PRICE AND INCOME ELASTICITIES OF DEMAND FOR ENERGY

M. K. King,
Public Policy Analysis Program, University of Rochester,USA

D. L. Weimer,
Robert M. La Follette School of Public Affairs, University of Wisconsin-Madison.,USA

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Contents

1 Introduction: Elasticities in Economic Modeling and Policy Analysis

Researchers and policy analysts are often required to articulate and answer questions similar to the following, "how will the consumption of energy change in a developing country if its national income rises by 5 percent?" Or, "how will the global market for crude oil respond to a 20 percent reduction in world price?" "Is natural gas consumption more or less responsive to price fluctuations than gasoline?" Such questions become more complicated when the variables in question are not measured in the same units. The concept of elasticity allows economists and policy analysts to answer these sorts of questions. Elasticity can be simply defined as a measure of the sensitivity of one variable to another. This essay introduces the economic concepts of price and income elasticities and reviews the empirical literature that estimates them for aggregate energy, crude oil, gasoline, and other sources of energy.

2 Basic Concepts

Specifically, elasticity expresses the percentage change in the quantity of one variable that results in response to a one-percent change in another. The concept of elasticity has many different applications, but we will primarily discuss demand elasticity in relation to price and income changes. Demand elasticity is based on the assumption that consumers choose to purchase quantities of goods in a manner that simply brings the most satisfaction for their money. In more technical terms, this is called utility maximization, subject to 1) a budget constraint (income) and 2) a given set of market prices. This maximization yields an equation for each good purchased that indicates that each particular quantity demanded by the consumer is determined by the prices of all goods considered and the consumer's income. These equations are called the consumer's ordinary, or Marshallian, demand equations. For the i^{th} good, the demand equation is given by:

$q_i = f(p_1, p_2, \ldots p_N, Y)$

In this equation, q_i, is the total quantity of good i demanded by the consumer at prices $p_1, p_2, \ldots p_N$, for goods $q_1, q_2, \ldots q_N$, respectively, and Y is the consumer's income. Based on this demand equation, three relevant elasticities can be defined in terms of partial derivatives as follows:

1) Own-price elasticity of demand for good i:
   $\epsilon_{ii} \equiv (\delta q_i/\delta p_i)p_i/q_i$

This equation indicates how changes in the price of good i, p_i, will affect the quantity of the good, q_i , demanded by the consumer. The own price elasticity of demand for good i quantifies this response. Multiplication of the partial derivatives by p_i/q_i causes the units of measurement to cancel out of the equation, leaving a pure number.

2) Cross-price elasticity of demand for good i with respect to the price of good j:
   $\epsilon_{ij} \equiv (\delta q_i/\delta p_j)p_j/q_i$

Cross price elasticity measures how much the quantity of good i demanded changes in relation to changes in the price of good j. If goods i and j are substitutes -- meaning one good can be substituted for the other, as is the case with electricity and natural gas in home space heating, then the elasticity will be positive. If the price of electricity increases, for example, then the quantity of it demanded will fall while the quantity of natural gas demanded will increase. This assumes that the price of natural gas remains constant. If the goods are complimentary -- meaning the goods tend to be used together, like automobiles and gasoline, then the elasticity will be negative. If the price of gasoline falls, then demand for automobiles will increase, under the assumption that automobile prices and income remain unchanged.

3) Income elasticity of demand for good i:
   $\epsilon_{iY} \equiv (\delta q_i/\delta Y)Y/q_i$

This equation expresses the relationship between changes in the consumer's income and the quantity of good i demanded. Income elasticity varies based on the type of good considered. For normal goods, that is, goods consumers demand more of as income increases, income elasticity is positive. These normal goods contrast to inferior goods, for which consumers demand less as income rises, which implies a negative elasticity.

Four points are worth noting. First, the standard assumptions that each good has positive but declining marginal utility leads to demand equations with negative own-price elasticities. The own-price (or simply price, unless otherwise noted) elasticity is sometimes defined as the absolute value of ϵ_{ii}. Under this definition, elasticities greater than one in absolute value are considered to be elastic – the percentage change in quantity exceeds the percentage change in price so that total expenditure on the good declines. Elasticities smaller than one in absolute value are considered to be inelastic – the percentage change in quantity falls short of the percentage change in price so that total expenditure on the good increases. Finally, elasticities equal to one in absolute value are considered to have unitary elasticity -- the percentage change in quantity demanded equals the percentage change in price so that total expenditure on the good remains unchanged. Table 1 summarizes these.

