1 Introduction

The dramatic increases in energy prices that occurred when the Organization of Petroleum Exporting Countries (OPEC) quadrupled the world price of oil in 1973–74 has had profound implications for the economies of all the industrialized countries. Other commodities have experienced rapid and substantial increases in price—the prices of bauxite and coffee, for example, both tripled in recent years, and the prices of grains and other agricultural products have experienced price fluctuations on the order of 300 or 400 percent over the years. Few people, however, would be as concerned about these events, or expect them to have anywhere near the impact on our standard of living that increases in the price of energy are likely to have. Higher energy prices have contributed to reduced economic growth in many countries, and in the long run may result in basic changes in lifestyles.

How fast energy prices rise in the future will depend in part on the rate at which conventional energy resources become scarcer and more difficult to find, in part on the rate of technological change that lowers the cost of nonconventional energy sources, in part on the behavior of the OPEC cartel, and in part on the domestic energy policies of various countries. Although the dramatic increases of 1973 to 1975 are not likely to continue, we should probably expect to see energy prices continue to rise in real terms, at least slowly, for the next few decades.

There is little doubt that past and future increases in energy prices will have a dampening effect on energy demand, as well as at least a temporary dampening effect on employment and economic growth. The questions that are of interest now are, first, to *what extent* will higher energy prices reduce energy demand, and second, will higher energy prices (combined with perhaps less energy use) necessarily mean reduced economic growth and a lower standard of living? As we will see, these questions are partly interrelated—both the extent to which prices affect demand *and* the effect of prices on our standard of living depend on the role that energy plays in the production of other goods and as a part of consumers' overall purchases of goods and services.

As can be seen in table 1.1, energy is indeed a major item in the consumption baskets of private households. Expenditures on energy in 1965 accounted for 9 percent of total household consumption expenditures in the U.S., and 7 percent to 9 percent in Japan and the European countries. These numbers stayed level over the next seven or eight years as real energy prices fell slowly, but energy consumption grew. By 1974 these energy expenditure shares had risen above their 1965 levels, largely because of the major increases in energy prices that occurred in 1973–74. Similarly, the cost of energy as a fraction of the total cost of industrial production in 1965 was 3 percent in the U.S. and 4 percent to 8 percent in Japan and the European countries. These numbers also stayed relatively stable over the next seven years as real prices fell, but production became more energy-intensive and began increasing in 1974.

The importance and impact of higher energy prices is only partly due to the relative magnitudes of energy expenditures. It is more a function of the particular characteristics of energy demand—the ability of consumers to use less energy directly and to shift their purchases of goods to those that require less energy, and the ability of manufacturers to produce their goods using less energy and instead more capital. A basic objective of this book is to obtain a better understanding of these characteristics.

1.1 The Impact of Higher Energy Prices

The conventional wisdom, as reflected in both popular opinion and the working assumptions often used for energy policy analysis, is that the price elasticity of the demand for energy is very small. (Elasticities in the range of 0.2 are often casually suggested as a basis for policy analysis.) The argument behind this conventional wisdom is that increases in energy prices tend to have a much greater impact on consumers and energy-using producers than do increases in the prices of other commodities because of the critical role that energy plays, both in the consumption basket and as a factor of production. The argument is made, for example, that consumers have very little flexibility to decrease their use of energy, or even to substitute between alternative fuels, while the consumption of food and other goods can be adjusted much more easily in response to changes in price.

This argument is probably valid in the short run. If energy prices suddenly increase, consumers cannot in the space of one or two years replace their cars with smaller, more fuel-efficient ones, replace their energy-consuming appliances (refrigerators, air conditioners, for example) with more energy-efficient ones, insulate their homes, and take other measures to significantly reduce their energy consumption. If the price of oil should suddenly rise while the price of natural gas remained fixed (and if supplies of natural gas continued to be available), it is not economical to quickly switch a home-heating system from oil to gas, so the potential for interfuel substitution is quite limited in the short run. Similarly, industrial users of energy cannot change their consumption patterns very much in the short run. Most capital equipment was designed to consume a certain amount of energy, so that capital and energy must be used together, that is, they are complementary inputs to production. Thus, when energy prices increase, producers, at least in the short run, do not have the flexibility to shift to more capital-intensive and less energy-intensive means of production. (Some shift to the use of more labor is possible, but this is costly in most industrialized countries where labor has become an increasingly expensive factor input.)

