Part II
Analytical Structure

The analysis on which this report is based uses an economic model built to explain how energy use changed with changes in the economy. Such an approach necessitates using special terms, making simplifying assumptions, and creating a simulation of reality which, like any imitation, has its strengths and weaknesses. The following section outlines these subjects.

DEFINITIONS AND ASSUMPTIONS

Looking at how different factors in the economy affect energy use requires use of a consistent set of terms that represent particular economic phenomenon, such as spending or output. (See box A for a summary of terms.) Foremost among these definitional issues is the need to distinguish between energy-intensity, energy efficiency, and structural change in the composition of the economy's output.

Energy Intensity

Energy intensity, on an economy-wide level, is the amount of energy consumed per *net* unit of economic value produced (e.g., British thermal units (Btu) per dollar of Gross Domestic Product (GDP)). On an industry-specific level, energy intensity is defined as the amount of energy consumed per unit of *gross* output produced. The difference between the use of gross and net output figures is that the net measure includes only the value a particular business adds in its production process. The gross measure includes this value as well as the value of all the inputs used in that firm's production process. On an economy-wide level, the net value of output is used because when the gross measure is aggregated across industries it results in double counting, since the output of one industry is frequently used in the production of the output of another industry. But on an industry-specific level, gross output is a better measure for calculating the energy intensity because the inclusion of all of the inputs makes it a better reflection of that industry's production process.[18]

The economy's energy intensity can change because of changes in the energy efficiency of the economy or because of a shift in the industrial makeup of the economy. For example, the energy used per dollar of GDP (energy intensity) can decline over time simply because a bigger share of the GDP is composed of services that are less energy-intensive relative to other industries like manufacturing. With such a shift, the energy intensity can decline without any change in the energy efficiency.

Energy Efficiency

The distinction between energy intensity and energy efficiency is achieved by narrowly defining energy efficiency as the introduction of new processes (e.g., electric arc furnaces in steelmaking) or as the improvements in the operation and maintenance of existing production facilities that affect the amount of energy used to produce a unit of output in a particular industry .19 In the model constructed for this analysis, the inputs such as energy, materials, and services, are known for each industry over time. Since each industry uses a different level and mixture of inputs to produce its output, the variations across industries look like different cooking recipes. Given this, the term production recipe is used to represent the combination of these inputs. (See box A). A change in the energy portion of this production recipe per unit of output is defined as a change in energy efficiency.

Structural Change

This definition of energy efficiency does *not* include energy efficiency gains realized outside of the formal marketplace such as in households. For example, household technologies such as more efficient appliances or more fuel-efficient automobiles are not included because households do not produce output that is officially counted as economic activity as defined by GDP.[20] But these technologies do affect the mixture of what households buy: a more energy-efficient refrigerator means that a household's market basket might include less electricity, freeing up money to be spent on other items such as clothing. This shifting mixture of what consumers buy, called spending mix in this analysis, has a direct affect on what businesses produce, which in turn alters the composition of output. In this example, the shift in spending from electricity to clothing translates into a shift in output to a less energy-intensive mix of industries as output in the electric utility industry declines relative to the apparel industry. Whether or not the clothing was domestically produced also has ramifications on the structure of U.S. output and energy use. Thus,

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Box A—Terminology

The model used in this analysis consists of several components or variables that can be separately analyzed to show their role in changing energy use from 1963 to 1985. For simplicity's sake, the variable names listed below are defined and consistently used throughout the analysis to represent a particular factor.

At the broadest level, the model consists of three primary variables: spending, production recipe, and an interactive factor.

Spending: Spending represents the purchase of finished (final) goods and services by personal consumers, all forms of government, business investment in plant and equipment, change in business inventories, and net foreign demand for U.S. products (exports minus imports). The sum of consumption across all products equals the Gross National Product. Consumption is analyzed from three perspectives: level and mix, product groups, and sources.

*Level **and mix:*** The level of spending refers to the total constant dollar value of spending (final demand) in a particular year. As the population and aggregate income of the country increases, the level of spending is expected to increase also. The level of spending in 1985 was 39 percent higher than the 1972 level.

The mix of spending represents the portion of consumption comprised of a particular product. Although the level of spending might not change, the mix of what is consumed could shift. For example, the share of personal consumption spent on health care increased from 8 percent to 10 percent from 1972 to 1985.[1]

Product groups: **Spending can be** divided into five product groups-energy, natural resource goods, manufactured goods, transportation services, and services-to show how consumption broke down by broad categories of products. Over time, each of the product groups reflect changes due to the level of spending of each group and changes in the mix of products within the broad groups. By separating energy products (e.g., oil, gas) from other products an estimate of energy that is used directly and indirectly can be derived.

