Energy Use and the U.S. Economy

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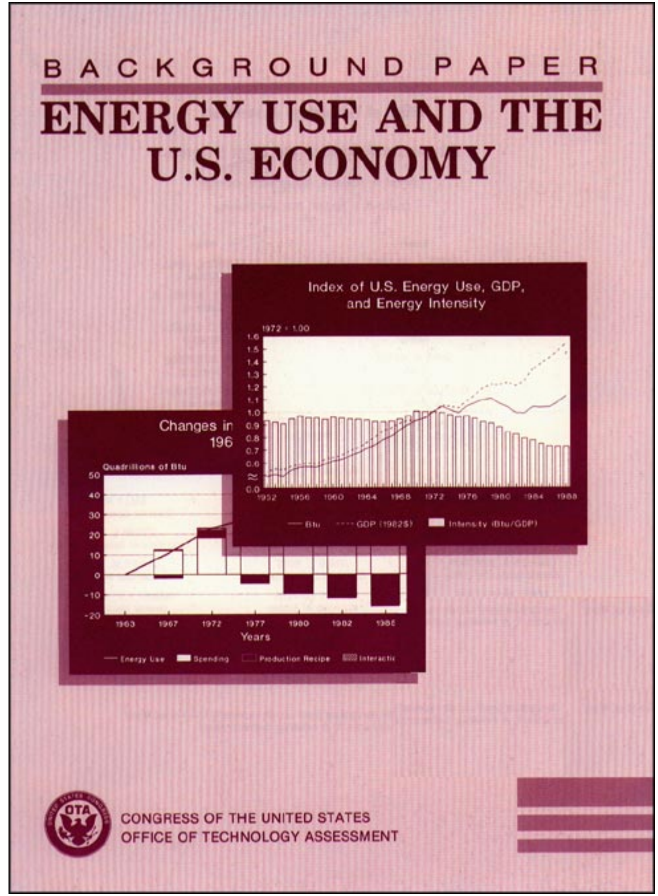

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Foreword

In 1988 the Office of Technology Assessment published *Technology and the American Economic Transition* outlining ways that new technologies have redefined options for stimulating economic growth. A centerpiece of that study was to trace how the structure of the U.S. economy had evolved by looking at how the demand for products and the processes used to produce those products (technology) had changed.

The Subcommittee on Energy and Power of the House Committee on Energy and Commerce asked OTA to use the experience gained in the economic transition study to provide a perspective on how patterns of energy use have changed with shifts in the economy. Instead of looking at specific technologies or individual economic sectors, this paper takes a broader perspective and looks at how the consumption of energy is affected by various macroeconomic factors such as international trade, technology, or mix of spending. By applying this analysis on the changes that occurred in the sixties, seventies, and eighties, the report offers some insights on the forces at work in the economy that could affect future trends in energy use.

In particular, we examine the period from 1972 to 1985, an era when the apparent link between energy use and economic growth became separated-a departure from the experience of most of the fifties and sixties. From 1972 to 1985, the average growth rate of the Gross Domestic Product (GDP) was 2.5 percent per year, but energy use increased at an annual rate of only 0.3 percent. We find that this leveling of energy use was due to large offsetting factors where increases in energy use associated with growth in the overall size of the economy were balanced by reductions in energy use associated with improved energy efficiency and changes in the structure of the U.S. economy.

The background paper extends the analysis of energy use into new areas by explicitly looking at how energy use has changed with the expansion of the service sector, the explosion of international trade, and greater complexity of the U.S. economy as the structure of businesses changed in response to new technologies and competitive challenges. The increasing sophistication of the U.S. economy means that the role of energy is less likely to be directly identified and is instead more likely to be an indirect factor that was added many steps before in the complex network that connects producer to consumer. This report explicitly separates direct from indirect energy use.

OTA acknowledges the generous help of the reviewers and contributors who gave their time to ensure the accuracy and completeness of this report. OTA, however, remains solely responsible for the contents of this background paper.

JOHN H. GIBBONS
Director

[1] **U.S. Congress, Office of Technology Assessment, *Technology and the American Economic Transition: Choices for the Future*, OTA-TET-283 (Washington, DC: U.S. Government Printing Office, May 1988).**

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NOTE: OTA is grateful for the valuable assistant and thoughtful critiques provided by the reviewers and contributors. The views expressed in this OTA background paper, however, are the sole responsibility of the Office of Technology Assessment.

Energy Use and the U.S. Economy
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Contents

Boxes

Figures

Tables

Part I
Introduction

OVERVIEW

Energy is a fundamental input into our economy, essential for running the country's factories, shipping the Nation's output, and ringing up the sales. Energy is also a final product consumed by itself, responsible for providing many of the comforts of life that people have grown accustomed to: heat in the winter, light at night, cool air in thesummer, and mobility, to name a few. But the consumption of energy has drawbacks as well. Energy use generates pollution and can hurt our balance of trade while making the United States vulnerable to foreign pressures.[i]

Shifts in Energy Use and Gross Domestic Product (GDP)

Given the critical role energy plays in our economy, it is important that we understand how energy use has changed with changes in our economy. Figure 1 gives an overview of this relationship. After World War II, growth in our economy, as reflected by GDP,[ii] and increases in energy, measured in British thermal units (Btu),[iii] appeared to be in lock step. From 1950 to 1971, energy use and GDP both increased at an average annual rate of 3.5 percent. Although deviations from this trend occurred in the mid- 1950s and mid- 1960s, growth in the two factors were highly correlated.[1] Economic growth was assumed to be linked to increases in energy use and public and private investments were made that rested on this assumption.[2]

In the early 1970s, the apparent link between increasing GDP and rising energy use came unraveled. Between 1972 and 1985, 20 million homes were added to the country's housing stock, the fleet of vehicles on America's roadways increased by 50 million, the number of business establishments rose by 1.5 million, and the GDP grew by 39 percent in real terms.[3] But energy use had remained basically flat. Although the average growth rate of GDP was 2.5 percent per year over this period, energy use increased at an annual rate of only 0.3 percent.[4] The energy intensity or units of Btu used to produce a dollar's worth of the economy's output (GDP), which was relatively flat from 1950 to 1971, fell by 2.4 percent per year from 1972 to 1985, resulting in an overall drop in U.S. energy intensity of over a quarter from 1972 to 1985.[5]

This trend of decreasing energy use per dollar of GDP ended in 1986. From 1986 to 1988, the two factors began to grow in parallel again with energy use increasing at a 3.9 percent annual rate and GDP growing at 4.1 percent. The energy intensity of the U.S. economy fell at a meager annual rate of 0.2 percent between 1986 and 1988.

Purpose and Scope

The purpose of this report is to:

- explore how this drop in energy intensity between 1972 and 1985 occurred,
- why it stopped between 1986 and 1988[iv] and
- briefly speculate about what is likely to happen in the future.

The factors underlying this changing relationship between energy use and the economy are important for understanding the role energy plays in the economy, how that role has changed, and how it is likely to evolve in the future.

Tracing how the connection between changes in energy use and changes in the economy has evolved requires identifying specific factors that are critical variables in the process. This report explicitly looks at how changes in the level of overall spending, the mixture of what is being purchased, international trade, and how things are made (technology) affect energy use.

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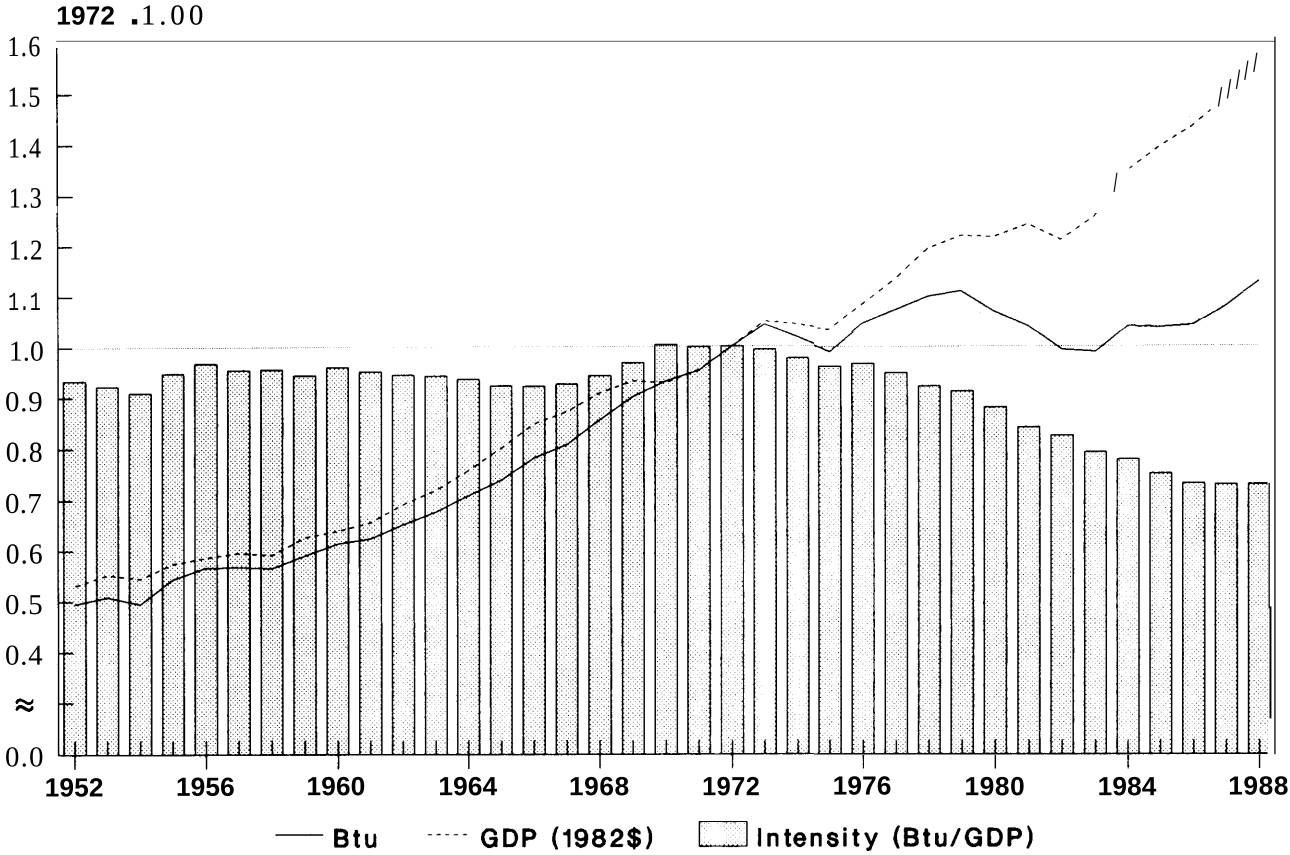
[i]An exception to this statement would be renewable sources of energy which constitute about 4 percent of the total 1988 energy use. U.S. Department of Energy, *Annual Energy Review 1988*, table 3, p. 11.

[ii]GDP is the sum of all output produced in a year that was sold in the formal market (GNP) minus net payments paid to foreigners as returns on their investments in the United States and the return gained by U.S. citizens on their investments overseas. All GDP figures used in this report are in constant 1982 dollars. (See the appendix for more detail.)

[iii]A British thermal unit (Btu) is the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit. A Btu equals 252 calories.

[iv]Data availability limit the analysis to 1988.

Figure l-index of U.S. Energy Use, GDP, and Energy Intensity



Energy use (Btu) and economic growth (GDP) grew in parallel from 1952 to 1971, causing the energy intensity (Btu/GDP) to be relatively flat. After 1971, GDP continued to grow, but energy use stayed relatively constant, resulting in a decline in the energy intensity until 1988. Due to an increase In energy use after 1985, the energy intensity stayed level from 1988 to 1988.

SOURCE: U.S. Department of Commerce, Bureau of Economic Analysis, National Income and Product Acoounts, table 1.2; U.S. Department of Energy, Energy information Agency, *Annual Energy Review 1987* table 4; and the *Monthly Energy Review,* August 19S9, table 1.4.

This separation is important because confusion abounds over how the United States was able to keep the economy growing during the 1970s and 1980s, but hold energy use steady. Some observers attribute the decline in Btu used per dollar of GDP solely to increases in energy efficiency.[6] This is only part of the story. Factors such as changing tastes, incomes, demographics, and international competition led to a shift in the makeup of the economy's output as "smokestack' industries' position declined relative to services and light manufacturing.[7] This change in the structure of the economy also led to less energy used per dollar of output produced. Some of this confusion between declining Btu per dollar of output (energy intensity) and increased energy efficiency is due to semantics and different assumptions. Part II of this report describes in more detail the definitions and analytic structure used in this analysis.

The bulk of the report focuses on the 1972-85 period when energy use stayed flat, but the economy continued to grow (part III). Many other studies have examined the relationship between energy use and the U.S. economy during the 1970s and early 1980s, focusing on the effect of energy efficiency and industrial shifts within the economy on energy use. This report is in general agreement with those studies, but extends the analysis into several new directions.[8]

One of these differences is that most previous research focused exclusively on the industrial sector of the U.S. economy—roughly 30 percent of GDP.[9] This study covers all sectors of the economy.

v Defined as the sum of the agriculture, mining, construction and manufacturing sectors.

Technological advances in information processing (computers, communications, robotics, etc.) are changing the nature of the U.S. economy, making it more complex and interdependent. For example, a dollar spent on food ends up providing only 15 cents to the sector that includes agriculture and 26 cents to manufacturing. Forty cents of the dollar spent on food is retained by services such as transportation and retail trade, an additional 13 cents goes to transactional services like banking, advertising, and law.[10] Information technologies have increased the interdependence of these different sectors, creating networks that link the consumer to the retailer, the retailer to the manufacturer, and the manufacturer to his suppliers.[11] In an economy such as this one, conventional divisions that separate manufacturing from services and the commercial sector from the transportation sector, miss the interaction that occurs between those components.

In a highly developed economy consisting of innumerable interconnections, the role of energy is less likely to be directly identified and is instead more likely to be an indirect factor that was added many steps before in the complex network that connects producer to consumer. For example, to assemble all of the motor vehicles made in 1985 required relatively little **direct** energy, about 0.23 quadrillion Btu (quads), but it required 1.22 quads of **indirect** energy use because the materials used in a car (steel, rubber, glass, plastic) require a lot of energy in their manufacture and fabrication. Thus, most of the energy associated with making a motor vehicle is not at the assembly plant, but was added a few steps before at the steel mill, tire plant, or glass factory. From this perspective, a change in the nonenergy inputs (e.g., material substitution) used to make a product could indirectly affect energy use. This report explicitly separates direct and indirect energy use.

This division between direct and indirect energy use is especially appropriate when the energy associated with international trade is considered. Most calculations presented in this analysis as well as most conventional measures of U.S. energy use, include only direct energy imports-such as barrels of oil or megawatt-hours of electricity. Nevertheless, as production networks continue to extend beyond a country's borders, the inclusion of the indirect energy embodied in the trade of nonenergy products is increasingly important in calculating a country's total energy use. For example, including only the direct energy needed to make a U.S. automobile would miss the energy embodied in a steel axle that was imported from Japan.

Lastly, this analysis goes beyond most previous work by sketching how energy use changes with shifts in the economy. This greater detail adds explanatory power and helps in connecting the findings to public policies. For example, the broad category of structural change is divided into changes emanating from consumers and businesses. Changes due to consumer spending are looked at from three angles: overall level and mix of the products purchased, sources of consumption (e.g., households, government), and type of product being consumed (e.g., manufactured goods v. services). Similarly, shifts in energy use due to changes in the way businesses make their products are broken down by type of product and by changes that either directly or indirectly affect energy use (e.g., material substitution).

The model used for this analysis, like all simulations of reality, is not free of shortcomings. These are outlined in part II. In particular, no attempt was made to explain *why* these changes in the economy or in energy use occurred. Instead, only the question of *how* shifts in the economy affected energy use is explored. As a result, although the industrial structure of the economy and the implementation of technology is undoubtedly affected by changes in tastes, incomes, government regulations, and the relative prices of products-especially the huge changes in the prices of energy-these factors are not explicitly addressed in this report.[12]

Summary of Findings

A number of policy issues, such as climate change, disposal of nuclear waste, the trade deficit, acid rain, and military security, are directly tied to energy use. Understanding how energy use has changed is instrumental to designing policies that address these issues. This section draws lessons from the findings in part III and part IV.

Economic Growth and Energy Use

- *Economic growth is not necessarily contingent on using more energy.* OTA analysis finds that between 1972 and 1985 economic growth, at least as it is broadly defined as growth in GDP, was not linked **to** ever-increasing levels of energy use;[vi] in fact, slow economic growth tended to cause changes that impeded strides towards improving energy efficiency. Although sheer growth, holding all other changes constant, does increase energy use, economic growth never occurs in a vacuum; rather, growth is likely to be associated with other factors such as shifts in the mix of spending towards less energy-intensive products and changes in the way the output of the economy is produced that result in a decline in energy use. Together, these factors contributed to little or no increase in energy use between 1972 and 1985 (table 1).

Energy Efficiency v. Structural Change

- *Energy-efficiency improvements implemented in the production process between 1972 and 1985 mean that the 1985 economy would have used 15 quads more of energy if these gains had not* ***been achieved.*** If these savings had not occurred, the U.S. economy would have required 20 percent more energy in 1985 to produce its output-more than the total amount of energy imports in 1985. (See figure 2.) Two-fifths of these savings came from the manufacturing sector, but another fifth came from the service sector.

- *The leveling of energy use from 1972 to 1985 was not solely due to improvements in energy efficiency, but was also caused by structural shifts in the economy.* Of the factors that offset the increase in energy use due to increases in the sheer size of the economy, nearly two-thirds of the 1972-85 decline was because of energy-efficiency improvements; the remaining third was due to a realignment of the industrial composition of the economy. The output of the economy shifted towards less energy-intensive industries such as services. This shift was caused by changes in the mix of what consumers demanded and by technological improvements in production processes which indirectly saved energy. If these structural shifts between 1972 and 1985 had not happened, the energy used in 1985 would have been about 13 percent higher (9.5 quads).

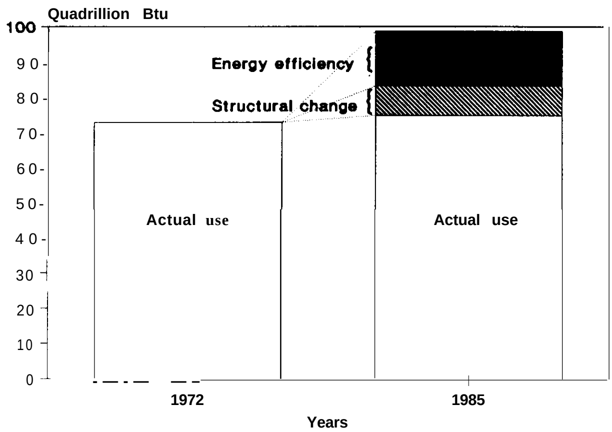
Table l-Changes in Primary Energy Use Due to Selected Factors, 1972-85
(quadrillion Btu)

Actual 1972 to 1985 energy use increase	1.9	
Change due to spending	14.4	
Change due to the level of spending		17.7
Change due to the mix of spending		-5.8
interaction of level and mix		2.5
Change due to production recipe	-19.5	
Change due to the energy portion		-15.4
Change due to the nonenergy portion		-3.7
interaction of the energy and nonenergy		-0.4
interaction of spending and production recipe	7.1	

NOTE: Numbers may not add due to rounding.

SOURCE: Office of Technology Assessment, 1990.

Figure 2-Changes in Energy Use, 1972-85



Actual energy use in the OTA mode, (clear boxes) increased from 72.5 quads in 1972 to 74.9 quads in 1985. Nearly 100 quads would have been used in 1985 if energy savings, because of efficiency improvements (black box) and structural changes (hatched box) in the economy, had not occurred over this period. Of these savings that occurred, nearly two-thirds were because of energy-efficiency improvements in the production processes employed by businesses. The remaining third of the decline, structural change, is indicative of shifts in the industries that make up the economy.

NOTE: This figure does not refleet changes in energy use due to overall growth or interactive factors. See table 1 for these effects.

SOURCE: Office of Teehnoiogy Assessment, 1990.

Direct v. Indirect Use of Energy

- *Energy is increasingly being consumed indirectly, embodied in nonenergy products, while the growth in the direct use of energy has been relatively small. Of the* increase in energy use between 1972 and 1985 due to spending on all products, only 8 percent was due to direct purchases of energy products like gasoline and

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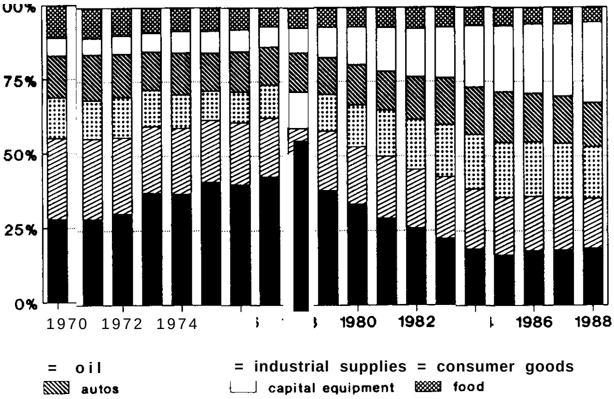
fiIt should be kept inmind that the economic experienee in the 1970s and early 1980s was not free from problems: several reeessions occurred, inflation and unemployment bit very high levels, productivity rates declined, and budget and trade deficits emerged.

heating fuel. The remaining 92 percent of the increase in energy use due to spending was indirectly induced by the purchases of nonenergy products that embody energy like clothes, tires, and automobiles.

- *The bulk of the increase in indirect energy use between 1972 and 1985 came from demand for services.*[vii] Although the energy intensity of the service sector is low, its size and rapid growth have meant that its total energy use is larger than manufacturing 's. The source of much of this indirect demand for energy is personal consumption (households), where indirect demand for energy outpaced direct demand by a factor of 3 from 1972 to 1985.
- *Energy savings can also be achieved indirectly.* Nearly a fifth of the reduction in energy use achieved from 1972 to 1985 because of changes in businesses production processes came indirectly as less energy-intensive inputs like plastic were substituted for more intensive inputs like steel. Almost all of these savings were made in the manufacturing sector.

Figure 3-Major Categories' Share of Merchandise Imports (1982 dollars)



Although the portion of all merchandise imports that are oil has dropped from a high of 42 percent in 1977 to 18 percent in 1988, oil imports are still a higher fraction of constant dollar imports than autos, all consumer goods, or all industrial supplies and materials (which exclude oil).

NOTE: In order to compare the trend over time, the data is presented in constant 1882 dollars. Due to changes in the pffees of some goods sines 1982, like oil, this may have a distorting effect on some categories.

SOURCE: U.S. Department of Commeree, Bureau of Economic Analysis, National Income and Product Accounts, table 4.4.