While this conventional wisdom is probably true for the short run, it may be far from true in the long run. Indeed, an important question facing us today is just how much flexibility there is in the use of energy in the long run. The answer to this question has important implications for the design of energy policy, and also for our assessment of the impact of higher energy prices on such macroeconomic variables as inflation, employment, and economic growth. If the household demand for energy is indeed sensitive to price in the long run, then eventually the impact of higher energy prices on consumers' budgets will be reduced as the quantities of energy consumed are reduced, and tax policies designed to reduce or limit household energy consumption would have a reasonable chance of success. Similarly, if energy and capital or labor are substitutable in the long run, and if the long-run price elasticity of industrial energy demand is sufficiently large, then increases in the price of energy will tend to drive up the cost of manufactured output by a smaller amount, and therefore have a smaller macroeconomic impact.

The long-run impact of changes in energy prices on energy use has an impact on energy prices themselves. The world price of oil is largely determined by the OPEC cartel, and changes in this price tend to drive changes in the prices of other fuels. Thus OPEC has the ability within limits to manipulate world energy prices. Of course, the prices actually faced by consumers will depend also on the taxes and/or price controls in individual countries, but these prices are still very much a function of OPEC's decisions with regard to the world price of oil. OPEC's ability to raise price, on the other hand, is to a considerable extent dependent on the price responsiveness of total energy demand, as well as the price responsiveness of non-OPEC energy supply. If in the long run energy demand is quite price responsive, then this means that OPEC cannot increase oil prices very much in the future (without incurring significant revenue losses). Thus our ability to predict energy prices in the long run (that is, to predict OPEC's pricing behavior) depends in part on our understanding of the long-run price and income elasticities of energy demand.

Another important question is the extent to which individual fuels can be substituted for each other in the long run. Over the next two or three decades reserves of oil and natural gas may be reduced considerably, so that the availability of moderately priced energy will depend in part on the ability of electric utilities and industrial consumers of energy to switch from these fuels to coal or perhaps nuclear power. In the somewhat shorter term, the impact on oil demand of increases in natural gas prices in the U.S. will depend on the extent to which these fuels are substitutes in different sectors. Finally, the extent of interfuel substitutability determines in part the impact of an increase in the price of oil or natural gas on the cost of manufactured output, and the impact of a shortage of oil or natural gas on the level of output. Thus a better understanding of the extent of interfuel substitutability and the magnitudes of cross-price elasticities of fuel demands is needed if we are to be able to evaluate the impact of changing fuel prices, and if we are to be able to design intelligently an effective energy policy.

The main focus of this study is to determine the characteristics of energy demand in the long run. We have had a rather poor understanding of the response of energy demand in the long run to changes in prices and income, and this has made it difficult to design energy and economic policies. By working with models of energy demand rather different from those that have been used before and by estimating these models using international data, we can better understand the long-run structure of energy demand and its relationship to economic growth.

1.2 The Structure of Energy Demand

The ratio of energy demand to GNP has been fairly constant for the U.S. over the period 1950 to 1974, and this has led some people to believe that a more or less fixed proportionality between energy use and total economic output must always hold. Such a belief, however, is completely unfounded. Until 1974, energy prices in the U.S. declined slowly but steadily in real terms, while recently we have experienced large increases in energy prices—increases which may significantly alter the amount of energy used per dollar of output. In addition, energy use per dollar of gross output has varied considerably across countries, and for many countries the ratio has changed significantly over time. This can be seen in figure 1.1, where we have plotted energy consumption per million dollars of gross domestic product (measured in constant 1970 U.S. dollars) for the U.S., Canada, the U.K., the Netherlands, France, and West Germany.[1] Note that the four European countries have energy/output ratios well below those of the U.S. and Canada, the ratio for the U.K. has declined somewhat over time, and that for the Netherlands has increased over time. There would certainly seem to be no magic number for an energy/GNP ratio.

Why do we observe these differences in energy/output ratios across countries, and why have the ratios increased in some countries, decreased in others, and remained more or less level in still others? An answer often given to these questions is that there are significant differences in lifestyles across countries which result in different needs for energy. Examples often cited include different sizes of cars driven because of basic inherent differences in tastes, or differences in the extent of home heating because of different habits. While tastes and habits may indeed differ across countries, and across time in any one country, this certainly does not provide

1. Energy use in that figure and elsewhere in this study is measured in teracalories (Tcals). 1 Tcal = 10^{12} calories = 3.97×10^{9} Btu. Note that the thermal content of a barrel of oil is roughly 1.5×10^{-3} Tcals.