Sources of spending: The consumption of any year can also be divided into five origins of expenditures--households, government, business investment, changes in inventories, and international trade (exports and imports). Like the product groups, each of the sources of consumption includes changes due to the level of spending associated with each source and changes in the mix of products bought by each source.

Production recipe% Production recipe refers to the formula by which businesses produce goods and services purchased by consumers. This formula explicitly includes the ingredients (inputs) used and implicitly includes the method and capital equipment employed. For example, the production recipe for motor vehicles includes such things as steel, rubber, and financial services. Broadly speaking, the production recipe is a proxy for changes in technology and know-how. The production recipe is divided into two categories: the energy portion and the nonenergy portion.

Energy: The energy portion of the production recipe refers to how energy is used as an input by industry. It represents the direct use of energy as an intermediate input by business. Changes in this factor per unit of output reflect changes in energy efficiency.

Nonenergy: The nonenergy portion of the production recipe represents all the other inputs to business such as steel, plastics, advertising, and financial advice. Each of these inputs indirectly embody energy because some energy was required in their creation.

Interaction: Interaction is the change that results from the simultaneous movement of two variables (e.g., spending and production recipe)--an effect that cannot be cleanly attributed to one variable or the other. An example might include the simultaneous decline in the consumption of gasoline due to more efficient automobiles (a consumption mix change) and the fact that automobile manufacturers decreased the energy intensity associated with a car's production recipe, making them smaller and lighter by substituting plastic for steel. This would generate an interaction effect between spending and production recipe. The interaction effect is discussed in greater length in the appendix.

1U.S. Department of Commerce, Bureau of Economic Analysis, National Income and Product Accounts, table 2.5.

2 The term recipe is used because it reflects the fact that production involves not only inputs (i.e., eggs and flour), and a process by which the inputs are combined (i.e., cook in a cake pan at 350 degrees for 30 minutes), but also know-how (i.e., preheat the oven). The term is borrowed from Wassily Leontief, "The Choice of Technology," ***Scientific American*****, vol. 252, No. 6, June 1985, p. 40.**

international trade is a critical component in this analysis.

Another part of structural change comes from how businesses alter the nonenergy inputs in their production recipe. Technological developments in equipment or methods can alter the type and mixture of inputs in this recipe. For example, to make 1,000 dollars' worth of motor vehicles in 1972 required, among other things, 28 dollars' worth of rubber and plastic inputs, 74 dollars' worth of steel, and $17 of business services. By 1985 the recipe for motor vehicle output had shifted so that to produce 1,000 dollars' worth of output the industry used $41 of rubber and plastic, 53 dollars' worth of steel, and $22 of business service inputs.[21] These types of shifts affect the relative output of different industries, acting as another component of structural change.

Thus, structural change, as defined in this report, is the combined effect of two factors: a changing mix of consumer spending on products and changes in the use of nonenergy inputs by businesses in their production processes.

Economic Growth

Besides being affected by changes in energy efficiency or structural change in the make-up of the economy, energy use can be altered by the overall size or level of the economy. The sum of spending on all products from all sources in a particular year is one way to measure the Gross National Product.[xiii] If the mix of what people buy (spending mix) and the method by which these products are produced (production recipe) does not change, energy use can still increase if the sheer number of things consumed increases (spending level). Therefore, if everything else is held constant, but there are more people buying more cars and living in more houses, energy use will increase.

Spending by Product Groups

By splitting overall spending into broad product groups-energy, natural resource goods, manufactured goods, transportation services, and all other services-direct spending on energy products like oil and gasoline can be separated from spending on nonenergy products such as clothing, autos, or insurance policies, which indirectly embody energy from the process used to produce them. Similarly, different industries' production recipes can be lumped together into product groups, revealing which sectors have achieved the bulk of the energy efficiency gains or have indirectly changed their energy use through altering the use of nonenergy inputs. As used in this analysis, changes in product groups reflect both changes in the level of spending for that product and changes in the composition of that group. For example, spending on transportation services has grown over time (spending level) and the makeup has shifted from spending on railroads to air travel (spending mix).

Sources of Spending

Spending is also broken down into the four sources it originates from: 1) households, 2) business investment, 3) changes in inventories, and 4) international trade (imports and exports). Obviously, households have a much different level and mix of spending than government.