International Trade

- *Imports of energy products (not including the embodied energy in nonenergy products) are a significant component of our trade deficit.* Although the portion of all imports that are energy ("petroleum and products") has dropped from a high of 42 percent in 1977 to 18 percent in 1988, oil imports are still a higher fraction of constant dollar imports than autos, all consumer goods, or all industrial supplies and materials (excluding oil) (see figure 3).[viii] Of the major merchandise trade categories experiencing a trade deficit in 1988, oil represented almost a quarter of the total[13] and its share seems to be increasing.[14] The share of oil that comes from imports has risen to 44 percent, almost matching our highest level of dependency set at 46 percent in 1977.[15]
- *The United States' gross*[ix] ***energy use*** *would be 9 percent higher if we included the energy embodied in nonenergy imports. The statistics* that show a leveling of domestic energy consumption fail to reflect the fact that the United States indirectly consumes energy by importing nonenergy imports like cars and steel. As the trade deficit has deepened, so has this indirect energy use. OTA estimates that in 1985, the United States consumed roughly 7 quads of energy in nonenergy imports like cars and steel. When this is added to our direct imports of energy, our 1985 foreign energy dependence increases by 50 percent. In terms of recognizing our dependence on foreign sources for energy or our global contribution to problems like climate change, it is important to include estimates of the energy associated with nonenergy imports.[16] Failing to make this adjustment, it would be easy to show declining energy use simply by importing energy-intensive final products and intermediate inputs from abroad. When this adjustment is made, instead of a 39 percent drop in the use of imported energy from 1977 to 1985, the decline is reduced to 21 percent.

[vii] See the appendix for a listing of industries included in the service sector.

[viii] In an effort to show how the composition of imports have changed over time, constant dollar data using 1982 as a base year was used. This creates some distortions in the relative position of products whose prices have undergone a large change since 1982, like oil.

[ix] The energy embodied in nonenergy exports such as grain has not been subtracted.

Differences Between Energy Types

- *Businesses' energy use in the United States is very flexible and adaptable. The* composition of energy use due to changes in production processes has changed dramatically from 1972 to 1985 with the use of crude oil& gas falling by 19 quads over this time period. The drop occurred primarily in manufacturing's use of crude oil & gas,[x] but the energy sector itself and the service sector also made significant contributions to the decline.
- *Declines in energy use were not universal across all energy types.* Energy is not a homogeneous entity, but is instead composed of widely differing products which have very different uses and qualities. The slight increase in overall energy use from 1972 to 1985 came from increases in the use of coal (primarily used to produce electricity) and primary electricity that were largely offset by declines in the use of crude oil& gas and refined petroleum. In aggregate, energy use per dollar of GDP declined from 1972 to 1985, but within individual energy types, all of the decline occurred in crude oil & gas, refined petroleum, and utility gas. Coal and primary electricity registered a slight increase in use per dollar of GDP during this period.

Energy Use From 1985 to 1988

- *The trend of level energy use established from 1972 to 1985 was broken between 1985 and 1988 when energy use increased by 8 percent (5.7 quads). The* energy intensity of the economy stayed constant from 1986 to 1988, dropping at a meager 0.2 annual rate as opposed to the –2.4 percent annual decline achieved from 1972 to 1985.
- Much *of the increase in energy use from 1985 to 1988 can be traced to strong economic growth and a shift in the mix of consumption towards more energy-intensive products. The 1985-88* period was a time of strong economic growth: real GNP grew at an annual rate of 3.6 percent, v. 2.5 percent for the 1972-85 period.
- *The major shifts towards an energy-intensive mix of spending occurred in the government and international sectors.* Federal Government spending on nondefense purchases fell by 16 percent over the 3-year period and defense purchases, which are about 1.5 times as energy intensive as nondefense purchases, grew by 10 percent. Likewise, the energy-intensive export sector experienced the fastest rate of growth of any sector[xi] during this period, increasing its share of GNP from 10 to 13 percent. Even "smokestack" industries like steel and aluminum experienced a resurgence.[17] Overall, exports between 1985 and 1988 grew in real terms by 44 percent while imports increased by only 28 percent.
- *Of the 10 major sectors of the economy,[xii] manufacturing increased its share of total shipments the most from 1985 to 1988, growing from 32.9 percent of all shipments to 33.8. This* increase in manufacturing's share of gross output halted a downward trend that had prevailed since 1972.
- *There is little data to support the idea that the 1985-88 increase in energy use was due to less efficient production processes. The* annual rate of investment in new plant and equipment from 1985 to 1988 was 7 percent, 2 percentage points higher than the 1972-85 annual investment rate-a period of declining energy use per dollar of output. It is unlikely that these 1985-88 investments caused a reduction in energy efficiency, rather they probably improved energy efficiency, but data detailed enough to confirm this is not available.

Energy Use in the Future

- *Predictions about the rate of economic growth suggest that the increase in energy use should be less in the future than what was experienced between 1976 and 1988. The* annual growth rate of GNP between 1976 and 1988 was 2.9 percent. The Department of Labor's moderate economic growth scenario for 1988 to 2000 assumes a 2.3 percent growth rate.

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[x] Most of this drop actually occurred in the use of refined petroleum products, but this analysis converts all energy use to its primary form which in this case would be crude oil & gas. See part II for a further explanation of this conversion.

[xi] Overall spending consists of five broad sectors: 1) households, 2) business investment, 3) all levels of government, 4) changes in inventories, and 5) international trade (imports and exports).

[xii] The sectors are: 1) agriculture; 2) mining; 3) construction; 4) manufacturing; 5) transportation, communication, and utilities; 6) wholesale trade; 7) retail trade; 8) finance, insurance, and real estate; 9) services; and 10) government.

- *In terms of energy use associated with changes in the composition of output (e.g., structural change) the picture is mixed. The manufacturing* sector is predicted to benefit from increases in exports as the trade deficit narrows, while being hurt by decreases in defense spending as efforts are made to decrease the budget deficit. On net, manufacturing's share of output is predicted to increase, but much of the growth is in "high-tech" products that have relatively low energy intensities. When viewed across all sectors, changes in energy use associated with changes in the structure of the economy do not appear to be signtificant.
- *The future impact of technology on energy use is even more speculative.* Nevertheless, a wide array of energy-saving technologies that are already in the market are available and hold the potential for significant gains in efficiency. The critical unknowns of the future are not ones of technical potentials, but rather whether the willingness to implement the technology will exist.

The following sections present the analysis behind these findings, showing them over time and breaking the change in energy use down into five energy types: coal, crude oil & gas, refined petroleum, primary electricity, and utility gas. (See part II for further description.) Part III starts with the broad changes that have occurred in energy use due to spending and changes in production processes (labeled production recipe in this analysis). (See part II for definition of terms.) These changes are then broken down into their various components. Changes due to spending are looked at from three angles: level and mix, the sources of spending (e.g., households, government), and the type of product being consumed (e.g., manufactured goods v. services). Production recipe changes are decomposed into changes that directly affect energy use and those changes that indirectly affect energy such as through material substitution. Part IV concludes the report by applying this analytical framework to the recent past (1985 to 1988) and to the near future (1988 to 2000). An appendix, part V, is provided to describe the data, methodology, and strengths and weaknesses associated with the model used for this analysis.

END NOTES FOR PART I

[1]The correlation coefficient of Btu and GDP was 0.992 from 1950 to 1971 which is statistically significant at the 0.01 level. U.S. Department of Commerce, Bureau of Economic Analysis, National Income and Product Accounts, table 1-2; and U.S. Department of Energy, Energy Information Agency, *Annual Energy Review 1987*, table 4, and the *Monthly Energy Review*, August 1989, table 1-4.

[2]J. Goldemberg, T.B. Johansson, A.K.N. Reddy, and R.H. Williams, *Energy for a Sustainable World*, World Resources Institute, September, 1987, p. 27; and W. Walker, "Information Technology and The Use of Energy," *Energy Supply*, October 1985, pp. 460-461. Some analysts argue that a strong link still exists. See Culter J. Cleveland, Robert Stanza, Charles A.S. Hall, and Robert Kaufman, "Energy and The U.S. Economy: A Biophysical Perspective," *Science*, vol. 225, August 1984, pp. 891-893.

[3]For comparison, the number of housing units in 1970 was 63.4 million, the number of cars and trucks stood at 98 million in 1970, and there were 4.1 million businesses established in 1975. Housing and vehicle data comes from U.S. Department of Energy, *Energy Conservation Trends*, Office of Policy Planning and Analysis, September 1989, p. 2; and the U.S. Department of Commerce, *Statistical Abstract of the United States, 1989* (Washington, DC: U.S. Government Printing Office, 1989), table 1243, p. 706 and table 1011, p. 594, respectively; business establishment data is reported in the *Statistical Abstract of the United States, 1989*, op. cit., table 858, p. 523; energy use data is from U.S. Department of Energy, Energy Information Agency, *Annual Energy Review, 1987* (Washington DC: U.S. Department of Energy, 1988), table 4, p. 13; the source for GDP data is U.S. Department of Commerce, Bureau of Economic Analysis, National Income and Product Accounts (July 1989 revision), table 1.2.

[4]U.S. Department of Commerce, Bureau of Economic Analysis, National Income and Product Accounts (July 1989 revision) table 1.2; and U.S. Department of Energy, Energy Information Agency, *Annual Energy Review, 1987* (Washington DC: U.S. Department of Energy, 1988), table 4, p. 13.

[5]This phenomenon is not unique to the United States. It has also been found to have occurred in the United Kingdom, France, Germany, Japan, and Austria. See J. Dunkerley, "Energy Use Trends in Industrial Countries," *Energy Policy* 8 (June 1980); and U.S. Department of Energy, *Energy Conservation Trends*, Office of Policy Planning and Analysis, September 1989, pp. 14-15; C.A. Jenne and R.K. Cattell, "Structural Change and Energy Efficiency in Industry," *Energy Economics*, April 1983, p. 117; C.P. Doblin, "The Impact on Energy Consumption of Changes in the Structure of U.S. Manufacturing, Part I: Overall Survey," working paper, International Institute for Applied System Analysis, Laxenburg, Austria, February 1987, p. 1; U.S. Department of Energy, *Energy Conservation Trends*, Office of Policy Planning and Analysis, September 1989, p. 15; A. Kahane, "Industrial Electrification: Case Studies of Four Industries," revised summary, October 1986; C. Lager, K. Musil, and J. Skolka, "Input-Output Analysis of Energy Conversion in Austria, 1955-1980," *Proceedings of the Fourth IIASA Task Force Meeting on Input-Output Modeling* (Laxenburg, Austria: IIASA, 1983), p. 287.

[6]For example, see C. Komanoff, "Increased Energy Efficiency: 1978-1986," *Science*, vol. 239, No. 4836, Jan. 8, 1988, p. 128; U.S. Department of Energy, Oak Ridge National Laboratory, *Energy Efficiency How Far Can We Go?* ORNL/TM-11441, January 1990, p. 1; and World Resources Institute, press release, "U.S. One of the World's Least Energy-Efficient Countries," Nov. 20, 1989.

[7]For more on how the structure of the U.S. economy has changed over the last decade-and-a-half, see U.S. Congress, Office of Technology Assessment, *Technology and the American Economic Transition: Choices for the Future*, OTA-TET-283 (Washington, DC: U.S. Government Printing Office, May 1988), ch. 5.

[8]Huntington and Myers found that at least one-third of the decline in energy intensity in the manufacturing sector from 1973 to the early 1980s was due to sectoral shifts. See G.H. Huntington and J.G. Myers,

"Sectoral Shift and Industrial Energy Demand: What Have We Learned?" p. 1; Hirst et al. found that a third of the industrial decline in intensity between 1972 and 1981 was due to sectoral shift. See E. Hirst, R. Marlay, D. Greene, and R. Barnes, "Recent Changes in U.S. Energy Consumption," *Annual Review of Energy*, vol. 8, 1983, p. 224; Doblin found that for the 1974 to 1980 period changes in structure accounted for half of the decline in energy intensity in the manufacturing sector. See C.P. Doblin, "Declining Energy Intensity in the U.S. Manufacturing Sector," *The Energy Journal*, vol. 9, No. 2, 1988, pp. 23 and 33; Boyd et al. found that for the manufacturing sector, structural changes accounted for about 16 percent of the 1971 to 1981 drop in energy use. See 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. 20; Williams, Larson, and Ross find that the decline in industrial energy intensity between 1973 and 1985 was due almost equally to efficiency gains and structural shifts. R.H. Williams, E.D. Larson, and M. Ross, "Materials, Affluence, and Industrial Energy Use," *Annual Review of Energy*, 1987, p. 100. For a survey of the literature analyzing the importance of structural shifts on industrial energy use, see 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, C. Geilings (eds.) (Columbus, OH: Battelle Press, 1985).

[9]A notable exception to this is the work authored by J. Roop. See U.S. Department of Energy, "Energy's Role in International Trade: Structural Change and Competitiveness," Office of Policy Planning and Analysis, July 1989.

[10]*Technology and the American Economic Transition: Choices for the Future*, op.cit., endnote 7, p. 160. The remaining 6 cents goes to construction, personal services, and social services.

[11]For example, DuPont has initiated a "Quick Response" system that ties the clothing retailer to the apparel manufacturer to the textile producer. See *Technology and the American Economic Transition: Choices for the Future*, op. cit., endnote 7, p. 238.

[12]For two different analysis of the how changes in the price of energy affect the economy, see Douglas R. Bohi, *Energy Price Shocks and Macroeconomic Performance* (Washington, DC: Resources for the Future, 1989); and Sam H. Schurr, "Electricity Use, Technological Change, and Productive Efficiency," *Annual Review of Energy*, vol. 9, pp. 409-425.

[13]U.S. Department of Commerce, Bureau of Economic Analysis, *Survey of Current Business*, National Income and Product Accounts, table 4.3.

[14]Petroleum and petroleum products share of merchandise trade imports (not seasonably adjusted) increased from 7.7 percent in November 1988 to 10.8 percent in November 1989. U.S. Department of Commerce, Bureau of the Census, "U.S. Merchandise Trade," news release, Jan. 17, 1990, exhibit 5.

[15]U.S. Department of Energy, Energy Information Agency, *Monthly Energy Review*, November 1989, table 1.8, p. 15.

[16]For example, policies that set a specific reduction in energy intensity should take this into account. See W.U. Chandler, H.S. Geller, and M.R. Ledbetter, *Energy Efficiency: A New Agenda* (Springfield, VA: George Washington Press, 1988), p. 21 for an example of such a policy.

[17]Exports of steel mill products increased by 121 percent from 1985 to 1988 while imports of steel mill products decreased by 14 percent. Aluminum exports increased by 44 percent and imports fell by 5 percent over this period. American Iron and Steel Institute, *Annual Statistical Report, 1988*, 1989, tables 14 and 18, pp. 34 and 44. The Aluminum Association, *Aluminum Statistical Review for 1988*, No. 94, 1989, p. 5.

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.

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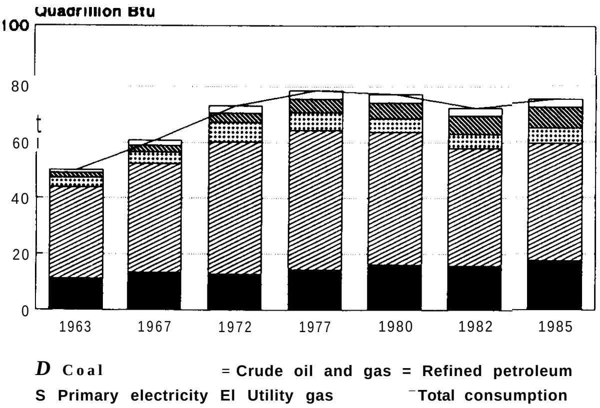
[1] U.S. Department of Labor, Bureau of Labor Statistics, ''Historical Input-Output Time Series Data Base,'' unpublished, January 1989. The 1985 input-output table became available when the report was in review. See U.S. Department of Commerce, Bureau of Economic Analysis, ''Annual Input-Output Accounts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

Recent Changes in Energy Use

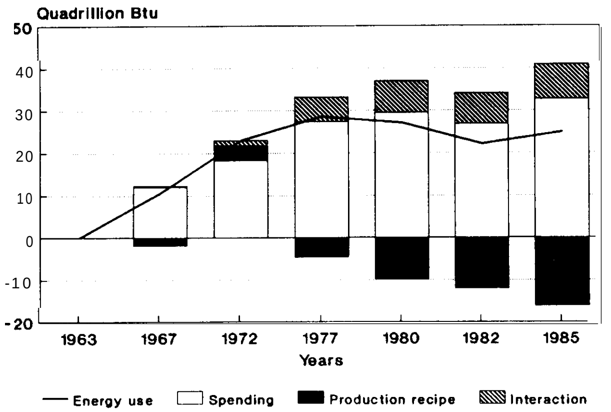
TRACING THE CHANGE IN ENERGY USE

Broad Changes Associated With Spending and Production Recipe

The continued growth of the economy without a corresponding increase in energy use in the 1970s and early 1980s was due to three broad factors: spending, production recipe, and the interaction of changes in spending and production recipe. Figure 5 shows the change in energy use from 1963 and illustrates how these three factors combined to push energy use up from 1963 to 1972, reduce the rate of growth from 1972 to 1977, and cause a leveling of energy use between 1977 and 1985.

Changes in spending have increased energy use, with the magnitude of its effect growing in every year, except for 1982—a severe recession year. Over time, the size of the U.S. economy, reflected by the overall amount of spending, has increased along with increases in population, motor vehicles, and homes—leading to an increase in energy requirements. If more people buy more things-everything else being equal-more energy will be used.

Figure 5-Changes in U.S. Energy Consumption, 1963-85

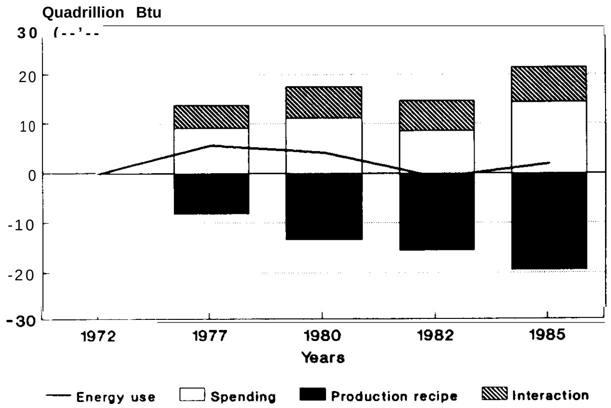


The solid line shows that U.S. energy use increased by nearly 30 quadrillion Btu (quads) from 1963 to 1977 and then declined so that by 1985 energy use had increased by 25 quads from 1963. Spending (and the interaction between spending and production recipe) caused energy use to increase in every year. This increase was offset by changes in the way products were made-the production recipe. in every year except 1972, changes in the production recipe caused a decrease in energy use relative to 1963.

SOURCE: Office of Technology Assessment, 1990.

The effect of production recipe changes on energy use, excluding any changes in spending, has been less constant. In 1967, production recipe played a relatively minor role, exerting a small downward influence on the increase in energy used since 1963. By 1972, the effect of the production recipe had a positive sign—more energy was required to produce a set level and mix of products in 1972 than it took in 1963, probably a reflection of the low, real price of energy in 1972.[23] The impact of changes in production recipe on energy use flipped back to a negative sign in 1977, most likely the results of the first oil shock in 1974. From 1977 on, the downward effect of production recipe on energy use continued to grow until, in 1985, the decrease in energy use due to production recipe was able to counterbalance the increase due to spending. The methods and processes used to produce a set level and mix of output had changed so that it required less energy to produce the output in 1985 than it did in 1972. When the changes in energy use attributable to spending, production recipe, and the interaction of the two are combined, the factors largely offset one other, resulting in a very small increase (2 quadrillion British thermal units (Btu)) from 1972 to 1985 (see figure 6).

Figure 6-Changes in U.S. Energy Consumption, 1972-85



In comparison to 1972, energy use in 1985 is up by a couple of quadrillion Btu. This small net increase is the result of offsetting factors. Growth in spending caused energy use to increase by 14 quads from 1972. The interaction of spending with changes in the production recipe also resulted in an increase in energy use of 7 quads. These increases were balanced by decreases in energy use stemming from changes in the recipe used for producing goods and services. By 1985, these changes had resulted in energy savings of almost 20 quads from 1972.

SOURCE: Office of Technology Assessment, 1990.

Fuels

In terms of fuel use, the 1972-85 change in energy consumption resulted in a nearly equal increase in the use of coal and primary electricity, balanced off by a relatively large decrease in crude oil& gas and a smaller decline in the use of refined petroleum (see table 2). Changes in spending caused an increase in the use of coal, crude oil & gas, and primary electricity while changes in the recipe of production caused a large decrease in the use of crude oil & gas while generating a slight increase in the use of primary electricity over the period. This increase in the use of electricity could be due to offsetting factors. For example, as a business increases its use of electricity for new technologies, such as computers, and new processes, such as the electric-arc furnace steel making, savings are also achieved as electricity-saving technologies, such as sensors and controls, are adopted.

The difference in energy use by fuel type is also indicative of the different qualities inherent in the various energy types. Decreasing the use of oil and gas is usually easier because these fuels tend to be used for the production of heat, which can be recovered and reduced more readily than electricity, which is used not only to produce heat, but also for motor drive, electrolytic reactions, and production control, to name a few.[24] The aggregate term, energy, should not be thought of as a fungible commodity but rather as a heterogeneous collection of energy types that have had a much different experience in the 1972-85 period.[25]

Table 2-Changes in Primary Energy Use From 1972 to 1985 by Energy Type Due to Major Factors (quadrillion Btu)

	Spending	Production recipe	Interaction	Total
coal	3.7	1.0	0.2	4.9
Crude oil & gas	7.4	–19.2	6.1	-5.7
Refined petroleum	–1.3	-0.5	0.2	-1.6
Primary electricity	3.9	0.2	0.1	4.1
Utility gas	0.7	-1.1	0.6	0.2
Total	14.4	–19.5	7.1	1.9

Energy use increased by 1.9 quads from 1972 to 1985. This was due to offsetting factors where spending caused a 14.4-quad increase, the interactive terms led to a 7.1-quad increase, and changes in the production recipe resulted in a 19.5-quad decrease. The use of both coal and primary electricity increased, reflective of increases in the use of electricity. Most of these gains emanated from changes in spending. Changes in the production recipe caused the use of crude oil and gas and refined petroleum to fall.

NOTE: Total may not add due to rounding.

SOURCE: Office of Technology Assessment, 1990.

Changes Associated With Spending: Level and Mix, Product Groups, and Source

Each of the variables discussed above can be broken into freer components that provide a greater understanding of how the economy interacts with energy use. These different perspectives shed light on whether the increase due to spending was simply due to buying more products or a different mix of products. Was the increase due to increased use of energy as an end product, such as oil for our homes or gasoline for our cars, or was it indirectly consumed through the purchases of nonenergy products that embodied energy? If it increased through indirect consumption, what type of product was it that boosted the consumption? Lastly, where is this increase in direct and/or indirect consumption coming from-households, the government, or international trade?