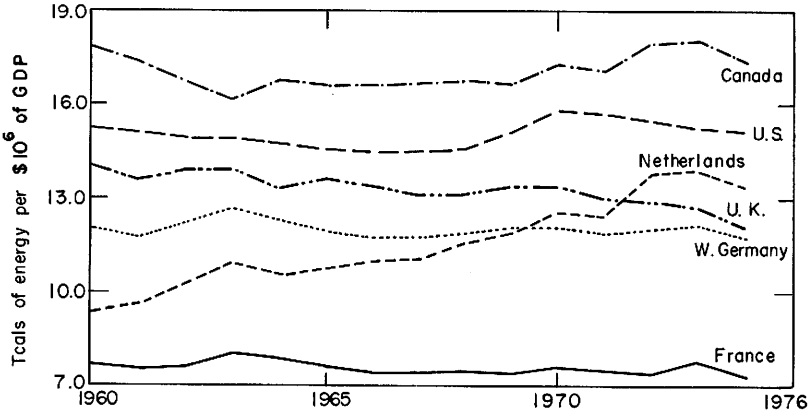

Figure 1.1
Energy use per million dollars of GDP (in 1970 U.S. dollars, converted using purchasing power parity indices for GDP)

a meaningful explanation for differences in energy use, and in particular does not provide a basis for predicting the kinds of changes in energy use that are likely to come about in the future from changing energy prices and changing GNP's. Tastes and habits may themselves be functions of price. Taking the price of gasoline and its relation to average car size as an example, we must ask to what extent car size differences can be attributed to differences in gasoline prices across countries and over time. It may well be that people choose to buy smaller and more fuel-efficient cars when gasoline prices are high (in fact get into the habit of driving smaller cars) for economic reasons. If this is indeed the case, it has important implications for the impact of higher gasoline prices (perhaps through taxes) on gasoline demand in the U.S. and elsewhere.

It is also important to recognize that differences in energy use cannot be explained in the aggregate but must be explained on a sector-by-sector basis. Clearly the structure of energy demand for home heating will be very different from that for industrial production, so that to look at energy/GNP ratios in the aggregate provides little in the way of useful information. Instead we must examine the characteristics of energy demand for each particular sector of use. In this study, we will focus primarily on three sectors of use: residential, industrial, and transportation.

For the residential or household sector, the structure of energy demand depends on consumers' preferences, and in particular the willingness of consumers to substitute between energy and other goods in their consumption baskets. For consumers, substituting away from energy as energy prices rise means less direct use of energy (for example, for home heating and cooling), as well as a reduction in purchases of energy-consuming appliances or the replacement of existing appliances with those that are more energy efficient. The characteristics of consumers' preferences also determine whether the consumption of energy (and the consumption of other items) rises proportionately with income growth, or whether income growth, with prices of all goods held fixed, is by itself likely to produce shifts in the proportions of expenditures allotted to energy and other categories of consumption.[2] Such shifts might occur, for example, if rising incomes encourage a more than proportional increase in energy-intensive consumption (through, say, increased purchases of labor-saving appliances). Finally, the extent to which fuels will be substitutable with each other as their relative prices change (given some overall level of energy use) is also likely to be different in the residential sector than in other sectors. In fact it will depend on the extent to which consumers prefer certain fuels for intrinsic qualities, such as cleanliness and security of supply, and in the long run the capital cost of substituting alternative fuel-burning appliances.

For the industrial sector, the structure of energy demand depends on the characteristics of production, and in particular the extent to which capital, labor, and energy can be used in different proportions in response to changes in the prices of these factors. The substitutability of capital, labor, and energy is a critical determinant of the industrial demand for energy, and also, as we will see, determines the macroeconomic impact of changes in energy prices. The characteristics of production further determine whether the industrial demand for energy, and the demands for other factors, rise

2. If shares of expenditures on particular consumption categories all remain fixed as income increases, then consumers' preferences are said to be "homothetic." We will discuss this concept in some detail in the next chapter.

proportionally with the growth of industrial output or whether output growth, with prices of factors held fixed, will by itself produce shifts in the proportions of expenditures allotted to each factor.[3] And finally, the characteristics of production determine the extent to which individual fuels will be substituted for each other as their relative prices change.

In the transportion sector, the demand for energy will depend on the demand for the specific form of transportation itself and the share in the cost of the transportation service represented by the cost of energy. (If energy costs are only a small share of the cost of the transportation service, then increases in the price of energy will only make a small change in the price of the service, and hence only have a small impact in the demand for the service even if that demand is highly elastic with respect to changes in the price of the service itself.) In addition, the demand for energy will depend on the ability to adapt the particular form of transportation to make it more fuel efficient (for example, by building smaller cars or driving existing cars at slower speeds). The demand for energy in the transportation sector will, of course, vary considerably across particular forms of transportation because of differences in the demands for the alternative transportation services themselves, differences in the energy cost shares for the services, and differences in the costs of improving fuel efficiency.