Interactive

A consequence of the analytical structure used in this report is the generation of an interactive factor.[xiv] Interaction is the change that results from the simultaneous movement of two variables (e.g., consumption and production recipe)--an effect that cannot be cleanly attributed to one variable or the other. As a result, the interactive factor tends to increase in direct relation to the gap between data points and the volatility of the time period being spanned. The largest jump in the interactive factor in this analysis occurs between 1972 and 1977-one of the longest gaps and a period that includes the frost oil price shock. The interactive factor should not be confused with a residual that is an unexplained remainder. The interactive effect is a real, identifiable factor, although it is intuitively difficult to understand and even harder to explain. An example might include the simultaneous decline in the consumption of gasoline due to more efficient automobiles (a consumption mix change) and the fact that automobile manufacturers decreased the energy intensity associated with a car's production recipe, by making them smaller and lighter by substituting plastic for steel (production recipe). This could generate an interaction effect between

[xiii]This is the expenditure side of the double column booking system used to measure GNP. The other method is to add up the income or value-added produced by each industry in a particular year.

[xiv]See the appendix for more on the analytical structure used in this study.

consumption and production recipe as they simultaneously move beyond the sum of the individual parts. The interaction effect is discussed in greater length in the appendix.

Energy Definitions

The analysis breaks the change in energy use down into five energy types: coal, crude oil & gas, refined petroleum, primary electricity, and utility gas (see box B). To avoid the double counting that would occur if both the coal used to make the electricity and the electricity that was generated from the coal were reported, the energy types are reported in their primary form (oil wells, coal mines, water power, and energy produced from nuclear reactors) .22 As a result, some of the more common energy types that are secondary forms of energy (largely the product of some primary fuel), i.e., electricity, are difficult to track. The electricity that is listed is primary electricity, which refers to electricity produced by hydroelectric and nuclear powerplants. When this is combined with coal use, a rough proxy for all electricity is generated because 84 percent of all coal used in 1985 was consumed by electric utilities.

THE OTA MODEL

Analytical Technique

This report makes use of an analytical technique called input-output analysis which shows the dollar value of inputs used by each industry in the economy to generate their output in a particular year. Input-output data are used in a wide variety of models; the model employed in this analysis is an open, static, physical input-output model that includes data from 1963, 1%7, 1972, 1977, 1980, and 1982. This data is augmented with energy use data from 1%3, 1967, 1972, 1977, 1980, 1982, and 1985 that shows how each industry uses energy in Btu for five energy types: coal, crude oil & gas, refried petroleum products, primary electricity, and utility gas. The strengths and weaknesses of the model are outlined in box C. The appendix describes the data sources, methodology, and technical aspects in greater detail. Input-output and energy use data by industry are not currently available after 1985, limiting the 1985 to 1988 analysis of energy use to less detailed sources.

Box B—Energy Types

Primary energy: Primary energy is energy in its most basic form, prior to any additional processing or conversion. To avoid double-counting, only energy from primary sources such as coal, crude petroleum, water power, or nuclear power is counted towards total energy consumption.

Coal: The definition of coal includes bituminous, anthracite, lignite, coke, breeze, and coke oven byproducts, except coke-oven gas.

Crude oil & gas: This category includes crude petroleum, natural gas sold by the crude petroleum and natural gas industry to gas utilities, and the following natural gas liquids: isopentane, natural gasoline, and plant condensate.

Refined petroleum: Refined petroleum includes refined petroleum products and all natural gas liquids other than those listed under the crude petroleum and natural gas category.

Primary electricity: Primary electricity refers to electricity that is not derived from a fuel such as coal, oil, or natural gas. Electricity from such as source would be a secondary form of energy. primary electricity is instead produced from natural sources such as uranium (nuclear power), water (hydroelectric), steam (geothermal), wind, or the sun (solar or photovoltaic), which are not considered fuels.

Utility gas: Utility gas includes natural gas sold to final consumers, manufactured gas, substitute natural gas, coke oven gas, and all other gases.

SOURCE: S. Casler, "Energy Flows Through the U.S. Economy, 1980, 1982, and 1985," contractor report prepared for the Office of Technology Assessment, Energy and Materials Program December 1989, p. 6.

Basis for Comparison

Because the emphasis of the analysis is on how the use of energy changed between 1972 and 1985, most of the data is presented as the *difference in* energy use. But in many instances, the significance associated with change depends on the size of the base from which the change occurred. Figure 4 shows the base energy use for each year by fuel type. Coal and primary electricity have increased in use while crude oil & gas, refined petroleum, and utility gas have all declined. As of 1985, roughly 24 percent of all energy used was coal, 55 percent was crude oil

Box C—The OTA Energy Model

This report is based on a series of open, static, input-output models that have been modified to show energy use by quantity (Btu) rather than value (dollars) for every sector of the economy for 1963, 1%7, 1972, 1977, 1980, 1982, and 1985. (A more complete description of the data, methodology, and limits and strengths of the model is contained in the appendix.)