If we want to understand how the different facets of the economy interact with energy use, it is important to answer these questions. For example, policies designed to affect household energy use (e.g., incentives to insulate) are different than policies that address reducing the dependence on foreign energy supplies (e.g., duties on imported oil).

Level and Mix

Spending can be split into two components:

- a change in the size or level of spending, where simply more of everything is purchased; and
- the changing mix of what is being bought.

If a consumer simply buys more of everything, keeping the proportions of spending the same across all products purchased, all energy changes will be attributable to an increase in the level of spending—no change in mix has occurred. But if more is being purchased and the mix of what is being bought shifts, the change in energy use is attributable to changes in growth *and mix*. By holding one component constant while allowing the other to vary, the change in the overall energy use associated with spending can be broken up into level, mix, and an interactive factor.

From 1972 to 1985, the increase in energy use associated with spending came both from the increased level of spending and the interactive effect generated between level and mix. Changes in the mix of spending resulted in a decline in energy use in every year examined, except for 1967 (see figure 7).[26] As the level of spending has grown, the mix of what is being purchased has shifted to less energy-intensive products, such as health care instead of gasoline. If the mix had not shifted between 1972 and 1985, the United States would have used 8 percent more energy in 1985 than what was actually used (see table 3).

As one would expect, the level of spending tends to track business cycles; the fact that energy associated with the *mix* of spending also tends to be affected by economic swings is somewhat of a surprise. In every year except 1967, the impact of changing levels of spending on energy use has been offset by changes in the mix of spending. In other words, just as an up-tick in economic growth causes an increase in energy use, it also frequently causes a shift in what is bought. The mix of purchases moved towards a less energy-intensive array of products-causing the two factors, level and mix, to partially cancel one another. Likewise, in the lean economic years of 1980 and 1982, the increase in energy use due to growth was reduced, but the mix of products purchased became more energy-intensive (see figure 8).

This suggests that as consumers are pinched by tough economic times, their market basket of products consumed shifts towards relatively more energy-intensive products, probably basic necessities such as heating fuel or gas for cars. During

Table 3-Changes in Primary Energy Use From 1972 to 1985 by Energy Type Due to Spending
(quadrillion Btu)

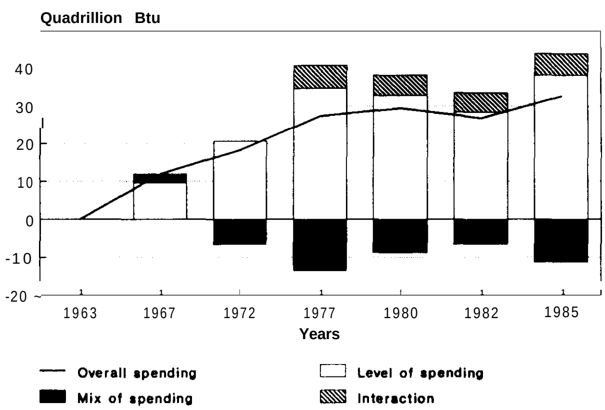
	Level	Mix	Inter-action	Total
Coal	4.6	–2.4	1.5	3.7
Crude oil & gas	11.6	-4.2	0.1	7.4
Refined petroleum	–1.2	–1.9	1.7	–1.3
Primary electricity	2.2	2.4	-0.8	3.9
Utility gas	0.4	0.3	–0.0	0.7
Total	17.7	-5.8	2.5	14.4

Holding changes in the production recipe constant, OTA estimates that changes in spending would have led to a 14.4-quad increase in energy use from 1972 to 1985. All of this increase is due to increases in the overall level of spending; the changing mix of what was purchased led to a decrease in energy use. The higher level of spending led to increased use in nearly every energy type, but particularly crude oil & gas. By and large, shifts in the mix of spending tempered these increase.

NOTE: Total may not add due to rounding.

SOURCE: Office of Technology Assessment, 1990.

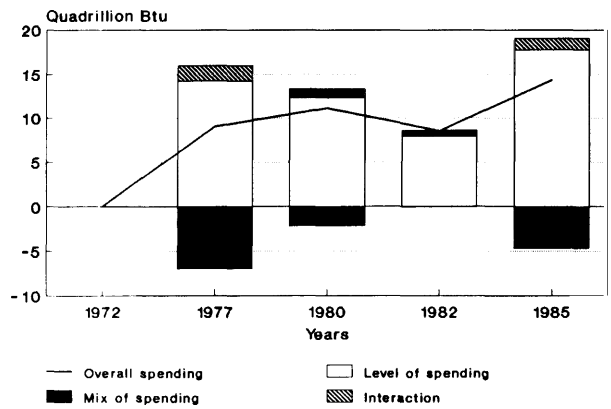
Figure 7-Changes in U.S. Energy Consumption Due to Spending, 1963-85



Overall spending can be broken down into two components: the level of spending and the mix of what is purchased. Holding changes in the production recipe constant, OTA estimates that the level of spending would have caused energy use to increase in every year from 1963 to 1985. The increase in energy use due to a higher level of spending is mitigated by a changing mix of what is purchased.

SOURCE: Office of Technology Assessment, 1990.

Figure 8-Changes in U.S. Energy Consumption Due to Spending, 1972-85



Changes in overall spending (solid line), holding other factors constant, would have caused energy use to increase by 14 quads from 1972 to 1985. All of this increase was due to higher levels of spending and an interactive term. The mix of spending (black box) shifted so that less energy was used between 1972 and 1985. By 1985, the shift in the mix of what was bought had led to over a 5-quad decrease in energy use from 1972.

SOURCE: Office of Technology Assessment, 1990.

periods of relative prosperity, the mixture of purchases shifts back to a less energy-intensive collection of items of a more luxurious nature, such as electronics, sporting events, or clothes.[27] Definitive conclusions cannot be drawn because of the sparseness of the data points. Nevertheless, the responsiveness of the mix of spending is indicative of a flexible buying pattern that can reduce the change in energy consumption by as much as 7 quads (1972 to 1977 change) or as little as 0.2 quads (1972 to 1982).

Fuels—Table 3 shows that about half of the increase in energy use from 1972 to 1985 attributable to spending was in crude oil& gas, and that all of this increase was due to an increase in the level of spending. Most of the remaining increase was in coal and primary electricity, both of which are indicative of increased electricity use. If a shift in the mix of what products were being bought had not occurred, an even larger increase in the amount of crude oil& gas would have occurred. This same relationship of increased use due to growth in the level of spending being tempered by a shift in the mix of what was purchased also occurred in the use of coal. The major exception to this pattern was in the use of primary electricity, which was boosted almost equally by increases attributable to changes in the level and mix of products consumed. Thus, the overall trend that associates a shifting mix of products consumed with a decrease in energy use does not apply to primary electricity.

The tilt in the mix of products purchased towards less energy-intensive goods and services is reflective of a whole group of events that occurred between 1972 and 1985: income growth,[28] demographic change,[29] new government regulations,[30] changing prices,[31] the end of the Vietnam War,[32] and technological innovations,[33] to name a few. The fuel economy of new passenger cars nearly doubled over this period. Consumers turned down their thermostats. Purchases of energy-intensive products like automobiles, stoves, and washers and energy-intensive infrastructure such as roads and factories hit saturation points, limiting the market for these items mainly to replacement.[34] As expenditures on energy products and energy-intensive goods drop, money is left to be spent on products that are less energy-intensive. The next section explores this further by breaking spending into five broad groups of products and tracing how changes in spending on each group affected energy use.

Product Groups[35]

The influence of spending on energy use becomes less abstract when spending is broken down into tangible goods and services that can be purchased. In this study, spending was broken into five broad groups-energy, natural resources,[xv] manufacturing, transportation services,[xvi] and services. (See table 17 in part V for a listing of the products that make up each group.) This separation of purchases of energy products from other products allows exploration of the question of how much of the increase in energy use due to spending was caused by direct purchases of energy and how much of the increase was the result of indirect uses of energy as consumers buy products like food or clothing that embody energy. In some cases, the division between direct and indirect is a result of whether or not the "amenity" being acquired is obtained within the formal market place or outside of the market (e.g., self-service). For example, the fuel purchased for personal travel would be counted as an energy product, a direct use of energy, while the energy associated with spending on air travel (a transportation service) would be an indirect use of energy.

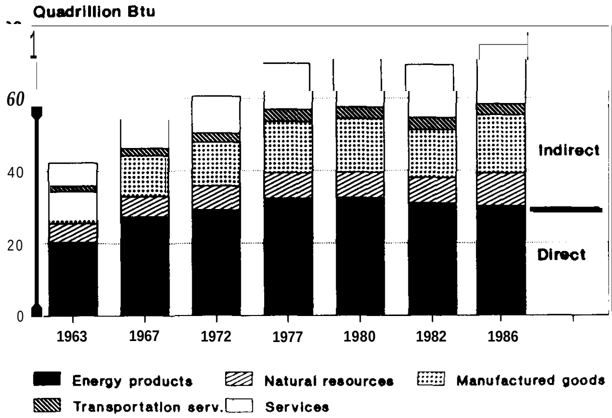
Direct purchases of energy products by final consumers have been constant or falling since 1977 (see figure 9). Only 1.1 quads of the overall 1972-85 total 14.4-quad increase in energy use due to spending came from direct demand for energy products. This would not seem to be small if the share of the increase was commensurate with the share of the overall base the product held in 1972. But for the energy product group, this increase translates into a disproportionately low 8 percent share of the 1972-85 increase, since energy products represented 48 percent of the energy associated with 1972 spending (figure 10). The energy product group was the only group to substantially lose share over this period.

The engine behind the growth in energy use due to spending was the indirect use of energy associated

[xv] Includes agriculture, mining, and construction.

[xvi] This group includes freight and passenger transportation services. Transportation provided by personal vehicles would not be included in this category because the transportation service in this case is not being purchased but is instead being supplied outside of the formal market by the individual himself—self-service. The fuel purchased to run the vehicle would be counted as a purchase of an energy product.

Figure 9-Changes in U.S. Energy Use Due to Spending on Different Product Groups



Changes in energy use due to spending can also be analyzed from the perspective of what is being purchased. Categories of purchases are divided into five groups. The bulk of the increase in energy use, particularly since 1972, has been associated with the purchase of nonenergy products, or the indirect use of energy. Of these product groups, the services category experienced the most rapid growth from 1972 to 1985.

SOURCE: Office of Technology Assessment, 1990.

with purchases of services (figure 10). Forty-five percent of the increase was due to services, more than double the energy associated with the 1972 spending on services. By 1985, spending on services used more energy than the energy associated with spending on manufactured goods. Although individual services are not very energy-intensive, the large segment of the economy they constitute, coupled with the dramatic growth they have experienced, means that they are an important demand-side factor in energy use.

The fact that energy use associated with the direct purchase of energy products have declined relative to service products is consistent with the finding that the mix of spending has led to less energy use since services are less energy-intensive than any other product group. (This will be discussed further in a following section on production recipe changes.) The fact that every product group increased its energy use from 1972 to 1985 is indicative of the overall increase in the level of spending (table 4).

Fuels—Not surprisingly, the different product groups had a varying affect on energy use by type of energy. Table 4 shows that of the change that occurred between 1972 and 1985 because of spending, services were responsible for 43 percent of the increase in coal use, 44 percent of crude oil& gas,[36] and 28 percent of the increase in primary electricity. Presumably, these increases are tied to increases in overall commercial space and the requisite heating, cooling, and lighting needs associated with the increasing size of the service sector. Changes in spending on manufactured goods caused an increase in the use of coal and crude oil & gas and a small increase in primary electricity. Within the energy product category, consumers moved towards electricity and away from refined petroleum. Consumers preferences of energy consumed as a final product shifted away from refined petroleum during the period and towards electricity.

Sources **of Demand**

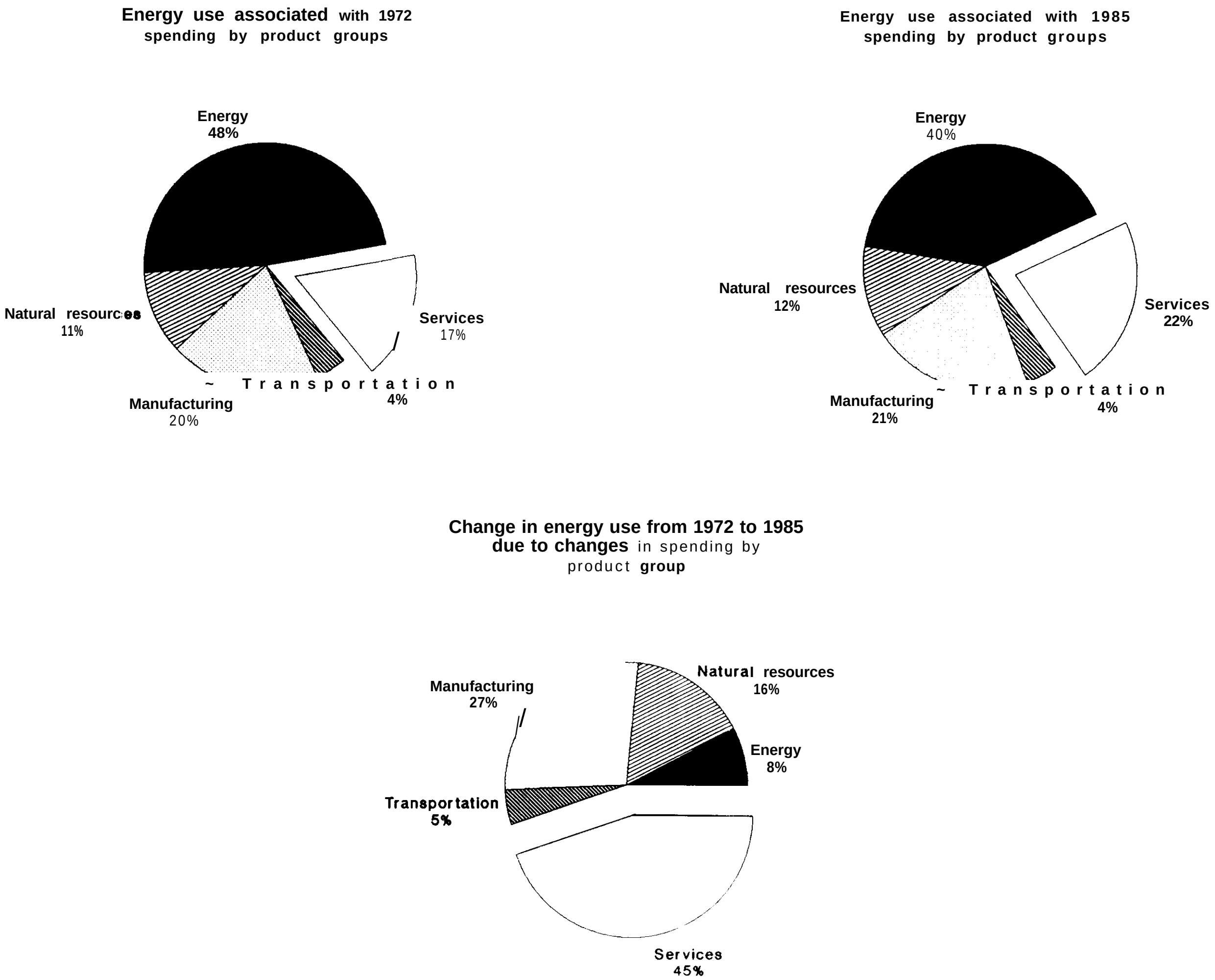
Consumers of final products area heterogeneous group, composed of households, Federal, State, and local governments, businesses,[xvii] and international tcade.[xviii] The overall consumption of a particular product is calculated by summing the expenditures made on that product from each of these sources. But spending by each source depends on widely differing factors. For example, household expenditures are affected by changes in wages, governments depend on taxes, businesses rely on revenues, while foreign trade is influenced by fluctuations in the value of currencies. The policy levers that affect each group are also very different. Given these differences, it is important to isolate how each group's demand for energy, both direct and indirect, contributed to the increase in energy use due to spending.

Households and Government —Figure 11 shows how energy use would have changed as a result of changes in spending from households (personal consumer expenditures) and government, which together constitute 85 percent of the 1985 GNP. Direct personal consumer expenditures on energy rose steadily from 1%3 to 1977 and then leveled-off, while the indirect use of energy associated with purchases of nonenergy products steadily grew from 1963 to 1985. By 1985, households indirect energy use was nearly as large as the energy directly

[xvii] Businesses are categorized as final consumers only when they buy products which are not reprocessed for further sale. Final products consumed include buildings and durable equipment such as machine tools, not intermediate purchases of inputs such as steel or rubber which are purchased for further processing. The energy changes associated with intermediate inputs are discussed in the next section.

[xviii] The change in business inventories represent a fifth category, but is excluded for simplicity.

Figure 10-Energy Use and Changes in Energy Use Associated With Spending by Product Groups



Direct spending on energy products represented 48 percent of all the energy use associated with spending in 1972. Energy use associated with spending on services showed the largest gain in share, jumping from 17 percent in 1972 to 22 percent in 1985. When the 1972-85 change in energy use due to spending is broken into product groups, it becomes evident that direct spending on energy was responsible for only 8 percent of the gain while spending on services resulted in 45 percent of the increase.

NOTE: Although spending was allowed to change, the way the products were made (the production recipe) was held constant at its 1985 form.

SOURCE: Office of Technology Assessment, 1990.

consumed. To some degree this growth in energy associated with nonenergy products is a result of sheer growth in the consumer sector and more generally the economy. Nonetheless, this growth did not affect household purchases of energy. The bulk of the 1972-85 increase in energy use due to spending came from the household sector where indirect energy use grew three times as fast as direct household demand for energy (see table 5). Most of this indirect energy use was in the form of coal and crude oil & gas. Primary electricity was the only energy type whose growth was balanced between direct energy demands and indirect energy demands during this period.

The indirect use of energy is even more apparent in government spending where the indirect use of energy has always exceeded direct energy pur-

Table 4-Changes in Primary Energy Use From 1972 to 1985 by Energy Type Due to Spending on Different Products (quadrillion Btu)

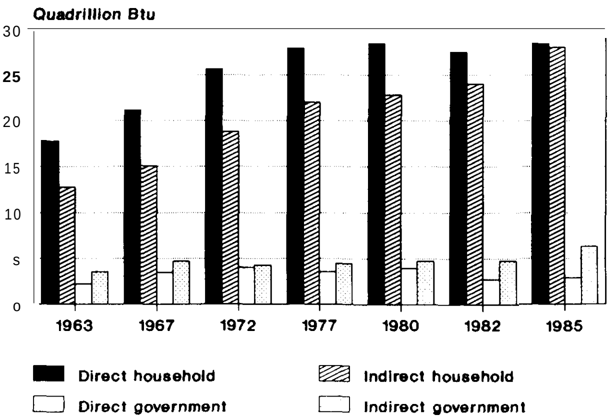
	Energy	Natural resources	Manufacturing	Transportation services	Services	Total
Coal	0.5	0.5	1.0	0.0	1.6	3.7
crude oil & gas	0.5	1.3	1.8	0.5	3.3	7.4
Refined petroleum	-1.6	0.1	0.1	0.0	0.1	–1.3
Primary	1.6	0.3	0.8	0.0	1.1	3.9
utility gas	0.1	0.1	0.2	0.0	0.2	0.7
Total	1.1	2.3	3.9	0.7	6.4	14.4

Of the 14.4-quad increase in energy use due to spending from 1972 to 1985,6.4 quads came from increased purchases of service products and 3.9 quads from purchases of manufactured goods. The build of these increases were in crude oil & gas.

NOTE: Total may not add due to rounding.

SOURCE: Office of Technology Assessment, 1990.

Figure 11—Direct and Indirect Energy Use by Households and Government Due to Spending, 1963-85



Most of the increase in energy use from the household sector has been in the indirect use of energy, especially since 1972. By 1985, households indirect use of energy was as large as its direct use.

NOTE: Although spending was allowed to change, the way the products were made (the production recipe) was held constant at its 1985 form.

SOURCE: Office of Technology Assessment, 1990.

chases. Of all the changes in energy use due to spending, only the government sector, and the ''other'' category,[37] had decreases in direct energy use between 1972 and 1985. For government, nearly all of the decrease was in crude oil & gas while for ''other'' most of the decline was in coal and can be traced to changes in businesses inventories.

Imports and Exports—The other major sources of energy use are the foreign demand for U.S. products (exports) and domestic demand for foreign products (imports).

Tracking the effect of trade on energy use through the U.S. economy is a difficult task, complicated further by the fact that conventional energy use accounting does not reflect the indirect energy embodied in nonenergy imports. Obviously, accounting for the energy used to produce every import would be a herculean task, but a rough approximation of the energy that would have been used if that imported product was produced domestically can be estimated.[38] By summing together this indirect energy use associated with imports, the direct imports of energy, and the use of domestically produced energy, a more accurate picture of the U.S. economy's *gross* energy requirements emerge.[xii] Without this correction, it would be easy to achieve a decline in the economy's energy use simply by importing energy-intensive goods like steel or aluminum. Given that nonenergy imports have doubled their share of GNP since 1970, the need to make this distinction has grown in importance.[39] Policies designed to achieve reductions in a country's energy-intensity should be aware of the ability of transnational companies to outsource components from foreign affiliates, effectively circumventing domestic policies.[40] Box E provides an example of this practice.

When this correcting adjustment is made, the energy embodied in 1985 nonenergy imports boosts the U.S. dependence on imported energy by over 50 percent from 13 quads to 20 (see figure 12).[41] While the indirect energy embodied in exports has stayed relatively steady in the 1980s, the indirect energy

[xix]Exports of direct (e.g., coal) and indirect (e.g., grain) energy should be subtracted to obtain a net figure. If a gross calculation was done around the world, double counting would occur; but on an individual, country basis, this type of calculation gives a more complete estimate of the energy dependence of the U.S. economy.

Table 5-Changes in Primary Energy Use From 1972 to 1985 by Energy Type Due to Sources of Spending
(broken Into direct and Indirect energy use) (quadrillion Btu)

	Households (PCE)		Government		Exports		Imports’		Other+		Adjustments@		Total change in consumption		
	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Export direct	Import direct	Direct	Indirect	Total
Coal	1.8	2.4	-0.1	0.5	1.2	0.7	-0.3	–1.2	-1.1	0.8	1.1	-0.1	0.5	3.2	3.7
Crude oil & gas.	-0.8	4.8	-1.1	1.2	1.3	1.4	-0.4	–1.8	-0.0	1.3	0.4	-2.0	0.5	6.9	7.4
Refined petrol. .	-0.1	0.2	-0.0	0.0	0.1	0.0	0.1	-0.0	0.0	0.1	0.0	1.6	–1.6	0.3	-1.3
Primary elec. . . .	1.5	1.6	0.1	0.3	0.0	0.3	-0.1	-0.5	-0.1	0.5	0.0	-0.1	1.5	2.3	3.9
Utility gas	0.3	0.4	-0.0	0.1	0.0	0.1	-0.0	-0.1	-0.0	0.1	0.0	0.1	0.1	0.5	
Total	2.8	9.4	–1.2	2.1	2.5	2.5	-0.8	–3.7	-1,2	2.8	1.6	-0.5	1.1	13.2	14.3

Of the 1972-85 increase in energy use due to spending, the overwhelming majority of the increase came from the indirect use of energy. The household sector was the main contributor to this increase in the indirect use of energy, particularly through the indirect use of crude oil & gas.