Energy is used in other sectors of the economy as well, in particular for energy transformation: largely the production of electricity, where interfuel substitution is an important aspect of demand, and as chemical feedstocks for the production of plastics and other basic materials, where interfuel substitution is less important. The scope of this study is limited, and we will touch only briefly on the characteristics of energy demand in these and other sectors.

1.3 Energy and the Macroeconomy

We will also be concerned in this study with the interrelationships between energy prices and energy use and such macroeconomic

3. The production structure is said to be homothetic if expenditure shares for each factor remain fixed as the total value of output increases. This, too, will be discussed in detail in the next chapter.

variables as employment, inflation, and GNP growth. It is important to recognize that the causal relationship between energy and the macroeconomy runs in both directions. Most people are aware of how increases in energy demand are brought about by growth in GNP, but only recently have people become aware of the importance of energy to GNP growth itself. A physical shortage of energy (or for that matter any other input used for production) can obviously depress GNP and increase unemployment by creating bottlenecks in the production of both intermediate and final goods. An increase in the price of energy, however, can also reduce the productive capacity of the economy. If energy or any other factor of production becomes more scarce (that is, more costly), this necessarily reduces the production possibilities of the economy, so that GNP will be lower than if energy prices had not increased. The question, of course, is how much lower GNP will be as a result of an increase in energy prices. Again this depends on the substitutability of energy with other factors. If the possibilities for substitution are great, then less expensive factors can be used in greater quantity in place of energy.

Because of the important interrelationships between the energy sector and the macroeconomy, energy use and energy policy are becoming increasingly important to the design of economic policy. We are beginning to realize, for example, that the rate of unemployment may depend not only on the particular monetary and fiscal policy in effect but also on changes in energy prices and energy use that took place over the last two or three decades.

To see this, consider the fact that between the end of World War II and 1972 a slow but steady shift occurred in the structure of industrial production in the U.S. and most of the other advanced economies. During this period two factor inputs of production—energy and capital—became significantly cheaper in real terms relative to a third important input, labor. This shift in relative prices occurred for a number of reasons. Reserves of energy resources, and energy production, were increasing worldwide, which drove down the real cost of energy. Tax policies in many countries (for example, the investment tax credit in the U.S.), designed to encourage new capital investment as a spur to economic expansion, helped to reduce the growth in the price of capital services. Finally, tax and social welfare policies, combined with greater wage demands on the part of workers, tended to greatly increase the effective cost of labor services for production. For the case of the U.S., this is illustrated in figure 1.2, which shows real price indices for capital, labor, and energy.

The result of these changing prices was a shift in the factor mix used in production. Gradually, producers replaced labor with less expensive capital and energy. In addition, there is evidence that capital and energy themselves came to be used in a complementary fashion. Since the particular forms of capital required large amounts of energy to be utilizable, there was little or no room for substitution between energy and capital, at least in the short run. (As we will see in this study, the evidence indicates that there may be more room for substitution in the long run when existing capital can be replaced by new, more energy-efficient, machines.) This shift in the relative quantities of factor inputs is illustrated in figure 1.3, which shows again for the U.S. quantity indices for capital, labor, and energy.

This shift away from labor and towards energy and capital served to exacerbate the impact of the increases in energy prices that were brought about by the OPEC cartel. When energy prices rose, industries in many countries were unable to achieve a significant shift away from energy-intensive production. For at least the short term,

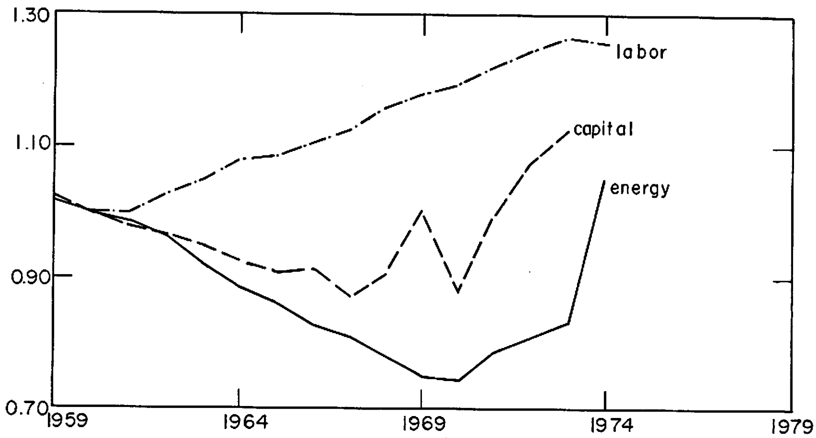

Figure 1.2
Real price indices for capital, labor, and energy in the U.S. (prices = 1 in 1960)