Strengths

- The-model covers the whole economy—including services, not just the manufacturing or goods-producing sectors.
- Input-output analysis has the unique feature of being able to trace the effect of a particular **industry's output back through its suppliers, and the companies that supplied its suppliers, all the way to the raw material processors. This characteristic is particularly well-suited to the analysis of a fundamental input such as energy. This feature allows the separation of the direct use of energy from the indirect use. For example, buying electricity to run an automobile assembly line would be a direct use of energy while the use of steel used to make a car is an indirect use of energy because of the energy embodied in the steel used to make the car.**
- **The design of input-output tables allows the researcher to look beneath broad variables such as "technological" or 'structural' change to see what factors caused these changes such as shifts in final consumption by consumers or intermediate use of an input by businesses.**
- **The creation of a mixed units ("hybrid") input-output table means that the each sector's unique price paid (implicit price) for energy is reflected rather than relying on an average price that can mask individual changes.**
- **Because they play a pivotal role in the GNP accounting system, input-output tables are compatible with many other economic data series such as the National Income and Product Accounts.**

Weaknesses

- **Input-output tables require extensive data for their construction. This data intensiveness results in a long time-lag between the collection of the data and its release in a published form. As a result, the 1985 endpoint used in this analysis is not an official Department of Commerce input-output table, but has been created by updating a 1982 table to 1985 levels using estimates of industrial output from a separate source.[1] The lack of any post-1985 data that conforms to this framework prevents the analysis from looking in detail at the changes that occurred from 1985 to 1988.**
- **The data intensiveness and availability of input-output tables make annual data points impracticable. This weakens the analysis because the data that is available might miss possible turning points or be subject to peculiarities of a particular year such as a recession.**
- **The mathematics of input-output analysis includes a number of assumptions that place limits on the interpretation of some results. Foremost among these is the assumption of "linear" or fixed input requirements. Calculations that estimate the energy associated with a product assume that the mix of inputs, the process employed, and the relative prices of goods and services are the same for making 1 product as they are for making 10,000.**
- **The input-output tables used in this model are in constant dollars so that a sector's relative rank in the economy can be attributed to true gains,** not just inflation. The elimination of price changes, however, excludes any analysis of how prices affected energy use. In this respect, the effect of prices is not explicit, but is instead a hidden and contributing element to observed factors such as energy efficiency and structural change.[2]
- Input-output tables are designed to generate the output needed to satisfy the demand for goods and services for a particular year. Technological changes, or for our purposes energy efficiency gains, are represented by changes that occur in how industries decide to create that output. This definition of energy efficiency ignores any efficiency gains made outside of industry such as the purchase of more fuel-efficient cars or adding more insulation to houses. These changes in energy use would be captured in a category that looks at the changing mix of products consumed. Since only a small portion of energy is directly purchased by consumers and an effort is made to separate changes in energy consumption by consumers from other products consumed, this assumption is not severely limiting, but can be a source of confusion.

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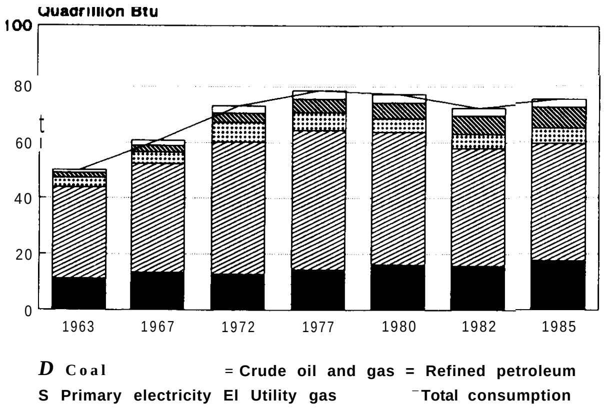
[1]U.S. Department of Labor, Bureau of Labor Statistics, ''Historical Input-Output Time Series Data Base,'' unpublished, January 1989. The 1985 input-output table became available when the report was in review. See U.S. Department of Commerce, Bureau of Economic Analysis, ''Annual Input-Output Accounts of the U.S. Economy, 1985,'' *Survey of Current Business*, January 1990.

[2]This weakness can be overcome through construction of an input-output price model. See F. Duchin, ''Analysing Structural Change in the Economy,'' *Input-Output Analysis: Current Developments*, M. Ciaschini (ed.) (London: Chapman & Hall, 1988), p. 115.