NOTE: Total may not add due to rounding.

* To make the components add to total consumption, imports have to be treated as a negative change in energy use.

\+ Other includes gross private domestic investment and changes in business inventories.

@ Adjustments to energy exports and imports are needed to match conventional consumption estimates. The adjustments include subtracting primary direct exports of energy and adding direct imports of energy.

SOURCE: Office of Technology Assessment, 1990.

Box E—The World Car

U.S. auto companies offer a prime example of how global production networks can circumvent the intent of domestic policies. A sampling of the equity interests domestic auto companies have overseas reveals that GM owns a 50 percent stake in Saab-Scania (Sweden), 100 percent of Lotus (United Kingdom), 50 percent of Daewoo (South Korea), and 38 percent of Isuzu (Japan); Chrysler owns 12 percent of Mitsubishi (Japan) and 100 percent of Lamborghini (Italy); Ford owns 25 percent of Mazda (Japan), 10 percent of Kia (South Korea), and 100 percent of Jaguar (United Kingdom).[1]

This global reach recently allowed Ford to convert two of its less fuel-efficient cars (20 mpg), the Crown Victoria and the Grand Marquis, into "imports" by decreasing the share of U.S. produced parts from 90 percent to less than 75. This was done so that Ford's remaining "domestic" fleet of cars would meet the Federal Corporate Average Fuel Economy (CAFE) standards set for the 1989 model year of 26.5 miles per gallon.[2] Shifting these two cars into the import column, Ford expects to reduce its domestic CAFE average by 0.6 or 0.7 miles per gallon.[3]

The reverse is also happening. In another effort to boost its domestic CAFE average, Ford plans to increase the domestic content of two of its smaller cars, now classified as imports, the Ford Probe and the Mercury Tracer. Doing so, will shift these cars out of the import classification, making them domestic cars where due to their small size they will help Ford meet the domestic CAFE standards.[4]

[1]"Spot the Difference," *The Economist*, Feb. 24, 1990, p.74.

[2]This switch did decrease the fuel efficiency of Ford's imports, but since this group is largely composed of small cars, the average across all imports was above Federal standards. Warren Brown, "Ford to Convert 2 Cars Into Imports," *The Washington Post*, June 20, 1989, p.D1.

[3]David Versical, "CAFE Crisis: Ford to Count Big Cars as Imports," *Automotive News*, June 19, 1989, p. 8.

[4]David Versical, "Small-Car Content Shift Leads GM's CAFE Plan," *Automotive News*, June 26, 1989, p. 1.

embodied in imports has increased as our trade deficit has deepened.[42] To a large degree, the gains the United States has achieved in reducing its direct imports of energy have been offset by the indirect energy use associated with nonenergy imports. Instead of a 39 percent drop in the use of imported energy from 1977 to 1985, the decline is reduced to 21 percent when the indirect energy embodied in imports is included. The lack of post-1985 data may skew this picture since the trade balance has improved as exports have increased with the decline in the value of the dollar, and increases in the level of imports have been more modest.[43]

Given the fact U.S. citizens do not consume U.S. exports, some analysts argue that calculations including the energy embodied in imports should be *net* of the direct and indirect energy associated with exports, failing to do so biases estimates of U.S. energy use upwards.[44] The net trade line in figure 12 reflects this calculation. From 1977 to 1982, the net trade balance of energy, including both direct and indirect energy, was improving. This improvement was due to reductions in the level of direct imports of energy and a balance between the indirect energy associated with imports and exports. After 1982, the net trade line (figure 12) began to fall. This turnaround was not due to increased direct imports of energy—they stayed roughly constant over this time period. The cause of the decline was an increase in the indirect imports of energy. Not surprisingly, this deficit mirrors the current account trade balance (dollars), which went from a surplus of $26 billion in 1982 to a deficit of $104 billion in 1985.[45]

To a large degree, the decision as to which measure, net energy trade or gross, to use depends on the questions being addressed. If the issue is how the world's energy use is divided by country, then a net figure, subtracting out the energy embodied in exports, is appropriate. But if the question is "how dependent is the United States on foreign energy?" or "what is the United States' contribution to greenhouse gases such as carbon dioxide?' or "how much energy does it take to operate the U.S. economy?" then the gross energy use estimate is better suited since it reflects the true energy requirements needed to satisfy all of the U.S. economy's consumers, which in a global economy are both domestic and foreign.

Summary of Changes Due to Spending

Changes in spending would have led to an increase in energy use of approximately 14.4 quads from 1972 to 1985 if there had not been offsetting factors. This 14.4-quad increase can be viewed from

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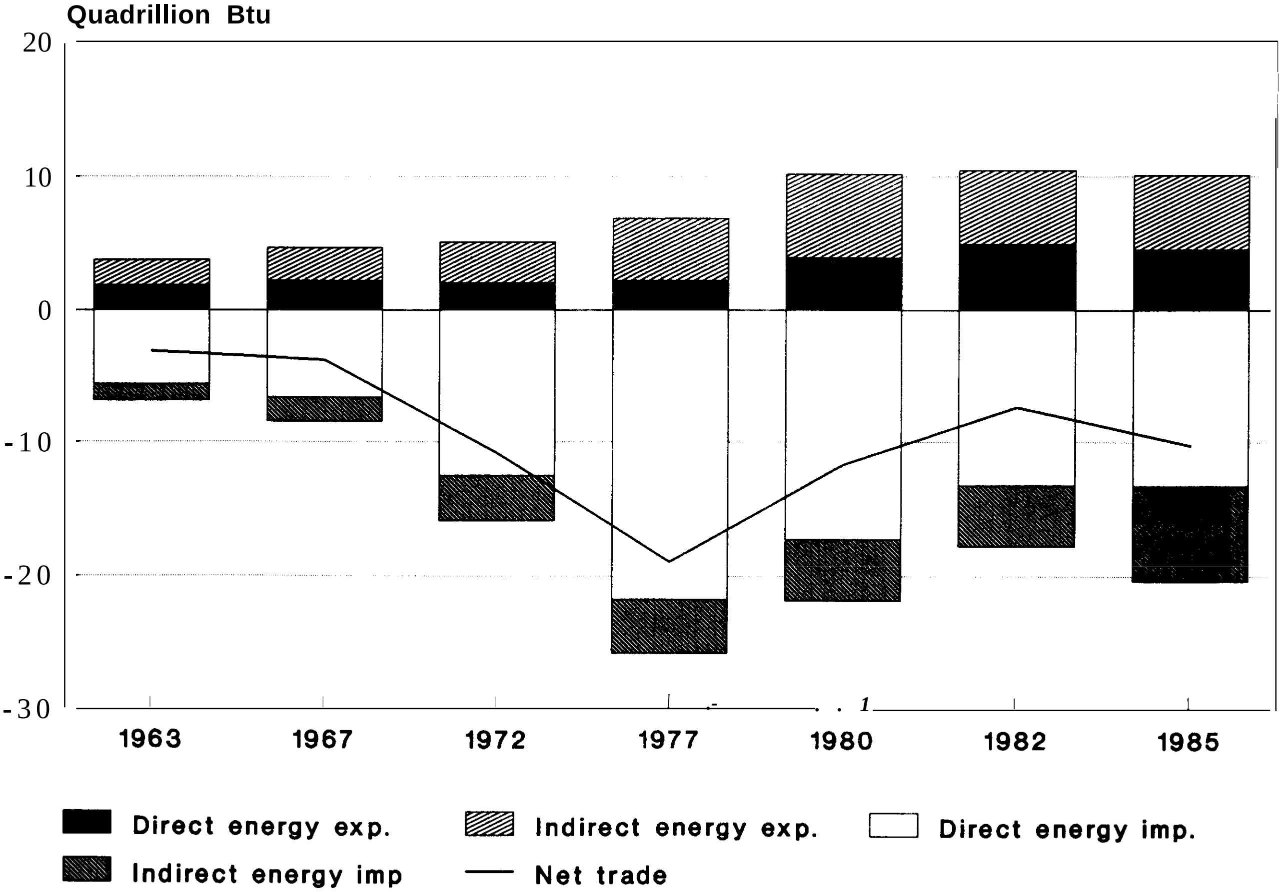
Figure 12—Direct and Indirect Energy Use Associated With Imports and Exports



The United States directly imports and exports energy. Although direct exports have stayed relatively steady, imports rose dramatically between 1983 and 1977andthen declined from 1977 to 1985. The United States also uses energy indirectly in the form of energy embodied in nonenergy exports (e.g., grain) and in imports (e.g., autos). Prior to the emergence of a trade deficit this indirect use of energy was in balance, but by 1985 the indirect use of energy associated with imports boosted our dependence on foreign sources of energy by 50 percent.

SOURCE: Office of Technology Assessment, 1990.

three different angles: the level and mix of spending, the type of products purchased, and the sources of spending.

- All of the increase in energy use due to spending from 1972 to 1985 was found to be attributable to increases in the overall level of spending. The economy simply required more energy as the population increased, more homes were constructed, more automobiles were driven, and more output was produced from the Nation's industries. Nevertheless, the shifting mix of what was being purchased caused energy use to decline. Combining the decrease in energy use associated with the change in the mix of spending (–5.8 quads) with the increase due to a higher, overall level of spending (+17.7 quads) and the interaction of the two effects (+2.5 quads), energy use due to spending increased by 14.4 quads from 1972 to 1985.[46]
- The 14.4-quad increase in energy use from 1972 to 1985 attributable to spending was largely the result of indirect purchases of energy embodied in products. Direct purchases of energy were responsible for only 8 percent (1.1 quads) of this increase. Purchases of services (not including transportation services) generated over 40 percent of the increase in energy use due to spending between 1972 and 1985.
- The source of this increase in energy use attributable to spending came from the house-

hold sector, which led in increases of energy use, both directly and indirectly. The second largest contributors to energy use were the foreign trade sectors: exports and imports. When the definition of energy consumption is changed to include the indirect use of energy as it is embodied in nonenergy imports, the U.S. dependence on imported energy in 1985 increases by over 50 percent from 13 to 20 quads.

Examining how the spending of goods and services affected energy use presents only half of the energy dynamic that is occurring in the United States. It ignores the energy use associated with how these products were produced. Since nearly all of the 1972-85 change in energy use due to changes in spending was due to the indirect use of energy embedded in nonenergy products consumed, understanding how this energy is embodied in products via the production process is essential to tracking how energy use has changed.

Changes in Energy Use Associated With the Production Recipe

Spending on goods and services triggers the production of output as businesses try to satisfy this demand. Whether it is something as mundane as the gasoline in the car that delivers the pizza or as sophisticated as the laser used in surgery, every product requires some energy, directly or indirectly, along the complex network that connects the extraction of raw materials with processing plants, assemblers, distributors, retailers, and ultimately the consumer.[47]

The term production recipe refers to the ingredients and processes that are used to make a product through this whole complex chain of activities that might involve hundreds of individual businesses. In terms of trying to track energy, the production recipe has been split into two parts:

- the energy portion of the production recipe that shows the use and manipulation of direct energy inputs like coal, oil, gas, and electricity; and,
- the nonenergy portion of the production recipe which contains inputs such as steel, plastics, advertising, and financial advice that indirectly embody energy.

On a dollar-value basis, the direct use of energy products in production recipes represent only about a fifth of all inputs.[48] The remaining four-fifths of inputs, however, include significant amounts of indirect energy use. As mentioned before, to produce all of the cars sold in 1985 required relatively little *direct* energy, about 0.23 quad, but 1.3 quads of energy were *indirectly* used because the inputs into a car (steel, rubber, glass, plastic) embody a lot of energy. Changes in the nonenergy inputs (e.g., material substitution) of a production process indirectly affects energy use.

Estimates of the amount of energy associated with changes in the production recipe requires that the level and mix of spending be kept constant. Under this experiment, any changes in energy use are attributed to the production recipe or the interaction of the production recipe with spending. Changes in the production recipe can be examined in more detail by breaking the production recipe into two broad categories of inputs-energy and nonenergy—and then selectively varying each component to see how much of the change can be attributed to each factor. Changes in energy use associated with changes in the energy portion of the production recipe are indicative of changes in energy efficiency: it requires fewer direct energy (Btu) inputs to make the output needed to satisfy a constant set of demand. Variations in the nonenergy portion of the production recipe are a partial reflection of the structural change that is occurring in the United States as technology, prices, and tastes increase the demand for some inputs and slacken the demand for others.[=] For example, as substitutes for steel are discovered, such as high-strength polymers, the relative position of the plastic industry will rise in the economy while the steel industry declines.

As can be seen in figures 5 and 6, it has been changes in the production recipe of the U.S. economy that have acted as the offset to the increased energy use associated with spending. Holding the effect of changes in spending constant, changes in the production recipe from 1972 to 1985 reduced energy use by almost 20 quads.

Energy Inputs

Both the energy and nonenergy components of the production recipe changed so that U.S. industry used less energy in 1985 than in 1963 to produce the same

'*The* other component of structural change is a changing mix of spending.

mix and level of products. Nevertheless, a majority of the decline was attributable to changes in the direct use of energy inputs, indicative of improvements in energy efficiency.

The trend towards steady gains in energy efficiency did not emerge until after 1972. Compared to the energy efficiency of the 1963 production recipe, the energy efficiency of 1967 improved significantly, only to have all the improvements eliminated by 1972. In other words, the 1972 economy had the same level of energy efficiency as the 1963 economy (see figure 13). As mentioned before, this is probably due to the relatively low price of energy in 1972 compared to 1963.

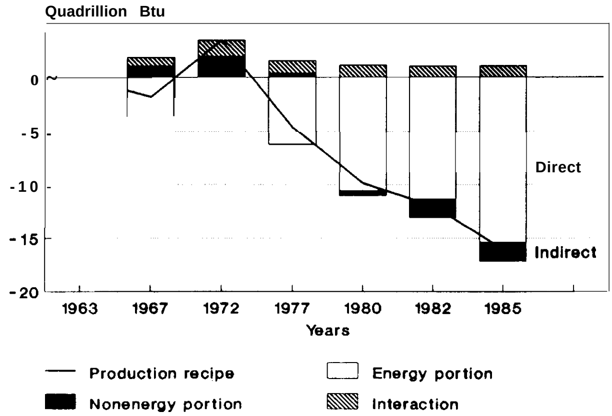
After 1972, the economy's energy efficiency improved dramatically. Changes in the energy portion of the production recipe led to a 15.4-quad drop in energy use from 1972 to 1985 (see figure 14). This change was responsible for over three-quarters of the entire decline due to production recipe changes from 1972 to 1985.[49]

In terms of fuel use, nearly all of the decline in energy from 1972 to 1985 due to changes in energy inputs occurred in crude oil& gas (see table 6). Coal and, to a lesser extent, primary electricity were the only energy types to experience an increase in use because of changes in the energy portion of the production recipes. The next section examines how these changes are distributed across the different sectors of the economy.

***Changes by* Sectors—Forty percent** of the **1972** to 1985 drop in energy use due to changes in the use of energy inputs came from the manufacturing sector (see table 7). This change is disproportionately large given that using a 1972 production recipe, manufacturing only used 27 percent of the total energy required. Of the drop originating in the manufacturing sector, over 90 percent of it was due to decreased use of crude oil & gas. Although few, if any, manufacturing concerns directly use crude oil & gas, the drop is a reflection of counting energy use in its primary form where a decrease in the use of secondary products like refined oil and natural gas force decline in the primary energy source: crude oil & gas. A number of technological advances and process changes such as sensing and control systems,[50] heat recovery systems,[51] use of variable speed motors,[52] continuous casting of steel,[53] and the application of new membrane technologies for the separation and purification of materials[54] have improved the energy efficiency of manufacturing's production recipe.

The energy sector itself and the services sector each contributed about 20 percent of the 15.4-quad drop in energy use from 1972 to 1985, caused by direct changes in the use of energy inputs (energy

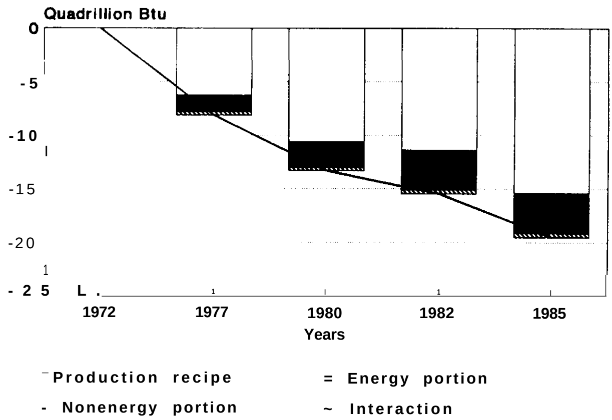
Figure 13-Changes in U.S. Energy Use Due to Changes in Production Recipe, 1963-85



Changes in the production recipe (holding spending constant) would have caused energy use to decline from 1963 in every year, except 1987. These changes are broken into two parts, the energy portion or direct energy savings (energy efficiency) which is responsible for most of the change (dear box), and the nonenergy portion or indirect savings (black box).

SOURCE: Office of Technology Assessment, 1990.

Figure 14-Changes in U.S. Energy Use Due to Changes in Production Recipe, 1972-85



Between 1972 to 1985, changes in the production recipe caused energy use to decrease by nearly 20 quads. Four-fifths of this decline was due to energy-efficiency improvements or changes in energy inputs of the production recipe (clear box). The remaining fifth of the decline was due to nonenergy input changes (material substitution) in the production recipe (black box).

SOURCE: Office of Technology Assessment, 1990.

Table 6-Changes in Primary Energy Use From 1972 to 1985 by Energy Type Due to Production Recipe Changes (quadrillion Btu)

	Energy	Nonenergy	Interaction	Total
Coal	2.5	-1.7	0.1	1.0
Crude oil & gas	-17.0	-1.6	-0.5	-19.1
Refined petroleum	–0.4	-0.0	–0.0	-0.5
Primary electricity	0.4	-0.3	0.1	0.2
Utility gas	–0.9	-0.1	-0.0	–1.1
Total	–15.4	-3.7	-0.4	-19.5

Of the 19.5-quad decrease in energy use due to changes in the production recipe, 15.4 quads were due to changes in the energy portion of the production recipe (energy efficiency) and 3.7 were due to nonenergy changes in the production recipe. Nearly all of the energy efficiency changes occurred in the use of crude oil and gas while the nonenergy changes in the production recipe were more evenly spread across energy types.

NOTE: Total may not add due to rounding.

SOURCE: Office of Technology Assessment, 1990.

efficiency). As in the manufacturing sector, nearly all of the decrease was in crude oil& gas. But unlike the manufacturing sector, this change was not disproportionately large given their 1972 consumption. The overall decline in energy use in the energy and service sectors conceals increases in the use of coal by both sectors and an increase in the use of primary electricity by the service sector. The increased use of coal and the decrease in the use of oil by the energy sector is reflective of fuel switching by electric utilities that occurred during this period. The percentage of the electricity generated from coal jumped from 44 to 57 percent from 1972 to 1985, while the share made from oil dropped from 16 to 4 percent.[55] The Department of Energy attributes over 80 percent of the decline in energy use by the commercial (a proxy for services) sector to "nonenvelope" retrofits such as more efficient heating and cooling systems or more efficient lighting.[56]

Increases in the use of primary electricity and coal by the service sector is reflective of how the production process in services has incorporated more capital equipment,[57] such as copiers, computers, scanners, and communication equipment that require electric power.[xxi] The typical daytime electricity use associated with office machines in a modern office building is as much as the electricity required for lighting.[58] Modern office equipment, such as a laser printer, requires 5 to 10 times as much electricity as an old impact printer; more powerful desk-top computers, like the IBM AT, use almost twice as much electricity as the previous generation IBM PC.[59]

Nonenergy Inputs

Although less significant in magnitude than the changes occurring in the energy portion of the production recipe, the indirect energy savings associated with changes in nonenergy inputs have grown in size and have reinforced the energy savings gained from pure energy efficiency. By 1982,[xxii] over a quarter of all the decline due to recipe changes from 1972 to 1982 was caused by changes in nonenergy inputs.[60] As figure 13 shows, prior to 1977, nonenergy input changes were actually increasing the amount of energy used by the economy in comparison to a 1963 base.[61] Since 1972, the drop in energy use attributed to changes in the use of nonenergy inputs has been relatively steady and have grown in size (figure 14). It can be estimated that if 1985 nonenergy input data were available, it is likely that another 1.4-quad reduction in energy use would have been achieved from 1982 to 1985.[62]

The types of energy indirectly affected by changes in the nonenergy portion of the production recipe differ significantly from those affected by direct shifts in energy inputs (table 6). Changes in nonenergy inputs from 1972 to 1982 led to a decrease in the use of coal, while coal increased under the changes that occurred in energy inputs. Similarly, primary electricity use declined under nonenergy changes while it increased under changes in energy inputs. Changes in nonenergy portion of the production recipe caused the use of each energy type to fall between 1972 and 1985.

These declines are a result of the shifting mix of nonenergy inputs in the production process. Less energy-intensive inputs are being used relatively more than energy-intensive inputs. For example, of the inputs that registered a gain in share between 1972 to 1980, wholesale and retail trade was the largest. Number two was business services. Both of these inputs have relatively low energy intensities.

[xxi]As discussed in part V, the model used for this analysis does not include capital equipment as an input because it is considered a final good, but the energy used to run that equipment (an intermediate input) would be included. The service sector's use of coal is a reflection of the accounting method in this study which reports energy use in its primary form to avoid double counting. Thus increases in electricity use show up as increases in the primary fuels used to generate electricity, coal, and primary electricity (hydroelectric and nuclear).

[xxii]Data limitations restrict the endpoint of the analysis of nonenergy changes in the production recipe to 1982, since a 1985 Input-Output table did not exist when this analysis was being performed. The 1985 table was published in January of 1990.

Table 7-Changes in Primary Energy Use From 1972 to 1985 by Energy Type Due to Energy Production Recipe Changes (quadrillion Btu)

	Energy	Natural resources	Manufacturing	Transportation services	Services	Total
coal	1.0	0.4	0.1	0.0	1.0	2.5
Crude oil & gas	-3.8	-3.0	-5.9	-0.4	-3.9	-17.0
Refined petroleum	-0.1	–0.1	-0.1	-0.0	-0.1	-0.4
Primary electricity	0.0	0.1	-0.0	0.0	0.2	0.4
Utility gas	-0.2	–0.1	-0.4	-0.0	-0.2	-0.9
Total	-3.0	–2.7	-8.3	-0.4	-3.0	–15.4

Nearly half of the reduction in energy use due to changes in the energy portion of the production recipe occurred in the production of manufactured goods where most of the decline was in the use of crude oil & gas.

NOTE: Total may not add due to rounding.