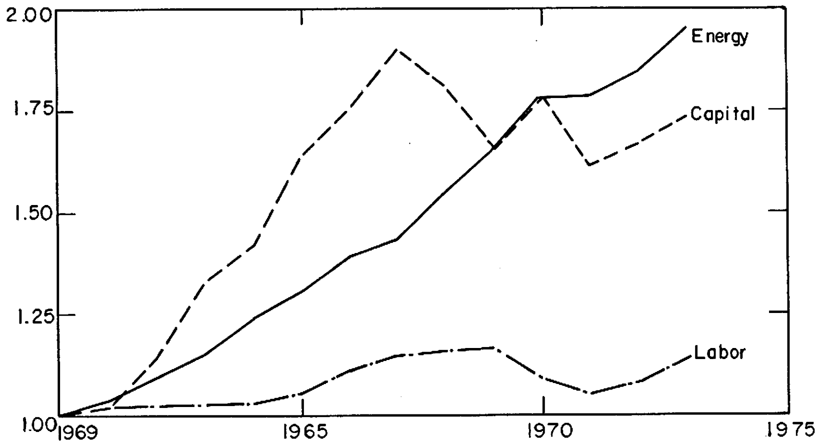

Figure 1.3
Quantity indices for capital, labor, and energy in the U.S. (quantities = 1 in 1960)

energy and capital were complementary inputs, and the only substitutable alternative—labor—was already very expensive. Thus increases in energy prices were translated into an increase in the cost of industrial output—an increase in cost nearly as large as the percentage increase in the price of energy times energy's share in the total cost of output. But with labor and capital fixed in the short run, this meant a drop in the level of real output. The result was a recession, and the likelihood of lower economic growth during the next several years.[4] In the short run at least, the shift towards more energy- and capital-intensive production meant a greater reduction in the productive capacity of the economy as a result of higher energy prices. The shift itself, on the other hand, came about because of gradual changes in energy prices (as well as changes in the prices of other factors).

Even if energy prices do not rise very rapidly in the future (and we will argue in chapter 8 that a fairly slow but steady rise in energy prices is in fact a more probable scenario for the future), the large and dramatic increase in energy prices that has already occurred will cause some reduction in economic growth in the industrialized

4. We will discuss this problem later in chapter 8.

countries, at least through 1985. The question now is the extent to which growth will be diminished over this intermediate range. The answer depends in part on the degree of substitutability of capital, labor, and energy in the long run. If capital and energy are substitutable, then the impact of higher energy prices on the cost of output (and thus on GNP) will be ameliorated. Determining the long-run relationship between capital, labor, and energy in aggregate production is therefore an important objective of this study.

1.4 The Need for an International Study

An important feature of this study is that it deals with differences in energy prices and energy use across a number of industrialized countries. There are three basic reasons for conducting an international study of energy demand. First, the use of international data permits us to identify the long-run structure of energy demand to an extent not possible using data for a single country. Second, we are interested in some of the ways in which the structure of energy demand might differ across countries, as well as the possible reasons for such differences. Third, we would like to better understand how world energy markets, and the world demand for energy, are likely to change in response to changes in the prices and availabilities of energy supplies.

As we explained above, our objective in this study is to analyze the long-run characteristics of energy demand. This is difficult to do using data for a single country. Until recently energy prices in most countries have changed only slowly over time, so that the estimation of models of energy demand for a single country is most likely to capture short-run or intermediate-run price and income elasticities. In order to estimate long-run elasticities of demand, it is necessary to compare the equilibrium demands for energy corresponding to prices that are significantly different from each other. By equilibrium demand we mean the demand that would prevail after sufficient time had elapsed for consumers to completely adapt to a new price or set of prices. How much time is sufficient will depend on the particular sector (or even subsector) of energy use, but it might be anywhere from five to twenty years.