Point Elasticity Value	Terminology	Expenditure Response to Price Increase	Expenditure Response to Price Decrease
$\|\epsilon_{ii}\| > 1$	Elastic	Falls	Rises
$\|\epsilon_{ii}\| = 1$	Unit Elastic	No Change	No Change
$\|\epsilon_{ii}\| < 1$	Inelastic	Rises	Falls

Table 1: Terminology and Responses to Price Changes

Second, it is important to distinguish between point elasticity and arc elasticity. Elasticities defined in terms of partial derivatives measure change at a particular value of the demand equation. These elasticities are referred to as point elasticities. Differentials are useful in describing infinitesimal changes in quantities. When the size of the percentage change in price or income is large, however, differentials may vary over the range of the change. Replacing differentials with measurable changes makes clear the interpretation of elasticity as the percentage change in quantity demanded in response to a percentage change in one of the arguments of the demand equation. For example, we could write the own-price elasticity as $(\Delta q_i/q_i)/(\Delta p_i/p_i)$, which is the ratio of the percentage change in quantity divided by the percentage change in price. This expression makes clear that multiplying the elasticity by a percentage change in price yields the corresponding percentage change in quantity. Elasticities expressed in terms of measurable changes are referred to as arc elasticities. Arc elasticities allow calculations over a range of values of the demand equation as opposed to at particular values.

Third, demands for energy goods are generally derived from consumption of final goods such as space heating and automobile travel. Energy goods such as gasoline, natural gas, and electricity are sufficiently close to these final demands to be reasonably treated as goods directly demanded by consumers. In contrast, crude oil, which is not directly consumed as a final product, is more appropriately thought of as demanded by refiners rather than directly by consumers.

Fourth, appropriately identifying price is sometimes complicated. It is relatively simple only in well-functioning markets for goods of homogeneous quality, such as electricity in developed countries, where the monetary price seen by consumers accurately reflects how much they have to pay for each kilowatt consumed. Monetary price may not be the appropriate price for understanding demand, however, when markets are constrained, say by government regulation. For example, in a regime in which government imposes price ceilings at below market clearing prices, the true price seen by consumers is not the monetary price but also includes the costs they must bear to search for available supply and to wait in queues to obtain it. Heterogeneity in the quality or composition of goods also complicates the identification of appropriate prices. This is the case, for example, when the good in question is the total energy provided by a bundle of different fuels. An index based on the fuels contributing to total energy is required. Heterogeneity can also arise with respect to specific energy goods as well. For example, crude oil varies significantly in terms of the fraction of light hydrocarbons and sulfur that it contains and the costs of transporting it to refineries. Consequently, crude oil price is often stated in terms of a particular, marker, crude oil. While this may be appropriate for following short run fluctuations in the crude oil market, indexes may be required for both quantity and price in estimating the demand for crude oil.

2.1 Market Elasticities

In practice, economists usually estimate elasticities based on market demand. The equation for the market demand for a good, that is, the amounts demanded by all consumers at various prices holding all other prices and incomes constant, results from summing all the demand equations of individual consumers. The interpretation of own- and cross-price elasticities corresponds directly to those for the individual consumer. The interpretation of income elasticity is more complicated, however, because it requires some assumption about how a change in income is distributed among consumers. If one is considering a national market, then a change in national income may have very different effects depending on whether it is distributed in proportion to income (the case corresponding directly to the aggregation of individual demand equations) or distributed disproportionally.

Markets are typically defined geographically. Sometimes it makes sense to consider a single world market. For example, when crude oil is freely traded worldwide, it is meaningful to think in terms of a single world price, and hence a single world market. More often, however, it makes sense to think of more localized markets because of high transportation costs and variation in local conditions relevant to consumption. For example, the high distribution costs of natural gas tend to segment its market regionally by pipeline systems; differences in governmental policies that affect relevant prices tend to segment markets nationally. So, for example, price elasticities for gasoline may vary considerably across national markets.