SOURCE: Office of Technology Assessment, 1990.

The input with the largest decline in share was primary iron and steel, one of the most energy-intensive industries.[xxiii] Shipments of steel from U.S. plants fell by 41 percent from 1972 to 1985.[63] Since the bulk of the coal not used by the electric utility industry is used to make steel, a decline in domestic production of this magnitude would have a large indirect effect on the use of coal.

Changes by Sector

Nearly all of the indirect decreases in energy use due to nonenergy changes in the production recipe from 1972 to 1985 occurred in the manufacturing sector (table 8). This decline primarily affected the consumption of crude oil & gas and coal and to a lessor extent the use of primary electricity.[a] Three of the sectors-energy, transportation services, and services-actually had nonenergy changes that led to an increase in energy use from 1972 to 1985. Combined, these increases in energy use caused a slight (0.4 quad) increase in the use of crude oil & gas.

Examples of how changes in the nonenergy portion of the production recipe can decrease energy use include the automobile industry, where lighter materials such as high-strength plastics have been substituted for metals. From the mid-1970s to the mid- 1980s, the iron and steel content of a car fell by 30 percent while the amount of plastics and composites increased by 33 percent.[G5] Automated manufacturing technologies such as computer-assisted design (CAD), which are becoming more commonplace in industries such as the motor vehicle industry, allow products to be designed so that fewer parts are required, reducing the amount of material wasted and energy required for assembly. Fiat's recent investments in automation means that the Fiat Uno has over a third fewer major parts, reducing the number of welds required for assembly by 43 percent from the previous generation model, the Fiat 127.[ti]

Advances in information technologies have made it possible to substitute information for materials, leading to changes in the production recipe that indirectly save energy. Instead of creating dozens of prototypes, Levi Strauss is using computers to test out new fabrics, patterns, and designs before ever cutting a piece of cloth.[G7] Ten years ago, four-fifths of the value of a computer was embodied in its hardware, the remainder being associated with software. Today, these are ratios are reversed, resulting in a drop in the energy associated with a dollar's worth of output.[G8]

Energy Intensities

The total amount of energy (direct and indirect) associated with the complex chain of businesses that interact to make a product (the production recipe) is reflected in a product's energy intensity. Generally, a product's energy intensity is the total amount of direct and indirect energy (Btu) needed to generate a dollar 's[xxiv] worth of the product, except in the case of energy products where the intensity is the amount of energy (Btu) needed to make a Btu of output.[G9]

The analysis presented in the preceding sections made use of each product's energy intensity in calculating energy use under different conditions. By themselves, energy intensities are useful in understanding how the energy associated with

[xxiii] *Technology and the American Economic Transition*, op. cit., endnote 7, p. 155.

[xxiv] Measured in constant 1982 dollars.

Table 8—Changes in Primary Energy Use From 1972 to 1985 by Energy Type Due to Nonenergy Production Recipe Changes (quadrillion Btu)

	Energy	Natural resources	Manufacturing	Transportation services	Services	Total
Coal	0.1	–0.2	–1.5	–0.0	0.0	–1.7
Crude oil & gas	0.2	–0.1	–1.8	0.1	0.1	–1.6
Refined petroleum	0.0	–0.0	–0.0	0.0	0.0	–0.0
Primary electricity	0.0	–0.0	–0.4	–0.0	0.0	–0.3
Utility gas	0.0	–0.0	–0.1	–0.0	0.0	–0.1
Total	0.2	–0.4	–3.9	0.1	0.2	–3.7

Almost all of the reduction in energy use due to nonenergy changes in the production recipe came from changes in the production of manufactured goods. Most of this decline was in the use of coal and crude oil & gas. The nonenergy portion of the production recipes used to make services and energy products actually led to indirect increases in the use of energy from 1972 to 1985.

NOTE: Total may not add due to rounding.

SOURCE: Office of Technology Assessment, 1990.

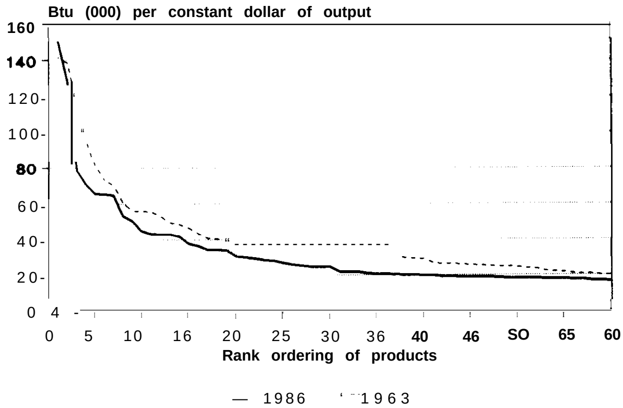
different products roughly compare, what the distribution of energy intensity across products looks like, and where some of the biggest declines in energy intensity have occurred.

Table 9 provides a listing of the energy intensities for each of the 88 products that make up the economy in our model for 1963, 1972, and 1985, and the change in each product's intensity iiom 1972 to 1985. The first five products are energy commodities where electricity stands out due to the fact that it takes over 3 Btu inputs of energy for every Btu of electricity output because of conversion losses.[70]

The most remarkable characteristic of the nonenergy products (no. 6 through no. 88) is the huge range that is covered, extending from a high of 150,000 Btu per dollar of pavement (product no. 34) to a low of 2,000 Btu per dollar of real estate services (product no. 81) (figure 15). Exact comparisons of each product's energy-intensity is difficult because the denominator in the ratio, gross output or shipments, differs between products depending on the amount and value of inputs. Since the value of inputs are included in estimates of gross output, double counting occurs. Thus, products that include. a large number of purchased inputs, like automobiles, will have more of this double counting, boosting the value of their shipments, as opposed to products, such as hair styling, that have relatively few inputs. These differences in output caution against exact comparisons of product's energy intensity, but do not affect comparisons in a product's energy intensity over time.

Nevertheless, some general comparisons for purposes of imparting a general sensitivity of which products are energy-intensive and which are not, can

Figure l&Ranking of Primary Energy Intensity of Selected Products



The energy intensity of a product is the direct and indirect energy used to produoe a dollar's worth of that product. When calculated across all products and ranked, the distribution of these intensities reveals that only a few products are extremely energy intensive and that the bulk of the products have an energy intensity between 20,000 and 40,000 Btu per dollar of output.

SOURCE: Office of Technology Assessment, 1990.

be made. The most energy-intensive products are paving, asphalt, chemical mineral mining, chemical products, water transportation, primary iron and steel manufacturing, plastics, and primary nonferrous metals manufacturing. Many of these products use energy as a material input (feedstock) in addition to using energy as a source of heat or power. In all, only about 15 percent of the products had primary energy intensities in excess of 40,000 Btu per dollar of output and these products composed less than 9 percent of all 1985 output shipments.[71] Because of the uneven distribution of energy intensities, increased efficiency in a few industries or a realignment of the economy away from these energy-

Table 9—Primary Energy Intensities by Commodity for Selected Years

	1963	1972	1985	1972-85 chan~
(Btu input per Btu of output)				
1 Coal mining	1.01	1.02	1.03	0.01
2 Crude petroleum and natural gas	1.06	1.06	1.06	0.00
3 Petroleum refining and related industries	1.19	1.19	1.16	–0.02
4 Electric utilities	3.81	3.80	3.48	–0.31
5 Gas utilities	1.17	1.15	1.09	–0.07
(Btu per dollar of output)				
6 Livestock and livestock products	21,343	27,475	17,732	(9,742.9)
7 Other agricultural products	23,304	34,799	20,314	(14,485.2)
8 Forestry and fishery products	11,370	21,547	29,921	8,373.4
9 Agricultural, forestry and fishery services	19,007	24,761	14,116	(10,645.6)
10 Iron and ferroalloy ores mining	30,895	45,063	65,272	20,209.0
11 Nonferrous metal ores mining, except copper	31,086	44,155	42,975	(1,180.2)
12 Stone and clay mining and quarrying	35,613	42,993	37,634	(5,359.4)
13 Chemical and fertilizer mineral mining	69,822	78,339	78,254	(85.7)
14 New Construction	20,430	24,377	19,680	(4,697.1)
15 Maintenance and repair construction	19,258	23,876	17,782	(6,094.2)
16 Ordnance and accessories	14,911	18,683	10,820	(7,862.4)
17 Food and kindred products	24,274	26,528	19,969	(6,558.4)
18 Tobacco manufacturers	8,847	11,218	10,813	(404.9)
19 Broad and narrow fabrics, yarn, and thread mills	48,708	56,016	34,365	(21,651.2)
20 Miscellaneous textile goods and floor coverings	55,838	57,183	33,962	(23,221.0)
21 Apparel	29,402	34,022	18,092	(15,929.4)
22 Miscellaneous fabricated textile products	36,731	38,493	21,845	(16,647.6)
23 Lumber and wood products, except containers	19,472	32,305	28,138	(4,166.9)
24 Wood containers	22,175	30,331	20,040	(10,291.1)
25 House hold furniture	25,227	26,987	18,625	(8,362.0)
26 0therfurniture and fixtures	25,666	26,414	18,598	(7,816.4)
27 Paper and ailied products, except containers	60,864	60,570	43,234	(17,336.3)
28 Paperboard containers and boxes	37,745	40,073	28,456	(11,617.6)
29 Printing and publishing	19,925	21,819	16,351	(5,468.2)
30 Chemicals and selected chemical products	115,958	88,896	70,923	(17,973.1)
31 Plastic materials and synthetic materials	96,533	83,779	53,272	(30,506.8)
32 Drugs, cleaning and toilet preparations	43,727	27,595	20,572	(7,022.9)
33 Paints and allied products	55,380	52,151	34,329	(17,821.9)
34 Paving	141,689	146,386	150,858	(4,472.4)
35 Asphait	138,490	136,543	127,952	(8,590.7)
36 Rubber and miscellaneous plastic products	40,767	39,041	29,171	(9,869.7)
37 Leather tanning and finishing	32,802	36,651	21,765	(14,885.9)
38 Footwear and other leather products	17,348	23,156	15,702	(7,453.7)
39 Glass and glass products	46,774	46,873	36,345	(10,527.8)
40 Stone and clay products	52,984	55,953	42,993	(12,960.1)
41 Primary iron and steel manufacturing	72,990	69,272	64,436	(4,836.0)
42 Primary nonferrous metals manufacturing	55,710	64,587	50,478	(14,108.8)
43 Metal containers	40,568	41,966	30,482	(11,484.0)
44 Heating, plumbing, and structural metal products	37,478	35,778	24,735	(11,043.1)
45 Screw machine products and starnpings	33,783	37,468	25,159	(12,308.8)
46 0ther fabricated metal products	33,461	33,599	24,639	(8,960.2)
47 Engines and turbines	25,768	23,655	18,939	(4,715.7)
48 Farm and garden machinery	29,109	24,872	18,796	(6,075.6)
49 Construction and mining machinery	24,480	21,376	17,888	(3,488.5)
50 Materials handling machinery and equipment	24,936	24,770	17,923	(6,847.8)
51 Metal working machinery and equipment	20,419	20,540	15,234	(5,305.7)
52 Special industry machinery and equipment	19,749	20,644	16,779	(3,864.8)
53 General industrial machinery and equipment	24,596	23,768	18,279	(5,489.5)
54 Miscellaneous machinery, except electrical	19,864	22,874	13,568	(9,306.4)
55 Office, computing, and accounting machines	35,118	59,496	12,636	(46,860.3)
56 Service industry machines	32,694	30,066	19,630	(10,436.2)
57 Electrical industrial equipment and apparatus	26,474	25,155	16,722	(8,433.2)
58 Household appliances	38,745	33,295	21,027	(12,268.1)
59 Electric lighting and wiring equipment	26,265	24,475	18,640	(5,835.8)
60 Radio, TV, and comrnunication equipment	20,890	22,330	14,053	(8,277.0)
61 Electronic components and accessories	37,833	35,976	20,568	(15,407.3)

Table 9-Primary Energy Intensities by Commodity for Selected Years-Continued

	1963	1972	1985	1972-85 change
62 Miscellaneous electrical machinery and supplies	26,216	27,229	18,171	(9,058.5)
63 Motor vehicles and equipment	31,788	28,182	18,889	(9,292.7)
64 Aircraft and parts	14,922	15,456	12,460	(2,996.3)
65 Other transportation equipment	29,579	26,664	17,393	(9,271.6)
66 Scientific and controlling instruments	21,647	21,477	14,444	(7,033.4)
67 Optical, ophthalmic, and photographic equipment	35,975	25,551	18,192	(7,358.5)
68 Miscellaneous manufacturing	23,657	25,130	17,547	(7,583.5)
69 Railroad	37,908	36,754	25,732	(11,022.2)
70 Local transport	31,323	21,914	21,891	(22.9)
71 Motor freight transport	18,714	21,432	26,932	5,500.7
72 Water transportation	81,532	79,994	65,485	(14,508.9)
73 Air transportation	49,560	49,100	44,807	(4,292.8)
74 Pipe lines, except natural gas	38,591	24,881	24,473	(407.9)
75 Transportation arrangements	12,342	4,498	7,724	3,226.4
76 Communications, except radio and television	12,630	7,357	6,325	(1,031.9)
77 Radio and TV broadcasting	6,945	10,738	8,154	(2,583.2)
78 Water and sanitary services	30,969	18,417	41,901	23,483.4
79 Wholesale and retail trade	12,323	13,440	12,948	(492.3)
80 Finance and insurance	9,576	8,513	6,661	(1,852.5)
81 Real estate and rental	5,874	4,627	2,432	(2,195.2)
82 Hotels: personal and repair services (excluding auto)	12,460	16,230	13,264	(2,966.7)
83 Business services	11,622	9,882	6,162	(3,719.4)
84 Automobile repair and services	10,504	14,622	14,208	(413.8)
85 Amusements	9,707	13,998	10,492	(3,506.3)
86 Health, education, and social services and nonprofit organizations	10,100	12,390	11,603	(786.8)
87 Federal Government enterprises	7,026	10,636	7,138	(3,498.4)
88 State and Local Government enterprises	17,769	19,065	15,889	(3,176.4)
Median energy intensity of non energy products, nos. 6 through 88.	26,265	26,528	18,939	

The energy intensity for a particular product represents both the direct and indirect energy used to produce a dollar's worth of that product. In the case of energy products like coal it is the number of Btu used to produce a Btu of output. These intensities range from a high of 150,900 Btu per dollar of output (paving) to a low of 2,400 (real estate services). Nearly every product's energy-intensity declined from 1972 to 1985.

SOURCE: Office of Technology Assessment, 1990.

intensive industries could have a dramatic effect on the overall energy intensity of the economy.[xxv]

The least energy-intensive products tend to be services such as real estate and rental, business services, communications (except radio and television), finance and insurance, Federal Government, transportation arrangements,[72] radio and TV broadcasting, amusements, and medical services.[73] Nevertheless, when the direct and indirect energy associated with a product is accounted for, some services like water and sanitary services and water transportation are relatively energy-intensive, respectively consuming two and three times the median energy intensity of all products.

The common factor among most products is the nearly universal drop in energy intensities since 1972 (figure 15). Economy-wide, the median energy intensity has fallen by 29 percent from 1972 to 1985 with most of the decline occurring within the manufacturing sector where the median intensity fell by 35 percent. The median energy intensity of the transportation services sector[xxvi] has stayed roughly constant while the service sector has declined by 15 percent and natural resources fell by 19 percent.

The single largest decline in a product occurred in the office, computing, and accounting machine category. To some extent this decline is a vestige of the deflation process used on output, which adjusts the value of a good over time for inflation and quality changes. This process allows a more accurate comparison of the value of production over time since changes in a product's price are eliminated and changes in the characteristics of a product are accounted for. In this sense, the deflation process attempts to convert the value of a product into a quantity measurement. This is relatively easy for

[xxv]It is because of this uneven distribution that the median, rather than the mean is used to describe the energy intensity of all products.

[xxvi]The transportation services sector does not include personal transportation. Personal travel would be reflected in the consumption (not production recipe) of automobiles and gas.

products like corn or steel, but is much more difficult for products experiencing a rapid change in quality, i.e., computers. Although somewhat arcane, the importance of this deflation process to estimates of constant dollar output should not be underestimated. An example is provided in box F.

Significant declines in energy intensity were also made in plastics, chemicals, textiles, paper, water transportation, and primary ferrous and nonferrous metals. The only significant increases in energy intensity over the period involved iron and ferroalloy ore mining and water and sanitary services. The jump in iron ore mining is probably connected to increased use of energy for excavation, processing, and transportation[74] while the increase in water and sanitary services is probably associated with expanded service and regulatory changes (the Safe Drinking Water Act and the Clean Water Act) that led to increased use of the chemical treatment of water.

Summary of Changes Due to the Production Recipe

Between 1972 and 1985, changes in the process by which the economy produced output to match a fixed level and mix of spending, would have led to a 19.5-quad decrease in energy consumption. Collectively, these changes are referred to as changes in the production recipe. When these changes are broken down into energy and nonenergy categories, roughly a fifth (19 percent) of this decline can be attributed to changes occurring in the nonenergy portion of the production recipe--indirect energy savings.[75] the other four-ftiths (79 percent) of the decline was traced to changes in the

Box F—An Example of the Deflation Process: Computers

Because of tremendous recent advances made in computers such as more memory, faster speeds, and better storage capabilities-all at lower costs- the output deflator for computers fell by a factor of 4 between 1972 and 1982 and then fell by nearly another factor of 2 between 1982 and 1985.[1] These changes have a huge effect on output when it is revalued into constant dollars.

This change in the deflator means that the type of a computer that cost $1,000 in 1972 would only cost $250 if purchased in 1982. Technology that was new and expensive in 1972 has been perfected by 1982 and costs much less. Similarly, a computer which was purchased for $1,000 in 1985 would have cost $1949 if it was purchased in 1982. Features that are commonplace and standard in 1985 like a hard disk, commanded a premium in 1982. In other words, even though the purchasing power of the dollar decline from 1982 to 1985 because of inflation, the nature of the product was so improved that to have purchased a product of similar quality in 1982 would have required almost twice the money.

Assuming for the moment that the energy required to produce that computer did not change over that time period, that the level of output was fixed at one machine, and the price (nominal) of a computer in each year was $2,000, but that a huge improvement in quality was sustained over the time period, the following table shows how the energy intensity would have changed because of changes in the deflator.

Product example	1972 IBM-PC[2]	1982 IBM-XT	1985 IBM-AT
Btu (thousands) required for production	20	20	20
Price at time of purchase	$2,000	$2,000	$2,000
Price if purchased in 1982 (constant 1982 dollars)	$500	$2,000	$3,898
Energy Intensity (Btu per dollar of constant output)	40	10	5

This example illustrates the fact that the deflation process alone reduces the energy intensity associated with a computer by a factor of 8 between 1972 and 1985. Conceptually, this adjustment makes sense. For the same price (or even less) and amount of energy inputs overtime, the consumer has gotten progressively more computer power. Thus the real cost of a computer and the energy intensity of a computer has fallen.

[1]U.S. Department of Labor, Bureau of Labor Statistics, Office of Economic Growth, Output and Employment Database, unpublished, Sector 72, "Electronic Computing Equipment," SIC 3573.

[2]This is a little far-fetched since the IBM-PC didn't hit the market until 1981. The first commercial personal computer was the Apple II in 1976. The year 1972 marked the debut of "Pong," an arcade game by Atari. Rory Donaldson, "An Incomplete History of Microcomputing," *Whole Earth Review*, Spring 1987, p.116.

energy portion of the production recipe, reflective of direct energy efficiency gains. Although the savings due to changes in the nonenergy portion of the production recipe are smaller, they constitute an energy saving factor that is growing in importance and has reinforced and accelerated the savings caused by pure energy-efficiency gains.

The energy and nonenergy factors had a much different impact on the type of energy saved. Changing energy inputs led almost exclusively to a decrease in the use of crude oil & gas while the savings due to nonenergy inputs were more evenly split between coal and crude oil & gas.

Lastly, the sectors responsible for the change differed depending on the factor involved. Savings due to energy efficiency improvements were distributed between the manufacturing (40 percent of the decline), energy (20 percent), and services (20 percent) sectors. The change in energy use due to changes in nonenergy inputs actually led to a increase in energy use in the energy, transportation services, and services sectors. Only the manufacturing sector, and to a much lesser extent the natural resource sector, experienced a drop in energy use due to changes in the nonenergy portion of the production recipe. All told, over half of the decrease in energy use due to changes in the production recipe occurred in the manufacturing sector.

SUMMARY OF THE CHANGE IN ENERGY USE SINCE 1972

This analysis has focused on why the U.S. consumption of energy has stayed relatively constant since 1972 while the real size of the economy has grown by 39 percent.[76] The relatively flat level of energy consumption is due to two countervailing factors: spending and production recipe.[xxvii] Had all the other factors remained constant, changes in the level and mix of products consumed between 1972 and 1985 would have resulted in a 14.4-quad increase in energy consumption. This increase would have been even higher (17.7 quads) if the mix of spending had not shifted towards products that are less energy-intensive (–5.8 quads).[xxviii]

Nevertheless, this net increase attributable to the consumption of goods and services was offset by a large (–19.5 quad) decrease due to shifts in the way products are produced. The majority (–15.4 quads) of the decline came from more efficient use of energy inputs, although changes in nonenergy portion of the production recipe also led to a decrease (–3.7 quads) in the amount of energy consumed. Figure 16 shows the effect of each factor on changes in energy use from 1972.

Most studies that analyze the declining energy intensity of the economy, normalize for changes in the sheer growth of demand and split up the interactive effects across identifiable factors[77]. By rearranging and adding the results of this analysis, the findings can be made to conform to this paradigm. The sum of the change in energy use due to the changing mix of spending and the changes in nonenergy production recipe can collectively be called a "sectoral shift" or "structural" effect.[78] The change attributed to the energy portion of the production recipe is frequently called "the efficiency improvement" or the "technology" effect. When measured using these classifications, more than a third (38 percent) of the decline in energy consumption from 1972 to 1985 is attributed to structural changes, the remainder being due to efficiency improvements.[79] As figure 17 illustrates, the bulk of this decline due to changes in structure is attributable to changes in the mix of spending.