Given the limited time horizon for which data is available for any one country, it is clear that we cannot compare equilibrium prices

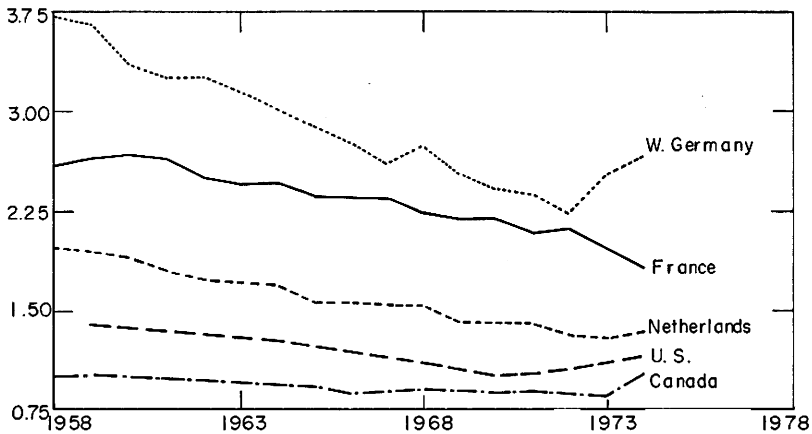

Figure 1.4
Energy price index for the residential sector (price = 1 for the U.S. in 1970)

and demands by working with time-series data for only a single country.[5] Cross-sectional data might be used that span a number of different regions in a single country (for example, interstate data for the U.S.), but in most cases energy prices and per capita consumption levels show little regional variation within a country. On the other hand, energy prices are and have been quite different across countries, so that by using data that span a number of countries, we can effectively compare long-run equilibrium values of energy prices and demands.

The variation of prices across countries and through time is illustrated for the residential sector in figures 1.4 to 1.6. Figure 1.4 shows a real price index for energy (all prices relative to a price of 1.0 in the U.S. in 1970) for the U.S., the Netherlands, West Germany, Canada, and France. (The computation of this index is discussed in chapters 3 and 5.) Note that these prices have declined over time in all countries, but only slowly. The prices, however, vary considerably across countries, with energy prices in West Germany (the highest) about triple those in Canada (the lowest).

5. As we will argue later, it is for this reason that most econometric work on energy demand based on a single country has yielded price elasticities that are quite low—they are probably short-run and not long-run elasticities.

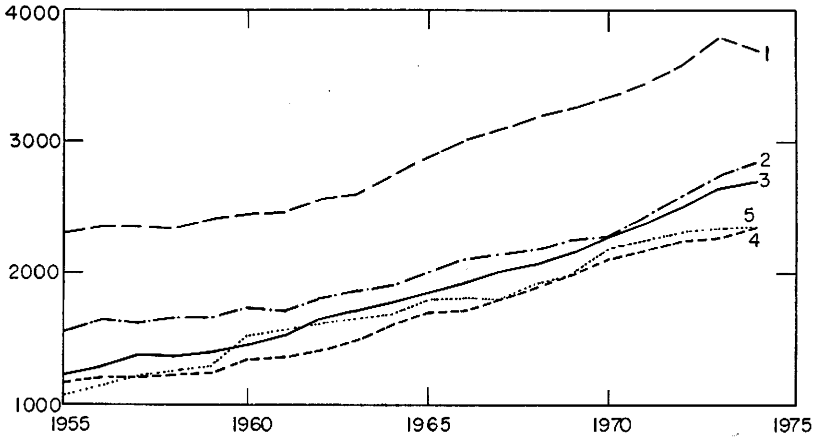

Figure 1.5
Per capita incomes (all in 1970 U.S. dollars): (1) U.S., (2) Canada, (3) France, (4) Netherlands, (5) West Germany

Figure 1.5 shows per capita disposable incomes in these same five countries, and again there is considerable variation across countries, but only slow change over time. Finally, per capita energy consumption in the residential sectors of each of these countries is shown in figure 1.6. These levels of energy consumption vary slowly over time, but the greatest variation is across countries, so that they can be viewed as comparative equilibrium levels.

There are certain problems involved in pooling data across a number of countries, the most serious of which is the possibility that the fundamental structure of demand may differ from one country to the next. In the industrial sector, for example, if the underlying structure of production (as represented in our models by a production function or cost function) differs across countries in a pooled sample, biased elasticity estimates may result. We try to minimize this potential hazard by testing wherever possible the homogeneity of demand structures across countries. This in turn provides information on the extent of and reasons for intrinsic intercountry differences in the structure of demand—which brings us to our second reason for conducting an international study such as this one.

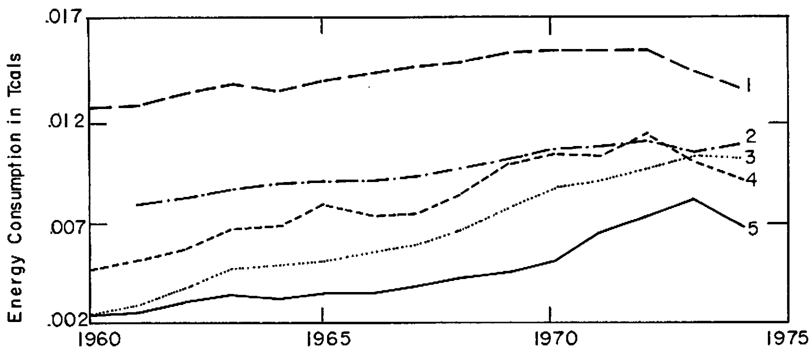

Figure 1.6
Per capita residential energy consumption: (1) U.S., (2) Canada, (3) West Germany, (4) Netherlands, (5) France