Variation across geographic markets provides econometric leverage for estimating elasticities. For example, although the price of gasoline at the refinery gate may be the same for a number of countries, consumers in these countries may see different prices because of variations in retail gasoline taxes, regulatory policies, or transportation costs. Thus, even though the refinery price does not vary, the price seen by consumers in different countries will vary. Relating variations in consumption to those in price, in cross-sectional statistical analyses, provides one of the major bases for empirically estimating demand elasticities.

2.2 Short-Run versus Long-Run Elasticities

Markets must be defined in terms of time as well as space. The definition of a market in terms of time is relevant to elasticities when the utility gained from the goods depends on the capital goods – typically long-lasting goods that facilitate final consumption -- available to the consumer.

Some goods, such as bread and water, yield utility to consumers independently, meaning no additional goods are required to attain satisfaction from them. Seasonal effects aside, the elasticity of demand for these goods will likely be the same whether we define the market in terms of days, weeks, months, or a year. However, other goods, such as gasoline, heating oil, and electricity yield utility to consumers through the use of goods such as automobiles, furnaces, and household appliances.

In the short-run, capital goods are effectively fixed for most consumers. Over the longer-run, however, consumers may change their stocks of capital goods substantially. Fluctuations in energy prices, technological innovations, seasonal change, or simple wear and tear in the existing capital stock may motivate consumers to replace their automobiles and appliances with newer models. In essence, time affects the flexibility of consumer demand. Greater flexibility in capital stock over the longer run means that the absolute value of price elasticities are generally larger in the long run than in the short run.

Consider, for instance, the actions available to consumers in response to a large increase in the price of gasoline. In the very short run, perhaps days, consumers can eliminate trips, share rides, switch to alternative travel modes, drive more slowly, and make sure that their tires are fully inflated to reduce fuel consumption or increase fuel efficiency. Over a period of weeks, they can have their automobile engines tuned.

Over a period of months, they can replace older, less fuel-efficient automobiles with newer, more efficient ones and adjust vacation plans to reduce automobile use. Over a period of years, they can change the location of their residence or employment to reduce travel distances. A similar progression of taking advantage of greater flexibility over time can be sketched for a price increase in heating oil: turning down the thermostat, buying more sweaters, closing off rooms, putting in temporary insulation, cleaning the furnace, installing permanent insulation, and replacing the furnace.

Note that some investments in capital stock are not quickly reversible – consumers do not immediately replace the fuel-efficient automobile or rip out insulation when prices fall. A substantial and long-lived price increase followed by an equal price decrease that returns price to its original level will not necessarily return consumption to its original level.

Consequently, price elasticities are not necessarily symmetric with respect to price increases and decreases. Additionally, consumers almost certainly look ahead to anticipate future prices in making decisions concerning changes in their capital goods, though empirical estimation is almost always based only on current and past prices.

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Biographical Sketches:

Myron K. King is a government affairs analyst in Fairfax, Va. King earned his M.S. in Public Policy Analysis from the Public Policy Analysis Program at the University of Rochester in 1999. He also received B.A. degrees in Political Science and Communitcation Studies from University of Missouri in 1997.

David L. Weimer, who earned his doctorate in public policy from the University of California at Berkeley, is professor of public policy and political science at the University of Rochester. He was editor of the *Journal of Policy Analysis and Management* (1985-89). His publications include: with William Gormley, *Organizational Report Cards* (Harvard, 1999); *The Political Economy of Property Rights: Institutional Change and Credibility in the Reform of Centralized Economies* (Cambridge,1997); with Anthony Boardman, David Greenberg, and Aidan Vining, *Cost-Benefit Analysis: Concepts and Practice* (Prentice Hall, 1996); with Aidan Vining, *Policy Analysis: Concepts and Practice* (Prentice Hall, 1989, 1992, 1999); *Institutional Design* (Kluwer, 1995); *Policy Analysis and Economics* (Kluwer, 1991); with George Horwich, Responding to International Oil Crises (AEI, 1988) and *Oil Price Shocks*, *Market Response, and Contingency Planning* (AEI, 1984); and *The Strategic Petroleum Reserve: Planning, Implementation and Analysis* (Greenwood Press, 1982).