Shifts in the structure of the economy that have caused a decline in the energy intensity are in sharp contrast to the effect structural changes had in the pre-embargo period where changes in the industrial composition of the economy resulted in a more energy-intensive economy (see figure 7 and 13).[80] This turnaround supports the idea that the primary factor behind the acceleration in the decline in energy intensity since 1972 has been due not only to efficiency improvements, but also to structural changes.[81]

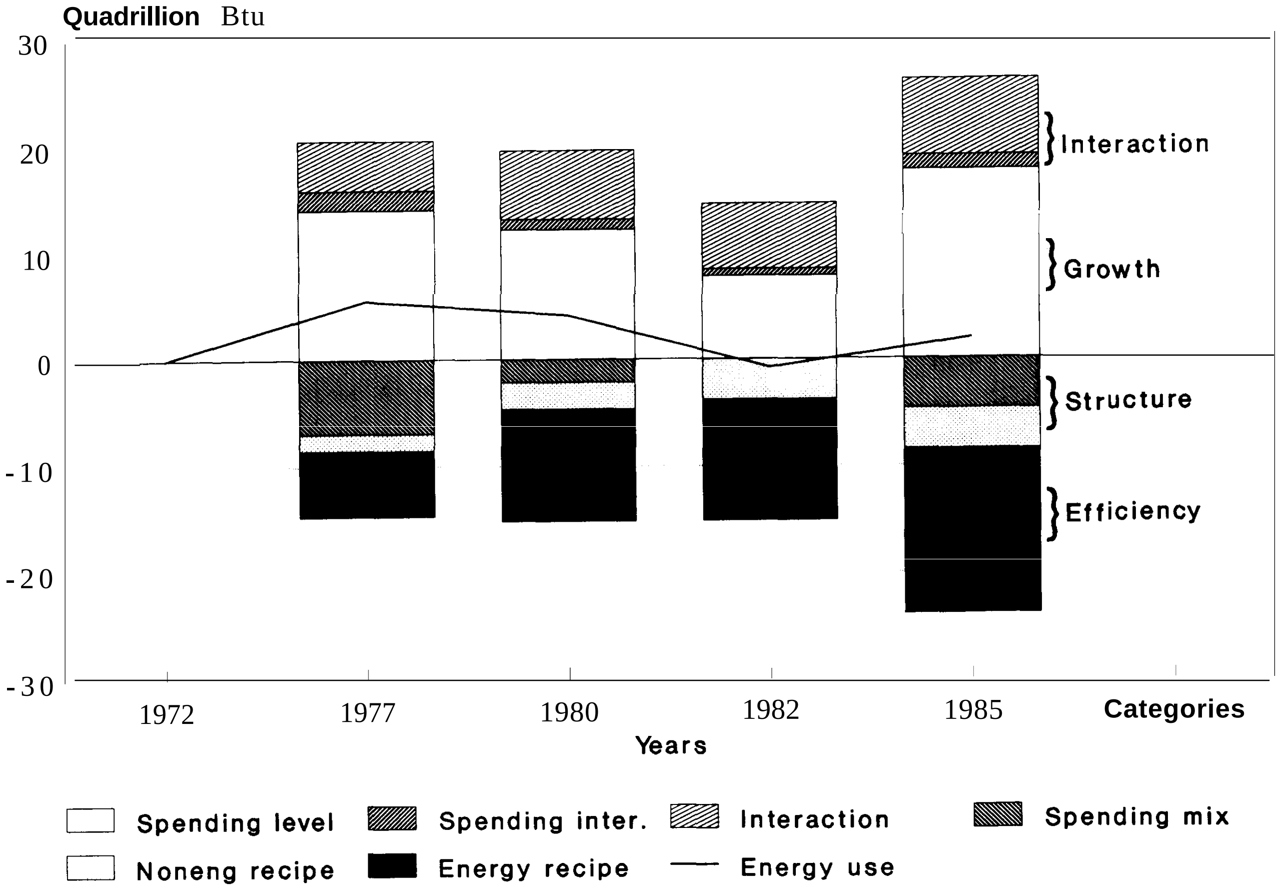
ENDNOTES FOR PART III

[23]The composite constant dollar price for energy in 1972 was 14 percent lower than it was in 1963. U.S. Department of Energy, Energy Information Administration, *Annual Energy Review, 1987* (Washington, DC: Energy Information Administration, May 1988), table 10, p. 25. Hannon also found that the role of the production recipe (technology) flipped from being negative from 1963 to 1967 to being positive from 1967 to 1972. See B. Hannon, "Analysis of the Energy Cost of

[xxvii]The interaction of consumption and production recipe is an unstated third component of this change.

[xxviii]The interaction of changes in the level and mix of consumption accounted for 2.5 quads of the increase attributable to the energy increase associated with consumption.

Figure I6--Changes in Energy Consumption, 1972-85



The factors used to analyze the change in energy use-spending mix and level, the energy and nonenergy portions of the production recipe, and the interactive terms can be rearranged so as to oonform to broader categories. The interaction terms can be aggregated into one overall term and level of spending is synonymous with the level of economic growth (GDP). Both of these factors, holding other variabies constant, caused energy use to increase from 1972 to 1985. Changes in the nonenergy portion of the production recipe and shifts in the mix of spending can be labeled structural ohanges in the eoonomy and they ied to about a third of the decline in energy use. The remaining two-thirds of the dedine was due to energy-efficiency improvements or changes in the energy portion of the production recipe.

SOURCE: Office of Technology Assessment, 1990.

Economic Activities: 1963 to 2000,'' *Energy Systems and Policy Journal*, vol. 6, No. 3, 1982, p. 266.

[24]R.S. Carlsmith, W.U. Chandler, J.E. McMahon, and D.J. Santini, *Energy Efficiency: How Far Can We Go?* Oak Ridge National Laboratory, ORNL/TM-11441, January 1990, p. 37 and Edison Electric Institute, ''Carbon Dioxide Reduction Through Electrification of the Industrial and Transportation Sectors,'' Issues and Trends Briefing Paper, No. 54, August 1989, pp. 3-5.

[25]G. Boyd, J.F. McDonald, M. Ross, and D.A. Hanson, ''Separating the Changing Composition of U.S. Manufacturing Production From Energy Efficiency Improvements: A Divisia Index Approach,'' *The Energy Journal*, vol. 8, No. 2. 1987, p. 90.

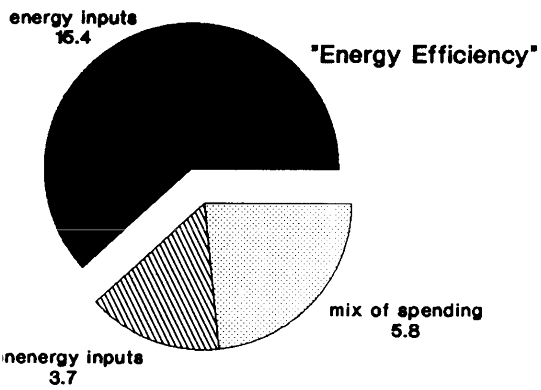
[26]This finding is in agreement with the results reported by Hannon and the Department of Energy. See Hannon (1982), op. cit., footnote 23, p. 266; and U.S. Department of Energy, *Energy's Role in International Trade: Structural Change and Competitiveness*, Office of Policy Planning and Analysis, July 1989, pp. 1-4, but contradicts results reported by Rose and Chen (1988) where the mix of demand led to an increase in energy use from 1972 to 1982. See C.Y. Chen and A. Rose, ''Sources of Change in Energy Use in the U.S. Economy, 1972-1982,'' Research Paper 8707, Regional Research Institute, West Virginia University, revised October 1988, p. 15.

[27]Indirect energy use is also positively correlated with income. See *A Time to Choose* (Cambridge, MA: Ballinger, 1974), p. 127.

[28]R. Lawrence, *Can America Compete?* (Washington, DC: The Brookings Institution, 1984), p. 4; and Williams, Larson, and Ross, op. cit., p. 110.

[29]L. Schipper, Sarita Bartlett, D. Hawk, and E. Vine, ''Linking Lifestyles and Energy Use: A Matter of Time?'' *Annual Review of Energy*, vol. 14, 1989, p. 317.

[30]K.G. Duleep, Energy and Environmental Analysis, Arlington, VA, ''Developments in the Fuel Economy of Light-Duty Highway Vehicles,'' contractor report prepared for the Office of Technology Assessment, August 1988, p. 2-14.


energy inputs
15.4
"Energy Efficiency"
mix of spending
5.8
nenergy inputs
3.7

1972 and 1981 was due to sectoral shift, p. 224. For a survey of the literature analyzing the importance of structural shifts on industrial energy use, see Huntington and Myers, op. cit., endnote 8.

[80]Doblin, op. cit., endnote 8, p. 127; and Huntington and Meyers, op. cit., endnote 8, p. 11.

[81]Doblin, op. cit., endnote 8, p. 129.

[50]M. Ross, "Improving the Energy Efficiency of Electricity Use in Manufacturing," *Science*, vol. 244, Apr. 21, 1989, p. 313.

[51]R.S. Carlsmith, W.U. Chandler, J.E. McMahon, and D.J. Santini, *Energy Efficiency: How Far Can We Go?* Oak Ridge National Laboratory, ORNL/TM-11441, January 1990, p. 37.

[52]S.F. Baldwin, "The Materials Revolution and Energy-Efficient Electrical Drive Systems," *Annual Review of Energy*, vol. 13, 1988, p. 87.

[53]J. Szekely, "Can Advanced Technology Save the Steel Industry?" *Scientific American*, vol. 257, No. 1, July 1987, p. 39.

[54]R.S. Wishart, "Energy Use in Industry," Comments in Office of Technology Industrial Energy Use Workshop, May 11, 1989, p. 4.

[55]U.S. Department of Energy, Energy Information Administration, *Annual Energy Review, 1987* (Washington DC: Energy Information Administration, May 1988), table 83, p. 193.

[56]U.S. Department of Energy, Office of Policy Planning and Analysis, *Energy Conservation Trends*, September 1989, p. 9.

[57]Electric Power Research Institute, *Office Productivity Tools for the Information Economy* (Palo Alto, CA: October 1988), p. 12-7.

[58]L. Norford, A. Rabl, J.P. Hariss, and J. Roturier, "Electronic Office Equipment: The Impact of Market Trends on End-Use Demand," *Electricity*, T.B. Johansson, B. Bodlund, and R.H. Williams (eds.) (Lund, Sweden: Lund Press, 1989), p. 427.

[59]Ibid., p. 432.

[60]Although Roop uses a different input-output methodology, the results he generates for the nonenergy effect (he calls it industry transactions) from 1972 to 1982 are similar in direction to those presented here for the 1972-85 period, but are significantly smaller in magnitude. This difference is probably due to the use of 1972 as opposed to 1982 as a base year for the calculation of deflators and the fact that his 1982 input-output table and corresponding demand vector is estimated by a private contractor, while the table used in this analysis is an updated table provided by the Bureau of Economic Analysis that incorporates survey data into their updating process. The appendix provides greater detail on the input-output matrices used in this analysis. See U.S. Department of Energy, op. cit., endnote 9, app. C, p. C-1; and M.A. Planting, "The History and Development of the U.S. Annual Input-Output Accounts," presented at the International Meeting on Problems in the Compilation of Input-Output Tables, Baden Austria, March 1988.

[61]The direction of the effect caused by changes in nonenergy inputs changes when the base on which the change is calculated shifts from 1963 to 1972. This accounts for why figures 13 and 14 do not agree.

[62]This can be estimated by assuming that the error generated by the model in 1985 is due to the lack of the nonenergy portion of the input-output table, forcing us to use 1982's nonenergy input-output table as a proxy for 1985. Since this is the only portion of the 1985 table that is lacking, it stands to reason that this is the source of the 1.4-quad difference between our estimates of energy production and those published by the U.S. Department of Energy. If this assumption is made, the overall interactive factor for the change in energy use between 1972 and 1985 would fall from 7.1 to 5.7 quads.

[63]U.S. Department of Labor, Bureau of Labor Statistics, "Historical Input-Output Time Series Data Base," unpublished, January 1989.

[64]Doblin found that the electricity intensity of manufacturing decreased by 0.5 percent per year from 1974 to 1980. Doblin, op. cit., endnote 5, p. 28.

[65]Based on weight. Source for steel and iron is for 1975 to 1985 from Williams, Larson, and Ross, op. cit., endnote 8, p. 120. Source for plastics and composites is for 1976 to 1986 from *Facts and Figures*, Motor Vehicle Manufacturers Association, various issues.

[66]D. Jones, "Future Perspectives on the Automobile Industry," *Information Technology and Economic Perspectives* (Paris: OECD, 1985), cited in Walker, op. cit., endnote 2, p. 470.

[67]"Computer Graphics Are Animating Another Market," *Business Week*, Mar. 16, 1987, p. 92.

[68]Office of Trade Representative, "U.S. National Study on Trade in Services," Washington, DC, December 1983.

[69]See S. Casler and B. Hannon, op. cit., endnote 22, pp. 95-96.

[70]The U.S. Department of Energy estimates that a quarter of the energy used in the United States is due to the conversion and distribution losses associated with the generation and delivery of electricity. U.S. Department of Energy, op. cit., endnote 2, p. 15.

[71]Output shipments are based on data from BLS input-output time series, op. cit., endnote 63.

[72]This includes transportation forwarding and packing services, travel agents, ticket counters, and freight services.

[73]These rankings of highest and lowest energy intensities match those calculated by Casler and Hannon using data from 1963 to 1977. See Casler and Hannon, op. cit., endnote 22, p. 96.

[74]B. Gelb, "A Look at Energy Use in Mining: It Deserves It," *The Energy Industries in Transition: 1985—2000*, J. Weyant and D. Sheffield (eds.), Proceedings of the Sixth Annual North American Meeting, San Francisco, Nov. 5-7, 1984, p. 953; and Cleveland et al., op. cit., endnote 1, p. 895.

[75]This result is very similar to that observed by Casler and Hannon who found that 17 percent of the change in energy use due to technology between 1972 and 1977 was due to changes in indirect (nonenergy) requirements, Casler and Hannon, op. cit., endnote 22, p. 106. For an extension of this work to 1982, see S. Casler and A. Afrasiabi, "Input Composition and the Energy Output Ratio," draft, June 1989.

[76]National Income and Product Accounts, op. cit., endnote 4, table 1.2.

[77]For example, the occurrence of an interactive factor in a divisia analysis is noted in Boyd et al. where they allocate the interaction effect equally to each factor. 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. 32.

[78]See Huntington and Myers, op. cit., endnote 8; Doblin, op. cit., endnote 8; R.C. Marlay, "Trends in Industrial Use of Energy," *Science*, vol. 226, Dec. 14, 1984; U.S. Department of Energy, op. cit., endnote 9; and Casler and Hannon for studies of this type.

[79]These estimates are roughly consistent with the findings of other researchers, a sampling of which includes Doblin, Boyd et al., Huntington and Myers, Williams et al., and Hirst et al. Doblin (1987), op. cit., found that for the 1974-80 period changes in structure accounted for half of the decline in energy intensity in the manufacturing sector, pp. 23 and 33. Boyd et al. found that, for the manufacturing sector, structural changes accounted for about 16 percent of the 1971 to 1981 drop in energy use. See 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. 20. Huntington and Meyers, op. cit., endnote 8, found that at least one-third of the decline in energy intensity in the manufacturing sector from 1973 to the early 1980s was due to sectoral shifts, p. 1. Williams, Larson, and Ross, op. cit., endnote 8, find that the decline in industrial energy intensity between 1973 and 1985 was due almost equally to efficiency gains and structural shifts, p. 100; Hirst et al. found that a third of the industrial decline in intensity between

Energy Use in the Recent Past and in the Future

Using the framework established in part III, part IV analyzes the recent increase in energy use registered from 1985 to 1988 and speculates about likely changes in energy use from 1988 to 2000.

OVERVIEW

The trend of constant energy use established from 1972 to 1985 was broken between 1985 and 1988 when energy use increased by 8 percent (6 quadrillion British thermal units (Btu) or quads.) Although the energy intensity of the economy continued to decline nom 1986 to 1988, it did so at a meager-O.2 annual rate as opposed to the –2.4 percent decline achieved from 1972 to 1985. The lack of detailed data preclude answering the question of what factors caused this increase, but it appears that an increase in the level of spending coupled with a shift in the mix of consumption towards more energy-intensive products contributed to the increase:

- Of the 10 major sectors of the economy, manufacturing increased its share of total shipments the most from 1985 to 1988, growing from 32.9 percent of all shipments to 33.8. This increase in the economy's share of gross output halted a downward trend that had prevailed since 1972.

This shift in output is reflective of a shift in the mix of spending:

- Federal Governrnent spending took a dramatic change as nondefense purchases fell by 16 percent over the 3-year period and defense purchases grew by 10 percent.
- The export sector experienced the fastest rate of growth of any sector during this period, increasing its share of Gross National Product (GNP) from 10 to 13 percent. Contributing to this surge were energy-intensive manufacturing products like aluminum where exports grew by 44 percent and steel mill products where exports increased by 121 percent horn 1985 to 1988.
- Household spending shifted away from non-**durable to durable goods like furniture and home electronics.**

Although the level and mix of consumption changed between 1985 and 1988 in such a way that energy use increased, reversing the trend set in the 1972-85 period, it does not appear that the energy efficiency of the production processes used to make these products declined over the period:

- Although the economy was experiencing rapid growth that could theoretically have led to inefficiencies as plant capacity was stretched thin, the level of capacity utilization from 1985 to 1988 was lower than that achieved from 1978 to 1980-a period marked by industrial energy-efflciency gains.
- The annual rate of investment in new plant and equipment from 1985 to 1988 was 7 percent, 2 percentage points higher than the 1972-85 annual investment rate. It is likely that these new investments improved energy efficiency.
- The cost of energy did decline significantly horn 1985 to 1988, providing an incentive to ease-up on pursuing energy efficiencies in production processes. But energy efficiencies have been sustained in other periods of falling prices such as horn 1958 to 1971 and 1982 to 1985—although the magnitude of the decline was not as large as that between 1985 and 1988.[82] Nevertheless, low energy prices do not preclude new investments in production process that are being adopted for reasons other that energy efficiency (e.g., higher product quality, increased production flexibility, or lower labor costs) but have the unintended benefit of reducing energy use.[83]

It appears that increases in the level of spending and changes in the mix of what was being bought from 1985 to 1988 caused a realignment of industrial output towards relatively energy-intensive industries, in turn causing an increase in energy use.

Predictions about how energy use and the economy are likely to change in the future are based on a model developed by the U.S. Department of Labor's Bureau of Labor Statistics. The "moderate-growth" scenario of this model has the GNP growing at a slower rate in the next 12 years than what occurred in the past 12. Thus, on the basis of sheer growth alone, the increase in energy use should be less in the future than that experienced between 1976 and 1988.

In terms of energy use associated with changes in the composition of output, i.e., structural change, the picture is mixed. The manufacturing sector is predicted to benefit horn increases in exports, while being hurt by decreases in defense spending." All told, manufacturing's share of output is predicted to increase, but much of the growth is in "high-tech" products that have relatively low energy intensities. When viewed across all sectors, changes in energy use associated with changes in the structure of the economy, do not appear to be significant.

The future impact of technology on energy use is even more speculative. Nevertheless, a wide array of energy-saving technologies are already in the market and hold out the potential for significant gains in efficiency. The critical unknowns of the future are less of technical potentials than the willingness to implement the technology.

CHANGES IN ENERGY USE FROM 1985 TO 1988

The 13-year trend of steady decreases in the number of Btu consumed per dollar of Gross Domestic Product (GDP) produced (figure 1) was broken between 1985 to 1988 as energy use increased by 8 percent (6.1 quads) in 3 years.[85] Over half of this increase was in petroleum; a fifth was in the form of coal.[8G] The increase was distributed across all three of the main sectors that the Department of Energy allocates energy use to:

- residentia1/comrnercial was responsible for 37 percent of the increase,
- industrial uses contributed 32 percent of the increase, and
- transportation provided 30 percent.[87]

Even though an increase of 6 quads in 3 years is a significant departure horn the flat level of energy use established between 1972 and 1985, the intensity (energy used per dollar of GDP) continued to fall because of the fast pace of real GDP growth (11 percent increase from 1985 to 1988).[88] Nevertheless, the pace of the decline in energy intensity has fallen from -2.4 percent per year horn 1972 to 1985 to-O.8 percent per year from 1985 to 1988.[89] From 1986 to 1988, the decline in energy intensity almost came to a halt, falling at 0.2 percent per year. Why has the rate of decline in energy intensity leveled off after 13 years of steady decreases? Has the rate of energy-efficiency improvements declined? Or has the structure of the economy shifted towards a more energy-intensive mix of industries?

Detailed data, in particular an up-to-date input-output table and industry-specific energy use data, are unavailable, precluding an analysis like that conducted in part III. Nevertheless, some hints as to why energy use increased can be obtained from the more limited data that are available.[w] The analytical framework established in part III suggests four possible factors that could have contributed to the increase:

- growth in the overall level of spending;
- a changing mix of spending towards energy-intensive products;
- changes in the nonenergy portion of the production recipe, requiring more energy; and/or
- changes in the energy portion of the production recipe, that have induced inefficiencies in the use of energy.

Changes in the mix of spending and in the nonenergy portion of the production recipe are collectively labeled structural changes, while changes in energy use due to changes in the energy portion of the production recipe are referred to as changes in technology or energy efficiency.

Growth

The 1985-88 period was a time of strong economic growth: real GDP grew at an annual average rate of 3.7 percent, v. 2.5 percent for the 1972-85 period.[9]1 As shown in part III, sheer growth or an increased level of spending, holding all other changes constant, does increase the use of energy. Finding a period in the past to act as a proxy for 1985 to 1988 is difficult because of the business cycles that affect growth. The 1982-85 period is probably the best proxy for the growth that occurred from 1985 to 1988, because it is the most up-to-date and the fact that both are periods of steady, uninterrupted economic growth. For every $100 billion increase in GDP from 1982 to 1985, energy use due to just growth would have grown by 2.16 quads. Thus, growth from 1982 to 1985 would have caused energy use to increase by 9.8 quads. Applying the 1982 to 1985 formula to the 1985-88 GDP growth, energy use would increase by 8.8 quads, over 40 percent more than the overall increase of 6.1 quads reported by the Department of Energy.[fi] The difference between what was actually observed from 1985 to 1988 and what would have happened if all other factors except growth in the level of spending were kept constant is very small. From 1982 to 1985, changes in the mix of spending (-4.6 quads) and changes in the energy portion of the production recipe or the energy efficiency of industry (-4.0 quads) reduced the increase due to sheer growth by 8.6 quads, resulting in a net, overall increase of only 2.7 quads,[-] less than half of what occurred between 1985 and 1988.

Thus, all of the increase in energy use horn 1985 to 1988 can be attributed to growth in the overall level of spending or GDP, holding all other factors constant. The questions that remain are why were the factors that usually limit this increase due to growth-shifts in the mix of spending, energy savings due to changes in the nonenergy portion of the production recipe, and improvements in energy efficiency of industry-of a smaller size than usual?

Shifts in the Mix of Spending

A shift in the mix of spending would occur if a product's share of growth between 1985 and 1988 was different than the share of spending it represented in 1985. This section looks at how spending on various products changed from 1985 to 1988 relative to the share of consumption that those products held in 1985. This is done for each of the four main areas of spending: households, government, business investment, and international trade. As shown in table 9, a shift in the mix of products purchased, such as horn services to manufactured goods, would cause an increase in energy use.