We wish to use the considerable differences in energy prices and energy demand levels across countries to obtain estimates of long-run demand elasticities, but also to determine if and how these elasticities might differ across countries, or across groups of countries. For example, we would expect long-run price and income elasticities to differ considerably between developed and less developed countries, but we also wish to determine whether these elasticities differ across the developed countries. One way to find this out is by estimating energy demand models using alternative subgroupings of countries, so that each subgroup displays enough cross-country variation in the data to identify long-run elasticities of demand. We will use such an approach to determine whether demand elasticities in, say, Canada and the U.S. differ from those in some of the European countries.

The third reason for conducting an international study of energy demand is to get a better understanding of how world energy markets are likely to evolve in the future and how the total world demand for energy is likely to change in response to the increases in oil prices initiated by the OPEC cartel, and in response to future changes in prices resulting from the cartel or from changing supplies in noncartel countries. This is important since it is a determinant of what OPEC itself can do to the price of oil in the future and, combined with projections of future energy production capacities, helps us determine the likelihood of stability in energy markets and energy supplies.

1.5 The Plan of the Book

This book describes the results of an econometric study of the world demand for energy. An important objective of the study has been to develop and estimate models that can better reveal the structure of energy demand and help to determine the long-run response of demand to changes in prices and levels of economic activity. We have concentrated on the residential, industrial, and transportation sectors of several industrialized countries, although we also briefly consider the demand for energy in other sectors, and in some of the developing countries. Finally, the study has been concerned with the relationship between energy use and economic growth, and in particular the impact of higher energy prices on the cost and level of economic output.

Our approach has been to specify and estimate consistent models of energy demand. By "consistent" we mean models that simultaneously describe the demands for energy and other competing commodities, as well as the demands for individual fuels within the energy aggregate. In studying the industrial sector, for example, we do not view energy in isolation but rather as one of three inputs to production, and therefore construct a model that simultaneously accounts for the demands for capital, labor, and energy. Similarly, the price of energy is derived from a submodel that describes the interrelated demands for each of four fuels (coal, oil, natural gas, and electricity).

Usually a model for the demand of some commodity presupposes a particular demand structure. The problem with this is that the estimated elasticities from this model are valid only insofar as the specification itself is valid. Our approach is to use functional specifications for our models that are as general as possible, in other words, that impose no or almost no a priori restrictions on the structure of demand. We then estimate these models, using pooled international time-series cross-section data in order to test particular restrictions on the structure of demand and to identify long-run demand elasticities.

The specification of our demand models is explained in some detail in the next chapter of this book. There we discuss the use of the indirect translog utility function as a basis for modelling the residential demand for energy, and the use of the translog cost function as a basis for modelling the industrial demand for energy. In addition, we introduce alternative demand specifications for the residential and industrial sectors, and also discuss model specifications for the transportation sector and for other sectors.

There are a number of important methodological issues that must be dealt with in estimating models of energy demand, and these are discussed in chapter 3. These issues include the use of purchasing power parities to convert prices and expenditure figures in the local currencies of various countries to common units, the measurement of energy use in "gross" versus "net" (efficiency-adjusted) terms, the calculation of aggregate energy price indices, the estimation of intercountry differences in energy demand, and the choice of econometric technique. In addition, chapter 3 discusses the construction of all the data series used in the estimation work.

The statistical results of this study are presented in chapters 4, 5, and 6. Chapter 4 deals with the residential sector, and discusses the role of energy as part of total consumption expenditures. This chapter presents alternative elasticity estimates for total energy use in the residential sector, as well as estimates describing the substitutability of fuels used in that sector. Chapter 5 deals with the industrial sector, and describes estimates of the elasticities of substitution between energy, capital, and labor, elasticities of total energy demand, as well as own- and cross-price elasticities for individual fuels. Chapter 5 also deals with the impact of higher energy prices on the cost of industrial output, and provides estimates useful for analyzing the macroeconomic impact of changing energy prices. Finally, chapter 6 describes the estimation of a model of motor gasoline demand, as well as elasticity estimates obtained for other fuels used in the transportation sector.