Figure 4--U.S. Energy Use by Type



U.S. energy use increased from 49.7 quadrillion Btu in 1983 to 72.5 quads in 1972 to a high of 78.2 quads in 1977. Energy use dropped from the 1977 level to 74.9 quads in 1985. From 1972 to 1985, the use of crude oil & natural gas, refined petroleum, and utility gas declined while use of coal and primary energy (mainly nuclear and hydroelectric power) increased. By 1985, roughly 24 percent of all energy used was coal, 55 percent was crude oil & natural gas, 7 percent was refined petroleum, 10 was primary electricity, and 4 percent was utility gas.

SOURCE: Office of Technology Assessment, 1990.

& gas, 7 percent was refined petroleum, 10 was primary electricity, and 4 percent was utility gas.

Correspondence to Conventional Categories

The structure of the OTA energy model forces a division between consumers' use of energy as a final product and businesses' use of energy as an intermediate input into their production processes. As a result, there is not an exact correspondence between the conventional categories of energy use—residential and commercial, industrial, and transportation-and those used in this analysis. Box D makes a rough comparison between the two classification schemes.

ENDNOTES FOR PART II

[18]See B. Gelb, "The Measurement of Output," The Conference Board, *Energy Consumption in Manufacturing* (Cambridge, MA: Ballinger Publishing, 1974), p. 80; and G. Boyd, D.A. Hanson, and M. Ross, "The Market for Fuels in the U.S. Manufacturing, 1959-81: Effects of Sectoral Shift and Intensity Changes," draft prepared for the Energy Modeling Forum Study 9, September 1987, p. 23.

[19]G.H. Huntington and J.G. Myers, "Sectoral Shift and Industrial Energy Demand: What Have We Learned?" *The Changing Structure of American Industry and Energy Use Patterns*, A. Faruqui, J. Broehl, and C. Gellings (eds.) (Columbus, OH: Battelle Press, 1985), p. 354.

[20]Carol S. Carson, "GNP: An Overview of Source Data and Estimating Methods," *The Survey of Current Business*, July 1987.

[21]Input shares are calculated using current dollars. U.S. Department of Commerce, Bureau of Economic Analysis, "Dollar-Value Tables for the 1972 Input-Output Study," *Survey of Current Business*, April 1979; and U.S. Department of Commerce, Bureau of Economic Analysis, "Annual Input-Output Accounts of the U.S. Economy, 1985," *Survey of Current Business*, January 1990.

[22]S. Casler and B. Hannon, "Readjustment Potentials in Industrial Energy Efficiency and Structure," *Journal of Environmental Economics and Management*, vol. 17, 1989, p. 95.

Box D-Correspondence Between Conventional Energy Categories and OTA Energy Model Categories

The Department of Energy's Energy Information Agency (EIA) maintains energy-use figures by three broad sectors: industry, transportation, and residential and commercial These categories form the basis of much of the analysis conducted on energy use and also form the conceptual framework many people use to think about and discuss changes in energy use. The categories used in this report represent a departure from this convention, but a rough correspondence can be achieved between these categories and OTA product groups.

Residential and commercial—EIA combines all the energy used by the residential (households) and commercial (non-manufacturing business establishments) sectors where commercial is defined to include the government. Most of this energy is used for heating, cooling, and lighting. The residential and the government portion of the commercial sector are reflected in the OTA model category of spending on energy products. Energy use associated with the nongovernment part of the commercial sector would be split between spending on services and the use of services as an intermediate input in the production recipe.

Transportation—EIA includes all type of transportation, both commercial and private, in its definition of transportation. The OTA model would count expenditures on gasoline for a car as spending on energy products. Only personal or government spending on transportation services such as air travel or rail would be allocated as spending on transportation services. Business expenditures on transportation such as hiring a trucking firm would show up as use of transportation services within the production recipe.

Industry-EIA's industry classification includes what is classified in the OTA model as spending on manufactured and natural resource products and uses of energy, natural resources, and manufactured products within the production recipe.

Although drawing an exact correspondence between the two classification schemes is difficult, each has its own advantages. The advantages of the OTA scheme is a greater level of detail, a separation of commercial from residential, a breakdown of industry into its parts, and a general separation of intermediate business use of energy from final use by consumers. The disadvantage of the OTA system is that a direct connection to a specific end-use such as personal energy expenditures on energy for transportation is not provided.

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[1]U.S. Department of Energy, Energy Information Administration, *Annual Energy Review, 1987* (Washington, DC: Energy Information Administration, May 1988), pp. 291-301.