Households[92]

The shift in the mix of household purchases (personal consumer expenditures) that occurred between 1985 and 1988, tilted spending towards durable goods as opposed to nondurable products. Although durable goods, such as furniture and home electronics, only represented 15 percent of all household consumption in 1985, they were responsible for 24 percent of the increase in household spending from 1985 and 1988. This disproportionate growth of durables came at the expense of nondurable goods such as clothing and food. Nondurable spending represented only 23 percent of the growth, below their 1985 share of 36 percent.

Energy products (which are classified as nondurable) had a mixed experience. Gasoline and oil's share of household purchases declined during this time period,[93] but purchases of fuel oil and coal increased.~ The other major product category within the household sector, services, slightly increased its share from 1985 to 1988 by generating 53 percent of the increase in household spending from a 1985 base of 49 percent.

All in all, products purchased by the household sector seem to have leaned towards a mix that is more energy-intensive: durable goods increased their share over nondurables.[95]

Government[9G]

Data limitations restrict the analysis of the changing mix of government expenditures to the Federal Government, where the mix underwent a radical realignment from nondefense purchases to defense purchases.[97] In real terms, nondefense purchases declined by 16.2 percent from 1985 to 1988, while defense purchases increased by 10.2 percent.[98] The disproportionate growth occurring within defense has been in durable goods (aircraft, missiles, tanks, etc.) which have been responsible for 51 percent of the 1985 to 1988 growth in defense expenditures horn a 1985 share of 30 percent.[w] Thus, government spending at the Federal level has undergone a shift horn nondefense to defense purchases, which are about 1.5 times as energy-intensive.l[m]

International Trade

Of all the sources of demand that make up the GNP, the one that showed the most pronounced disproportionate growth during this period was exports. Although net trade was still in deficit in 1985, exports were responsible for 30 percent of the real, gross[101] increase in GNP between 1985 and 1988, even though exports' share of GNP in 1985 were only 10 percent. Between 1985 and 1988, exports grew by 44 percent while imports increased by only 28 percent. This gain in exports is probably attributable to the sharp devaluation of the dollar that occurred after 1985, making U.S. exports more

[xxix]Calculation: 1982 to 1985 GNP grew by $452.7B, energy use due to growth increased by 9.78 quads, thus quads/GNP = 0.0216. Applied to a 1985 to 1988 GNP increase of $405.7B this results in energy use increasing due to growth of 8.76 quads.

[xxx]Interactive effects resulted in an increase in energy use of 1.6 quads.

attractive overseas.[102] For example, exports of steel mill products increased by 121 percent from 1985 to 1988, while imports of steel mill products decreased by 14 percent.[103] Aluminum also rebounded with exports increasing by 44 percent and imports falling by 5 percent.[104] Over one-half of the increase in overall exports came from capital goods (e.g., machine tools and computers) whose 1985 share was 37 percent.[105] The other leading category of increase was in consumer durables, which generated 11 percent of the growth from a 1985 base of 5 percent. Aside from imports, exports are the most energy-intensive component of demand because exports are largely composed of semifinished intermediate goods and manufactured products that have a high energy content.[106]

In conclusion, it appears that every category of spending either stayed constant or experienced a shift in the mix of spending towards products that are relatively energy-intensive. In particular, exports and defense purchases surged and are undoubtedly part of the reason why energy use increased between 1985 and 1988.

Shifts in Output

***If* the mix** of spending became more energy-intensive, the output horn energy-intensive sectors should also be disproportionately large. Figure 15 illustrates the fact that a slight shift in the composition of output towards energy-intensive industries could have a pronounced effect on energy use. Two data sources, the Federal Reserve Board's Industrial Production Index[107] and the Bureau of Labor Statistics (BLS) Output and Employment Database[108] indicate that a shift in the composition of output towards these energy-intensive sectors occurred between 1985 and 1988.[109]

The Industrial Production Index (IPI) grew by 10.6 percent from 1985 to 1988. Of the three major sectors covered by this index, manufacturing grew by 13.2 percent, mining declined by 5 percent, and utilities grew by 1.8 percent. Within manufacturing the largest percent gains in the index from 1985 to 1988 occurred in lumber (21.5 percent), printing and publishing (19.6 percent), chemicals (19.6 percent), rubber and plastic products (18.6 percent), nonelectrical machinery (which includes computers) (17.8 percent), and paper and paper products (17.4 percent). Three of these six industries produce products that are among the top 11 most energy-intensive (table 9).

The BLS database has shipment (gross output) data on every sector in the economy. Of the 10 major (one digit SIC) sectors, manufacturing increased its share of total shipments the most from 1985 to 1988, growing from 32.9 percent of all shipments to 33.8 percent. The service sector was second, growing from 13.8 percent to 14.2. The 0.9 percent gain in share by manufacturing sounds small, but translates into a $50 billion increase in real shipments over the 3-year period.* This gain in share breaks a trend where manufacturing fell from a 35.8-percent share of output in 1972 to 32.9 in 1985.

Within manufacturing, the three industries experiencing the largest gain in share of manufacturing's total output were machinery, except electrical (which includes the computer industry) whose share grew by 1.4 points, chemicals (0.5 point gain), and primary metals (0.3 gain). Chemicals, primary metals, and to a lesser extent machinery are all relatively energy-intensive industries.

When the increase in output achieved by the manufacturing sector between 1985 and 1988 is multiplied by the 1985 energy intensities shown in table 9, it reveals that just the growth in manufacturing output, holding the energy efficiency of the products constant at their 1985 level, could have caused energy use to increase by 7.7 quad. The big three contributors to this increase were the chemical industry (2.2 quads), primary metals (1.2 quads) and machinery (except electrical (0.8 quad)). A significant portion (90 percent) of this increase is due to sheer growth in the level of output. The change in output mix from 1985 to 1988 caused energy use in the manufacturing sector to increase by 0.77 quad. Although small, the fact that this change in mix led to a net gain in energy use is contrary to the trend established between 1972-85.

These preliminary findings, based on output data, support the idea that a shift in spending (final demand) did occur that caused energy use to increase. Instead of offsetting the increase in energy use due to arise in the level of spending, the mix of spending changed between 1985 and 1988 in such a way that energy use increased-reversing the trend set in the 1972-85 period. Thus it appears that the

***Based in constant 1982 dollars, the total value of gross output for the whole economy in 1988 was $7.3 trillion.**

industrial structure of the economy shifted into a more energy-intensive configuration.

Changes in Energy Efficiency

The other factor that has traditionally acted as a brake on increases in energy use due to growth has been energy savings associated with changes in the way products are made. From 1972 to 1985, nearly four-ftiths of the energy savings attributed to changes in the process of production (the production recipe) were due to changes in the way energy was used as an input.

Given that energy-efficiency improvements were the dominant factor behind the leveling of energy use between 1972 and 1985, could energy-efficiency gains have stopped or even reversed themselves between 1985 and 1988? Evidence indicating how energy efficiency has changed is very limited. In theory, some inefficiencies would be expected as the economy continues to expand and plant utilization begins to hit capacity constraints. For example, as demand for steel continues to rise, moth-balled, old facilities using outmoded technology, like open-hearth furnaces, might be brought back online, causing the energy efficiency of steel production to dip.[110]

At least for the steel industry this has not been the case. The percentage of steel made from relatively inefficient processes, such as open-hearth or blast furnace methods, declined between 1985 and 1988, with the most energy-efficient mode, electric arc, gaining.[111] More generally, the Federal Reserve **Board reports that capacity utilization in manufacturing did increase horn 80 to 83 percent horn 1985 to 1988[112] and that the bulk of this jump occurred in the more energy-intensive primary processing portion of manufacturing** where the capacity utilization rate jumped from 81 to 87 percent.[113] Nevertheless, these capacity utilization levels are below the rates set from 1978 to 1980 when manufacturing hit 86.5 percent of capacity and primary processing climbed to 89.1.[114] Even at these high levels set between 1978 and 1980, efficiency gains were still achieved.[115] It is thus unlikely that the 1985-88 levels of capacity utilization led to significant inefficiencies in energy use.[116]

In fact, this notion that businesses might reactivate old, inefficient modes of production might need updating to take into account the 1982 recession, which led some manufacturers, especially those in the "smokestack" industries, to permanently retire their oldest facilities or transfer operations to offshore sites. Thus, in some cases, the old capacity no longer exists. For example, Pittsburgh was once thought of as the U.S. capital of steel production, but today many of the old U.S. Steel facilities have been torn down and the local economy has shifted towards financial services. U.S. Steel has diversified into retail, transportation, and oil industries.[117]

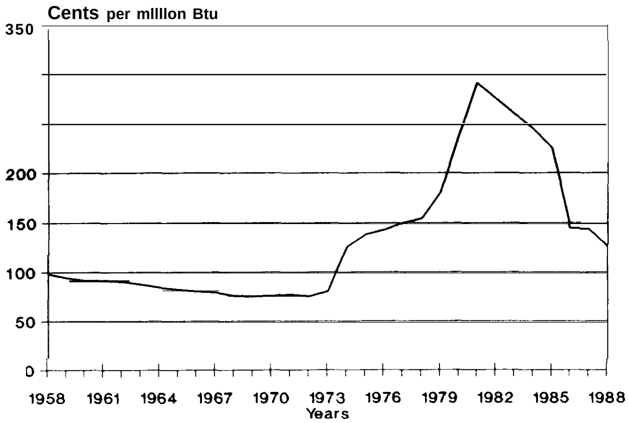
Coupled with this is the fact that investment in new equipment by businesses usually results in energy-efficiency gains as old equipment is replaced by new.[118] The investment rate by businesses during 1972 to 1985—a period of energy-efficiency gains by business-was an annual rate of 4.7 percent, significantly below the 1985 to 1988 rate of 6.9 percent.[119] It is unlikely that these new investments hindered energy efficiency, rather, they are likely to have improved efficiency.

Lastly, the real price of energy dropped from 1985 to 1988, reducing the incentive for making energy-efficiency improvements (figure 18). The price for crude oil & gas, for example, fell from $27 per barrel (current dollars) in 1985 to $14 in 1988.[120] But falling energy prices do not necessarily result in declines in energy-efficiency gains due to changes in the production recipe.[121] Figure 13 shows that savings in energy due to the production recipe were achieved from 1982 to 1985, another period of declining energy prices.[122] Likewise, fuel-efficiency improvements were made between 1958 and 1971, another period of low and falling fuel prices-albeit, not as steep a drop as what occurred between 1985 and 1988.[123] Energy efficiency gains are frequently associated with modernization efforts undertaken to achieve objectives other than energy savings such as improving quality, boosting yields, or increasing the flexibility of production.[124]

Summary

Although a conclusive answer cannot be reached, it appears from the data available that the rise in energy use from 1985 to 1988 was largely due to strong growth in the overall size of the economy and a shift in economic activity towards more energy intensive industries. No evidence was found that would indicate that businesses' energy efficiencies have declined during this period. Rather, it appears that structural shifts toward energy-intensive production could not be countered by energy-efficiency

Figure 18-Composite Fossil Fuel Prices (1982 dollars)



The real composite price of energy was relatively flat from 1958 to 1973. Between 1973 and 1981, the price more than tripled and then began to decline, failing sharply between 1985 and 1988.

NOTE: All fuel prices taken as close as possible to the point of production. Deflated using implicit GNP price deflators.

SOURCE: U.S. Department of Energy, Energy Information Agency, *Annual Energy Review, 1988* (DOE/EIA-0384(88)), May 1989, table 27, p. 65.

improvements, leading to a net increase in energy use. Some of this structural shift could be due to a leveling of household energy efficiency, which would affect the mix of household purchases.[125] It is important to note that changes in economic structure are not as permanent as the word 'structure' would suggest. Trends in both industrial structure and energy use can be reversed in a relatively short time. This increase in energy use due to changes in the structure of the economy could be hiding decreases in energy use due to efficiency gains that continue to be made.

In any event, a 6-quad, 8-percent increase in 3 years-reaching an all-time peak in energy use, which breaks a precedent established over 13 years of very little or no growth in energy use, is surprising and necessitates a more thorough analysis than that provided here. A prerequisite for that analysis is more timely and detailed data.[126]

SPECULATION ABOUT ENERGY USE IN THE FUTURE

This up-tick in energy use from 1985 to 1988 generates concern about whether we are approaching limits to the energy-efficiency improvements we can expect in the fiture.[127] Speculation about future energy use is fraught with difficulties and caveats. Factors that can be incorporated into a computer model tend to be insignificant in comparison to events that are nearly impossible to predict, such as the invention of the microchip or the Iranian Revolution. Attempts at specific forecasts made in the mid- 1970s accurately predicted that the energy intensity of the U.S. economy would decline, but underestimated the rate of the decline, leading to predictions that were 42 percent above actual use.[128]

For the purposes of this report, broad future trends, which lend a sensitivity to what is likely v. what is unlikely, are more appropriate than specific predictions. The discussion is broken into two sections, economic growth and technology, that roughly correspond to the framework of structure and energy efficiency used throughout this report.

Economic Growth

Economic growth is determined by a myriad of factors, including demographics, government spending, monetary policy, trade policy, income distribution, productivity rates, and savings rates.[129] Accounting for all these factors simultaneously, even in a broad framework, is beyond the scope of this report. As a result, this discussion relies on the findings of work done by BLS in their estimate of employment for the year 2000.[130] Their projections are based on a number of inputs, including an econometric model prepared by Data Resources, Inc.; demographic projections estimated by the Bureau of Census; and energy use projected by the U.S. Department of Energy.[131]

The BLS projections include three scenarios: high-, moderate-, and low-growth. Table 10 shows the 1988 to 2000 GNP growth rates and unemployment rates for each of the scenarios as well as corresponding figures for the previous 12-year period, 1976-88. The moderate-growth scenario is arbitrarily selected as a vehicle for setting parameters of what is likely and unlikely to happen. The growth rate of GNP under the moderate-growth scenario is less than that achieved between 1977 and 1988, largely because of a projected slowing of the growth in the size of the labor force and an expectation that the Federal budget and foreign trade deficits will be reduced.[132]

The slowdown in growth in the next 12 years in comparison to the last 12 means that expenditures from the household and government sectors will decline relative to growth in GNP, while exports will increase at a rate that exceeds GNP growth.[133] The

Table 1O--BLS Projections of GNP Growth Rates and Unemployment Rates Under Scenarios of Low-, Moderate-, and High-Economic Growth

Real GNP annual growth rate	1988-2000 Economic growth		
1976-1988	Low	Moderate	High
2.9	1.5	2.3	3.2

Civilian unemployment rate		2000 Economic growth		
1976	1988	Low	Moderate	High
7.7	5.5	7.0	5.5	4.0

SOURCE: Norman C. Saunders, "The Aggregate Structure of the Economy," *Monthly Labor Review*, November 1989, p. 14.

slowdown in the household sector is attributed to a slower rate of population growth and household formations. In particular, expenditures on household furnishings and motor vehicles are predicted to decline.l[w] The desire to reduce the Federal budget deficit is predicted to cause a reduction in the level of military expenditures and cause moderation in nondefense spending, leading to a balanced Federal budget late in the century. Assuming that the value of the dollar remains low, BLS projects that imports will decline as exports, particularly manufacturing machinery, increase due to strong economic growth overseas.[135] In such a scenario, the trade deficit comes into balance in the mid-1990s.[136]

This moderate-growth scenario translates into healthy output increases in durable manufacturing, wholesale trade, and services (health, business services, and child care) sectors (table 11).[137] In terms of energy use, 4 of the top 15 most energy-intensive industries are predicted to have above average growth from 1988 to 2000.[138] The largest gains occur in relatively high value-added but less energy-intensive manufactured products like computers, semiconductors, and optical products.[139] The fraction of output devoted to services continues to grow under this scenario with especially strong growth in computer and data processing, nursing facilities, outpatient facilities, child care, and residential care (senior citizen complexes)-industries that are relatively low in energy intensity.

BLS predictions suggest that economic growth in the next decade will be lower than it was in the recent past. Thus, on the basis of sheer growth alone, the increase in energy use should be less in the future than it was between 1976 and 1988. In terms of energy use associated with changes in the composition of output-structural change-the picture is mixed. The manufacturing sector is predicted to benefit from increases in exports, while being hurt

Table 11—BLS Projections of Output[a] by Major Industry Division Under a Scenario of Moderate Economic Growth

Real GNP annual growth rate	Percent distribution 1976	1988	2000 Moderate	Annual rate of change 1976-1988	1988-2000 Moderate
Total	100.0	100.0	100.0	2.7	2.3
Goods-producing	46.4	43.5	43.0	2.1	2.2
Mining	4.2	3.0	2.5	-0.1	0.6
Construction	6.7	6.6	6.5	2.6	
Manufacturing	35.5	33.8	34.0	2.2	
Durable	17.8	17.7	18.9	2.6	2.9
Nondurable	17.8	16.2	15.1	1.9	1.7
Service producing	50.3	53.9	54.5	3.3	2.4
Transportation and utilities	8.8	8.3	8.4	2.2	2.4
Wholesale trade	5.0	5.7	6.1	3.9	2.9
Retail trade	6.8	7.6	7.5	3.6	2.1
Finance, insurance, and real estate	11.1	11.8	11.9	3.2	2.3
Services	11.5	14.2	15.1	4.5	2.8
Government	7.1	6.3	5.5	1.6	1.0
Agriculture	3.1	2.5	2.4	0.7	1.9
Private households	0.4	0.3	0.2	0.7	0.8

aGross duplicative output.

NOTE: Totals may not add due to rounding.

SOURCE: Valerie A. Personick, "Industry Output and Employment: A SlowerTrend for the Nineties," Month/y Labor Review, November 1989, p. 28.

by decreases in defense spending. On net, manufacturing's share of output is predicted to increase, but much of the growth is in "high-tech" products that have relatively low energy intensities.[140] When viewed across all sectors, changes in energy use associated with changes in the structure of the economy do not appear to be significant.

Technology

By causing the mix of what people bought to change (spending mix) and by changing the way businesses produced output (production recipe), technology was a major factor in offsetting the increase in energy use due to sheer growth in the economy from 1972 to 1985. Detailed estimates about the technical potential of future energy-efficiency gains is beyond the scope of this analysis.[141] Nevertheless, a wide array of energy-saving technologies exist that could significantly improve U.S. energy efficiency.[142] Table 12 provides an incomplete listing of some of the technologies that are already commercially available, but have yet to be fully implemented. The intent is to provide a feel for the range and diversity of energy saving technologies, not a comprehensive list of all available technologies or a projection of potential gains or losses.

CONCLUSION

It is easy to be dazzled by the potential energy savings offered by technology, but realizing this potential is fraught with a great number of uncertainties.[143] What will it cost? How will it change my lifestyle? How will unknowns, such as geopolitical changes, affect the adoption of a particular technology? How will energy savings mesh with other public goals? Ultimately, energy use will be dictated by the answers to these questions.

Structural changes that result in less use of energy and the continued improvement in energy efficiency are likely to continue in the future. A driving force behind these two factors will be the continued development and diffusion of information technologies. Just as electricity generated tremendous energy efficiencies as it freed factory design from the restrictions associated with steam and water power, information technologies hold out the promise for another revolution in the reamer of production.[144] These information technologies will place a premium on exploiting flexibility and the ability to monitor and control production to exact specifications, characteristics that are inherently energy-conserving.

These energy savings associated with energy-eficiency gains should be bolstered by structural changes in the economy. The creation of a basic infrastructure (railroads, factories, highways) that requires inputs horn energy-intensive industries, such as steel and cement has been completed, although the repair and maintenance of these systems will require significant additional resources in the future.[145] Material-intensive consumer products such as stoves, washing machines, refrigerators, etc. have begun to hit saturation points.[146] The sectors of the economy that appear likely to dominate in the future-information processing, software production, biotechnology, aerospace, communications, advanced materials-have strong "energy-saving and-avoiding biases. "147 Even in energy-intensive sectors such as manufacturing, success in the future will hinge on the service component of a product—timeliness, quality, tailoring to the individual customer—not the energy-intensive material portion of the product.

In this sense, speculation about future energy use has to include consideration not only of how technology will affect energy consumption, but also how changes in the industrial makeup of the economy will affect the demand for energy. As can be seen from the 1972-85 and 1985-88 periods, these factors can change relatively quickly.

The future holds a unique opportunity for achieving economic growth without incurring the costs associated with increased energy use. Achieving this future in not a function of what the United States can or can not do. History illustrates that economic growth can be achieved with little or no increase in energy use. Rather, the future is dependent on what Americans choose to do as consumers, business people, and voters.

Table 12—Commercially Available Technologies That Improve Energy Efficiency

Residential/Commercial

- Switching from standard fluorescent ballasts to more efficient solid-state electromagnetic ballasts decrease energy use by 20 to 25 percent, adding an optical reflector to fluorescent lamps increases useful light output by 75 to 100 percent, cutting energy use by 30 to 50 percent.[1]
- It is possible to develop windows with thermal insulation equivalent to 3 inches of fiberglass.[2]
- The efficiency of most home appliances (refrigerators, freezers, central air-conditioners, electric water heaters) can be nearly doubled by using technology already on the market.[3]
- Demonstration homes in Minnesota that use new insulation techniques use 68 percent less heat than the average U.S. home.[4]
- Installing Variable Air Volume (VAV) systems that react to changes in heating and cooling needs by adjusting the amount of air-conditioning can generate savings from 25 to 80 percent over standard systems.[5]
- Information technologies, such as Energy Management Systems (EMS), can be applied to optimize the heating and cooling needs of a building. These systems range from simple timers to sophisticated microprocessor-based systems. Computerized EMS typically provides a 10 to 20 percent savings.[6]

Automobiles[7]

Available new technology	Prevailing technology	(Percent gain) fuel savings
4-valves/cylinder	2-valves/cylinder	10
Turbocharging	standard carburetor	5-10
Fuel injection	standard carburetor	6
Continuously variable transmission	3-speed automatic	10
Overdrive	3-speed automatic	7
Aerodynamic design	15% reduction in drag	3

Industry

- Electrically driven freeze process is estimated to use one-eighth as much energy as the fuel-based evaporators.[8]
- Recovery of waste heat in the chemical industry has reduced energy use per pound of product by 43 percent since 1974, and the potential for further cuts of 32 to 48 percent exist.[9]
- The use of ultraviolet radiation to dry paint and cure plastic resins, reduces curing time from 20 minutes to 1/15th of a second.[10]
- Use of continuous casting technology, as opposed to ingot casting, in the steel industry reduces energy consumption by half and increases product yield from 80 to 95 percent.[11]
- Adjustable-speed drives already in application get energy savings of 20 to 25 percent in compressors, 30 to 35 percent in blowers and fans, and 20 to 25 percent in pumps.[12] It is estimated that on average, adjustable-speed motors cut electricity requirements by one-fifth.[13]

[1]H.S. Geller, "Commercial Building Equipment Efficiency: A State-of-the-Art Review," contractor report prepared for the Office of Technology Assessment, May 1988, p. 12; Electric Power Research Institute, "Lighting the Commercial World," *EPRI Journal*, December 1989, pp. 12-13; and J.H. Gibbons, P.D. Blair, and H.L. Gwin, "Strategies for Energy Use," *Scientific American*, September 1989, p. 140.