Chapter 7 deals with energy demand in the less developed countries. Since meaningful price and quantity data is very difficult to obtain for these countries, our statistical work here is only very limited. However, we offer some arguments about the characteristics of energy demand in these countries, test these arguments to the extent possible given the data, and speculate on the ways in which demand might change in the future.

Finally, chapter 8 deals with the macroeconomic impact of higher energy prices in the industrialized countries, and the likely future evolution of world energy markets. In particular, this chapter considers the effects of changing energy prices on economic growth in the industrialized countries, the likelihood of increases in energy prices in the future, and the impact of price changes on world energy demand and supply. The chapter concludes with some remarks about the implications of our results for energy policy.

1.6 A Word on Units of Measurement

Energy can be measured using any one of a plethora of different units—calories, Btu, barrels of oil equivalent, and million tonnes of oil equivalent to name just a few—and this often creates confusion for readers of articles and books on energy. In this book we try to measure all energy quantities in teracalories (1 Tcal = 10^{12} calories). In some cases, however, it is more natural to refer to other units (such as dollars per gallon for the price of gasoline). In addition, many readers may want to convert our numbers into units they are more familiar with. We therefore present a set of useful conversion factors in table 1.2.

Note that there are basically three ways of measuring a quantity of energy: as a physical quantity of a particular fuel (such as tons of coal or barrels of oil), in terms of thermal content (such as millions of Btu), or in terms of the thermal-equivalent quantity of some numeraire fuel (such as barrels of oil-equivalent). The first approach is straightforward, and as long as the particular fuel in question is specified exactly (for example, coal of a particular grade and thermal content), there is no measurement error involved—a cubic foot of high Btu gas is a cubic foot of high Btu gas. However, this approach is not useful if we wish to talk about aggregate energy use, and add up coal, oil, and so forth. For this reason energy quantities are often measured in terms of thermal content or the thermal-equivalent quantity of a numeraire fuel.

Unfortunately these last two ways of measuring energy quantities can lead to certain errors. The problem is that the thermal content of a fuel depends on the particular way the fuel is burned, and fuels can be burned in very different ways. Although the conversion to thermal-content units is usually done assuming 100 percent thermal efficiency (that is, complete burning), different fuels and different uses of the same fuel can involve different thermal efficiencies, and this can make quantity comparisons misleading. Here we simply raise this issue as a warning; it is discussed in more detail in chapter 3.

Table 1.1
Magnitudes of energy expenditures

	Energy expenditures by households as fraction of total household consumption expenditures[a]		Energy expenditures by industry as fraction of cost of industrial output	
	1965	1974	1965	1973
U.S.	0.087	0.100	0.029	0.033
U.K.	0.083	0.084	0.069	0.047
France	0.068	0.076	0.052	0.045
West Germany	0.072	0.125	0.047	0.045
Italy	0.068	0.073	0.074	0.066

[a] includes motor gasoline

Table 1.2
Units of measurement

A. Physical quantities

1 metric ton (tonne) = 2,204 lbs = 0.984 long tons = 1.102 short tons = 1,000 kg

1 barrel crude oil = 42 U.S. gallons, and weighs 0.136 metric tons

1,000 cu ft (1 mcf) natural gas = 28.3 cu meters

1 kilowatt-hour (kwh) of electricity = 3411 Btu = 860 kilocalories (kcals)

1 Btu of energy = 252 calories = 10^{-5} therm

1 Tcal of energy = 10^{12} calories = 4×10^{9} Btu

1 Quad of energy = 10^{15} Btu = 2.5×10^{5} Tcals

B. Thermal equivalents

1 metric ton anthracite coal = 2.80×10^{7} Btu = 7.06×10^{9} calories

1 metric ton bituminous coal = 2.89×10^{7} Btu = 7.28×10^{9} calories

1 barrel crude oil = 5.80×10^{6} Btu = 1.46×10^{9} calories

1 barrel residual fuel oil = 6.29×10^{6} Btu = 1.58×10^{9} calories

1 barrel distillate fuel oil = 5.83×10^{6} Btu = 1.47×10^{9} calories

1 barrel regular gasoline = 5.25×10^{6} Btu = 1.32×10^{9} calories

1,000 cu ft natural gas = 1.035×10^{6} Btu = 2.61×10^{8} calories

C. Thermal-equivalent quantities of oil

1 metric ton of coal ≃ 4.9 barrels of crude oil

1,000 cu ft natural gas = 0.178 barrels of crude oil

1,000 kilowatt-hours electricity = 0.588 barrels of crude oil

10^{6} Tcals of energy = 93.8 million tons of oil equiv. (Mtoe) = 1.89 million barrels per day (mb/d)

1 Quad of energy = 23.5 million tons of oil equiv. = 0.474 mb/d