changing the price of electricity or the output, P_o, would influence coal demand, as would changes in technology, T. Environmental policies, E_p, such as regulations on the amount of sulfur that can be in the coal or the amount of carbon dioxide that may be omitted would reduce the desirability of coal.

For total business energy demand, the number of businesses, #B, would also be included. A general business energy factor demand function would be as follows:

$$Q_d = f(\overset{-}{P}, \overset{-}{P_c}, \overset{+}{P_s}, \overset{+}{P_o}, \overset{+/-}{T}, \overset{+/-}{E_r}, \overset{+/-}{\#B}) \qquad (8)$$

Where P = the own price of the energy factor, P_c = the price of complements, P_s = the price of substitute products, P_o = the price of output, T = technology, E_r = environmental regulation and policies, and #B = number of buyers.

The signs on technology and environmental policy are uncertain and depend on the particular technology, the fuel, and the policy. For example, environmental regulations requiring lower sulfur emissions would favor gas over coal, while new technologies that would make oil cheaper to use could increase oil demand at the expense of other fossil fuels.

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US Energy Information Administration, Department of Energy Website at http:www.eia.doe.gov. [This web site contains a wealth of data on energy consumption and production both in the United States and worldwide as well as forecasts and analysis of energy markets. It is the source of much of the actual production, consumption, price, and forecast data used in this article. It also has numerous links to other energy related web sites.]

Biographical Sketch

Carol Dahl received her Bachelors degree from the University of Wisconsin and her Ph.D. degree from the University of Minnesota in Economics. She is currently a Professor of Mineral Economics and Director of the CSM/IFP Joint International Degree Program in Petroleum Economics and Management, in the Division of Economics and Business at the Colorado School of Mines. She has supervised numerous Ph.D. students, published and traveled extensively pursuing her interests in modeling international energy markets. She has particular expertise in energy demand and supply elasticities. She authored the book *Energy Economics and International Energy Markets* (Penwell Press, 2002) and is developing material on international energy markets for a distance learning course.