[2]S. Selkowitz, "Window Performance and Building Energy Use: Some Technical Options for Increasing Energy Efficiency," *Energy Source: Conservation and Renewables*, D. Hafemeister, H. Kelly, and B. Levi (eds.) (New York, NY: American Institute of Physics, 1985).

[3]Howard Geller, "Residential Equipment Efficiency: A State-of-the-Art Review," contractor report prepared for the Office of Technology Assessment, December 1987, p. 3.

[4]J.H. Gibbons, P.D. Blair, and H.L. Gwin, "Strategies for Energy Use," *Scientific American*, May 1988, p. 141.

[5]H.S. Geller, "Commercial Building Equipment Efficiency: A State-of-the-Art Review," contractor report prepared for the Office of Technology Assessment, May 1988, p. 10.

[6]H.S. Geller, "Commercial Building Equipment Efficiency: A State-of-the-Art Review," contractor report prepared for the Office of Technology Assessment, May 1988, p. 8.

[7]K.G. Duleep, Energy and Environmental Analysis, Arlington, VA, "Developments in the Fuel Economy of Light-Duty Highway Vehicles," contractor report prepared for the Office of Technology Assessment, August 1988.

[8]M. Ross, "Improving the Energy Efficiency of Electricity Use in Manufacturing," *Science*, vol. 244, Apr. 21, 1989, p. 244.

[9]U.S. Department of Energy, Oak Ridge National Laboratory, *Energy R&D: What Could Make a Difference?* vol. 2, part 1, May 1989, p. 71.

[10]C.A. Berg, "The Use of Electric Power and the Growth of Productivity: One Engineer's View," draft, Northeastern University, Boston, MA, p. 33.

[11]U.S. Department of Energy, Oak Ridge National Laboratory, *Energy R&D: What Could Make a Difference?* vol. 2, part 1, May 1989, p. 86.

[12]S.F. Baldwin, "The Materials Revolution and Energy-Efficient Electrical Drive Systems," *Annual Review of Energy*, vol. 13, 1988, p. 87.

[13]A. Kahane and R. Squitieri, "Electricity Use in Manufacturing," *Annual Review of Energy*, vol. 12, 1987, p. 236.

NOTES FOR PART IV

[82]The composite constant dollar price for energy fell by an annual average rate of 1.9 percent between 1958 and 1971, 6.3 percent from 1982 to 1985, and 17.7 percent from 1985 to 1988. U.S. Department of Energy, Energy Information Administration, *Annual Energy Review, 1988* (Washington DC: Energy Information Administration, May 1989), table 27, p. 61.

[83]H.C. Kelly, P.D. Blair, and J.H. Gibbons, "Energy Use and Productivity: Current Trends and Policy Implications," *Annual Review of Energy*, vol. 14, 1989, p. 345; R.C. Marlay, "Trends in Industrial Use of Energy," *Science*, vol. 226, Dec. 14, 1984, p. 1282; and M. Ross, "Improving the Energy Efficiency of Electricity Use in Manufacturing," *Science*, vol. 244, Apr. 21, 1989, p. 316.

[84]Norman C. Sanders, "The Aggregate Structure of the Economy," *Monthly Labor Review*, November 1989.

[85]U.S. Department of Energy, Energy Information Agency, *Monthly Energy Review*, August 1989, table 1.4, p. 7.

[86]Ibid., table 1.4, p. 7.

[87]Ibid., table 2.2, p. 21.

[88]National Income and Product Accounts, op. cit., endnote 4, table 1.8.

[89]*Monthly Energy Review*, August 1989, op. cit., endnote 1, table 1.7, p. 12.

[90]For an analysis of the change that occurred between 1987 and 1988, see H.S. Geller, "U.S. Energy Demand: Back to Robust Growth?" Energy Efficiencies Issues Paper No. 1 (Washington, DC: American Council for an Energy-Efficient Economy, March 1989).

[91]U.S. Department of Commerce, Bureau of Economic Analysis, National Income and Product Accounts, table 1.2.

[92]The source for this analysis is the National Income and Product Accounts, op. cit., endnote 4, table 2.5.

[93]Although the number of miles driven by passenger cars increased over this time period, the miles obtained per gallon of gas (MPG or fuel-efficiency) also increased resulting in a decline in the average number of gallons consumed per car. *Monthly Energy Review*, August 1989, table 1.10, p. 15.

[94]Possibly because of an increase in the number of housing units. Geller reports that occupied housing units increased by 2.9 percent from 1986 to 1988. See H.S. Geller, "U.S. Energy Demand: Back to Robust Growth?" Energy Efficiencies Issues Paper No. 1 (Washington, DC: American Council for an Energy-Efficient Economy, March 1989), p. 3; and National Income and Product Accounts, op. cit., endnote 4, table 2.5.

[95]Hannon calculated that 1972 personal consumer expenditures on durable products were 7 percent more energy-intensive than nondurables. B. Hannon, "Analysis of the Energy Cost of Economic Activities: 1963 to 2000," *Energy Systems and Policy Journal*, vol. 6, No. 3, 1982, p. 261.

[96]Data for this section come from National Income and Product Accounts, op. cit., endnote 4, tables 1.2 and 3.9.

[97]The National Income and Product Accounts do not have expenditure data for State and local government for 1988 and do not publish any constant dollar figures for State and local expenditures by item.

[98]National Income and Product Accounts, op. cit., endnote 4, table 1.2.

[99]National Income and Product Accounts, op. cit., endnote 4, table 3.10.

[100]Hannon, op. cit., endnote 23, p. 261.

[101]This gross figure excludes the losses in GNP attributed to imports.

[102]The real dollar index of the dollar where 1973:Q1 is 100, fell from 117 in June of 1985 to 90.5 in June of 1988. Federal Reserve Bank of Dallas, RX-101 Real Dollar Index: Monthly, 1976-88.

[103]Measured in net tons. American Iron and Steel Institute, *Annual Statistical Report, 1988*, 1989, tables 14 and 18, pp. 34 and 44.

[104]Measured in millions of pounds. The Aluminum Association, *Aluminum Statistical Review for 1988*, vol. 94, No. 94, 1989, p. 5.

[105]National Income and Product Accounts, op. cit., endnote 4, table 4.3.

[106]U.S. Department of Energy, *Energy's Role in International Trade: Structural Change and Competitiveness*, Office of Policy Planning and Analysis, July 1989, p. 1-8.

[107]1985 data is from the U.S. Department of Commerce, Bureau of Census, *Statistical Abstract of the United States, 1989*, table 1273, p. 730. The 1988 data is from the U.S. Department of Commerce, Bureau of Economic Analysis, *Survey of Current Business*, vol. 69, No. 9, pp. s1-s2.

[108]U.S. Department of Labor, Bureau of Labor Statistics, "Historical Input-Output Time Series Data Base," unpublished, January 1989.

[109]Both of these sources suffer from limitations. The Industrial Production Index covers only manufacturing, mining, and utilities, preventing any analysis of the role the service sector might have played. Both the Industrial Production Index and the BLS database contain gross output or shipments data by industry, not value-added. Shipments data reflect the value of the whole product, which in most cases consist of components made by other businesses, not just the value contributed by the company. Businesses can boost their shipments simply by "out-sourcing" more intermediate parts—in some cases the whole product can be out-sourced. In this respect, shipments data include a lot of double counting since both the supplying firm and the buying firm count the same product as output. The double-counting makes calculating shares of output by industry and a shifting mix of the economy from gross output data problematic. In addition, the BLS 1988 data is of a preliminary nature. Unfortunately, there are no ready alternatives since constant dollar value-added by industry (Gross Product Originating) data—the preferred measure of structural change—also has drawbacks and is currently not available as it undergoes revision by the Bureau of Economic Analysis. See U.S. Congress, Office of Technology Assessment, *Statistical Needs for a Changing U.S. Economy*, OTA-BP-E-58 (Washington, DC: U.S. Government Printing Office, September 1989); and U.S. Department of Commerce, Bureau of Economic Analysis, "Gross Product by Industry: Comments on Recent Criticisms," *Survey of Current Business*, July 1988. See Bernard Gelb, "The Measurement of Output," The Conference Board, *Energy Consumption in Manufacturing* (Cambridge, MA: Ballinger Publishing, 1974), p. 80 for more on output measures.

[110]In some cases, higher levels of operating capacity result in greater energy efficiencies since many uses of energy are fixed inputs that are not strictly proportional to increases in the volume of production. Thus as production increases the energy used per dollar of output falls, resulting in efficiency gains.

[111]American Iron and Steel Institute, *Annual Statistical Report, 1988*, table 1B.

[112]Second quarter of 1988.

[113]U.S. Department of Commerce, *Statistical Abstract of the United States, 1989*, table 1274, p. 730, primary processing includes textiles, lumber, paper and pulp, petroleum, rubber, stone, clay, glass, primary metals, fabricated metals, and a portion of chemicals.

[114]*Federal Reserve Bulletin*, Board of Governors of the Federal Reserve System, Washington, DC, November 1989, table 2.12, p. A48.

[115]G. Boyd, J.F. McDonald, M. Ross, and D.A. Hanson, "Separating the Changing Composition of U.S. Manufacturing Production From Energy Efficiency Improvements: A Divisia Index Approach," *The Energy Journal*, vol. 8, No. 2. 1987, p. 86.

[116]Given that many of the industrial uses of energy are to run "fixed" rather than "variable" modes of production (e.g., motors), it is likely that high utilization rates result in an increase in energy efficiency. See U.S. Department of Energy, *Energy Conservation Trends*, Office of Policy Planning and Analysis, September 1989, p. 11.

[117]Barry Bluestone and Bennett Harrison, *The Deindustrialization of America* (New York, NY: Basic Books, 1982), pp. 6 and 40.

[118]U.S. Department of Energy, *Energy's Role in International Trade: Structural Change and Competitiveness*, Office of Policy Planning and Analysis, July 1989, pp. 2-11.

[119]National Income and Product Accounts, op. cit., endnote 4, table 5.7.

[120]Landed cost of imports. *Monthly Energy Review*, August 1989, table 9.1, p. 91.

[121]U.S. Department of Energy, *Energy Conservation Trends*, Office of Policy Planning and Analysis, September 1989, p. 10; W. Walker, "Information Technology and The Use of Energy," *Energy Supply*, October 1985, p. 461; C.P. Doblin, "Declining Energy Intensity in the U.S. Manufacturing Sector," *The Energy Journal*, vol. 9, No. 2, 1988, p. 117; C.A. Jenne and R.K. Cattell, "Structural Change and Energy Efficiency in Industry," *Energy Economics*, April 1983, p. 120; R.H. Williams, Eric D. Larson, and Marc Ross, "Materials, Affluence, and Industrial Energy Use," *Annual Review of Energy*, 1987, p. 103.

[122]Crude oil declines from $33 to $27 per barrel. Landed cost of imports. *Monthly Energy Review*, August 1989, table 9.1, p. 91.

[123]Marc Ross, "The Potential for Reducing the Energy Intensity and Carbon Dioxide Emissions in U.S. Manufacturing," unpublished draft, 1989, p. 2.

[124]H.C. Kelly, P.D. Blair, and J.H. Gibbons, "Energy Use and Productivity: Current Trends and Policy Implications," *Annual Review of Energy*, vol. 14, 1989, p. 345, Marlay, op. cit., endnote 78, p. 1282; Ross, op. cit., endnote 83, p. 316; and J. Goldemberg, T.B. Johansson, A.K.N. Reddy, and R.H. Williams, *Energy for a Sustainable World* (Washington, DC: World Resources Institute, September 1987), p. 6.

[125]U.S. Department of Energy, *Interim Report: National Energy Strategy*, April 1990, p. 20; and L. Schipper and A. Ketoff, "Energy Efficiency: Did We Reach a Plateau?" mimeo, Mar. 1, 1989.

[126]For a discussion on demand-side energy data, see E. Hirst, Oak Ridge National Laboratory, "Comparison of EIA Data Collections: Electricity Supply and Demand," mimeo, October 1989.

[127]For example, a number of witnesses in public hearings for the National Energy Strategy expressed the concern that substantial further energy efficiency gains in industry ". . . would likely require major capital investments in new processes yet to be developed." U.S. Department of Energy, *Interim Report: National Energy Strategy, April 1990, p. 33.*

[128]E.A. Hudson, and D.W. Jorgenson, "U.S. Energy Policy and Economic Growth, 1975-2000," *Bell Journal of Economics*, autumn 1974, vol. 5, No. 2, p. 491.

[129]For a more detailed discussion of the factors that affect economic growth and structural change, U.S. Department of Energy (July 1989), op. cit., endnote 9, p. 2-1.

[130]Norman C. Sanders, "The Aggregate Structure of the Economy," *Monthly Labor Review*, November 1989.

[131]Ibid., pp. 13-14.

[132]Ibid., p. 13.

[133]Ibid., p. 17.

[134]Ibid., pp. 17-18.

[135]The decline in purchases of imports and increase in exports is to some extent a reflection of foreign manufacturing firms' operating plants in the United States.

[136]Sanders, op. cit., endnote 130, p. 21.

[137]Valerie A. Personick, "Industry Output and Employment: A Slower Trend for the Nineties," *Monthly Labor Review*, November 1989.

[138]Based on 1985 product energy intensities shown in table 9. The four industries and their intensity ranks are plastic materials (no. 8), air transportation (no. 10), paper and allied products (no. 11), and water and sanitation (no. 14).

[139]Personick, op. cit., endnote 137, p. 35.

[140]Problems with valuing "high-tech" products like computers and semiconductors makes projections of output in these industries imprecise. See Personick, op. cit., endnote 137, pp. 37-38.

[141]See F. Duchin and G. Lange, "Technological Choices and Their Implications for the U.S. Economy, 1963-2000: Report on the Construction and Application of an Engineering/Input-Output Model and Database," Final Report to the National Science Foundation (grant no. ENG-8703347), March 1990 for a more rigorous analysis of technological effects on the economy.

[142]For a more comprehensive discussion of energy technologies, see U.S. Department of Energy, Oak Ridge National Laboratory, *Energy R&D: What Could Make a Difference?* vol. 2, part 1, May 1989; or J. Goldemberg, T.B. Johansson, A.K.N. Reddy, and R.H. Williams, *Energy for a Sustainable World* (Washington, DC: World Resources Institute, September 1987).

[143]For example, recent estimates predict that the most we can expect from superconductors is a 7 percent reduction in 1986 electricity levels. Achieving this reduction is estimated to take 30 to 40 years. Nils-Johan Bergsjo and Lars Gertmar, "Superconductivity and the Efficient Use of Electricity," *Electricity*, T.B. Johansson, B. Bodlund, and R.H. Williams (eds.) (Lund, Sweden: Lund Press, 1989), p. 422; and Walker, op. cit., endnote 2, p. 472.

[144]Baldwin, op. cit., endnote 52, p. 67; and Walker, op. cit., endnote 2, p. 463.

[145]Eric D. Larson, Marc H. Ross, and Robert H. Williams, "Materials, Affluence, and Industrial Energy Use," *Annual Review of Energy*, vol. 12, 1987, pp. 113-114.

[146]Ibid.

[147]Walker, op. cit., endnote 2, p. 463.

Appendix

The description of the model used for this analysis is broken into three sections: methodology, data sources, and strengths and weaknesses. The appendix assumes that the reader has a rudimentary knowledge of input-output analysis and mathematical modeling. If additional background material is needed, see one of the sources cited in box G.

METHODOLOGY

The model developed for this analysis consists of a series of seven input-output tables that have been moditled from a strict dollar basis to a mixed dollar and quantity format in which energy use is measured in British thermal units (Btu). This mixed format, which combines dollar values of a product with quantity values, is called a hybrid model and is discussed further in the next two sections.

Input-Output Analysis

Simplifying slightly, an input-output table consists of three parts: the Use table, the Make table, and final demand. The Use table is the heart of the analysis. Each column of this matrix shows the dollar value of inputs used in a particular year to generate that industry's output. Each row of the Make matrix shows what commodities each industry makes in a particular year (i.e., both primary and secondary products). For example, the chemical industry makes chemicals as well as drugs, plastics, paints, and rubber.1[48]

By normalizing the Make table by commodity output and multiplying it against the Use table which has been normalized by industry output, a matrix is created where each element in a column shows the value of the input commodity needed to make a dollar's worth of the commodity being produced (output). This matrix, A, is referred to as the direct requirements table. Basically, the matrix, A, represents a series of linear equations that can be solved simultaneously. The solution, shown below, results in an inverse matrix, $(l\text{-}A)^{-1}$, called the total requirements table or the Leontief inverse. Each column represents the production recipe for a particular product and each cell of a column in this matrix represents the direct and indirect inputs of a particular commodity required to satisfy a dollar's worth of final demand for a product. When the total requirements matrix is multiplied by the final demand for each product, the result is a vector consisting of the gross output required of each commodity in order to satisfy demand.

Algebraically:

$$G(j) = \sum_i M(j,i)$$

$$Q(i) = \sum_j U(i,j)$$

$$U'(i,j) = U(i,j)/G(j)$$

$$M'(j,i) = M(j,i)/Q(i)$$

$$A = U' * M'$$

$$X = (I - A)^{-1}\ Y$$

where:

- i represents commodities,
- j represents industries
- G is the sum of industry output from the Make table,
- M is the Make table,
- U is the Use table,
- Q is the sum of commodity output from the Use table,
- U' is the normalized Use table,
- M is the normalized Make table
- A direct requirements table $(I\text{-}A)^{-1}$ is the total requirements matrix or the Leontief inverse
- Y is final demand for each commodity
- X is calculated commodity output

Hybrid Input-Output Energy Analysis

The construction of a hybrid input-output energy model involves reorganizing the input-output commodities and industries so that the first five rows and the first five columns are energy commodities and energy industries.1[49] The dollar flows of energy inputs in the Use table are replaced with the quantity (Btu) of energy required. Similarly, the energy portion of final demand (the first five rows) are also converted to Btu. Instead of representing the dollar amount of an input needed to generate a dollars worth of output, the hybrid direct requirements or "A" table represents four different relationships:

Quadrant 1: Btu of energy input needed per Btu of energy sector output.

Quadrant 2: Btu of energy input needed per dollar of nonenergy sector output.

Box G—Input-Output Analysis

The logic of input-output accounts has been recognized since 1758, when they were published as a "Tableau Economique" by Francois Quesnay, a French economist. Refined and applied to the U.S. economy by Wassily Leontief in the late 1930s, input-output (I-O) accounts form the foundation of most modern econometric models. Leontief was later awarded the Nobel prize in economics for his work in developing I-O analysis. Input-output tables incorporate data from all of the Federal industry censuses and nearly 100 other data sources and are the basis for a number of economic statistics such as the national income and product accounts, the producer price index, and the multifactor productivity series (KLEMS).

I-O accounts are not economic models in the common sense of the term. Rather, they provide a mechanism for displaying and manipulating a large amount of data that has been forced into a consistent format. The central feature of the accounts is a table in which each column represents the inputs—materials, services, labor, and capital—required by an industry to produce its output. For example, to produce 1,000 dollars' worth of motor vehicles in 1984 required 56 dollars' worth of steel, $40 of rubber, and $300 of labor and capital.[1] In effect, this table represents a series of linear equations that can be solved simultaneously to convert a pattern of final demand to industry output.

Further Reading:

Wassily Leontief, *Input-Output Economics* (New York, NY: Oxford University Press, 1966, reprinted 1986).

Ronald E. Miller and Peter D. Blair, *Input-Output Analysis: Foundations and Extensions* (Englewood Cliffs, NJ: Prentice-Hall, Inc., 1985).

Faye Duchin, "Analyzing Technological Change: An Engineering Data Base for Input-Output Models of the Economy," *Engineering With Computers*, No. 4, 1988, pp. 99-105.

Paula C. Young, "The U.S. Input-Output Experience: Present Status and Future Prospects," presented at the International Meeting on Problems of Compilation of Input-Output Tables, Baden, Austria, May 19-25, 1985.

Philip M. Ritz, "Definitions and Conventions of the 1972 Input-Output Study," Bureau of Economic Analysis, U.S. Department of Commerce, July 1980.

Alpha C. Chiang, *Fundamental Methods of Mathematical Economics* (New York, NY: McGraw-Hill Co., 1974).

[1]U.S. Department of Commerce, Bureau of Economic Analysis, "Annual Input-Output Accounts of the U.S. Economy, 1984," *Survey of Current Business*, vol. 69, No. 11, November 1989, p. 30.

Table 13-Primary Energy Conversion Ratios

	1963	1967	1972	1977	1980	1982	1985
Coal mining	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	I.0000
Crude oil & gas	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Refined petroleum	0.0536	0.0540	0.0628	0.0493	0.0469	0.0624	0.0635
Primarv electricity	0.5436	0.5748	0.5732	0.6854	0.7168	0.8211	0.8401
Utility gas	0.0543	0.0644	0.0696	0.1072	0.1032	0.1059	0.1068

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

Quadrant 3: dollars of nonenergy input needed per Btu of energy sector output.

Quadrant 4: dollars of nonenergy inputs needed per dollar of nonenergy sector output.

Quadrants 1 and 2 correspond to the energy portion of the production recipe while quadrants 3 and 4 represent the nonenergy portion.

	Energy sectors	Nonenergy sectors
Energy inputs	Btu/Btu 1	Btu/$ 2
Nonenergy inputs	$/Btu 3	$/$ 4

By multiplying the inverted hybrid energy input-output table (A_e) by the hybrid final demand (Ye), a

column of outputs for each commodity is generated. The output for the first five rows represents the energy output by type required to satisfy the level and mix of demand specified. In forming a measure of aggregate energy use, it is necessary to eliminate the double counting of energy that would occur if both the coal used to make electricity and the electricity that is generated from the coal were counted. To eliminate this double counting, primary conversion ratios (table 13) are applied to the output of each energy type. As can be seen, by their nature crude oil and coal are already in a primary state, thus the conversion ratios are ones. Primary electricity has a relatively high conversion ratio because nuclear and hydroelectric power areme converted to Btu based on their fossil fossil fuel equivalent.150 After these primary energy conversion ratios are applied, the sum of energy across energy types represents the energy *produced in the* United States. To calculate the *consumption* of energy, the sum of the absolute level of energy imports minus the primary energy associated with energy exports are added to the production total.[fi]

Table 14 shows that the differences between energy consumption estimates produced by the OTA model and those published by the Department of Energy are relatively small, except for 1963 and 1967 where the differences exceed 3 percent. The differences that do exist can probably be attributed to revisions made in the raw energy use numbers and the primary energy conversion ratios that were not subsequently made in the National Energy Accounts data.

Decomposing the Change and the Interactive Factor

The calculation of the change in energy use due to different economic factors was achieved by using 1985 as a base year and systematically varying one factor over time while holding all other factors constant in their 1985 form. For example, to calculate the change in energy use due to shifts in spending, the production recipe was held constant in its 1985 form, and final demand for each year (1963, 1967, 1972, 1977, 1980, 1982, and 1985) was applied. The change in energy use horn 1972 to 1985 due to final demand (spending) was calculated by subtracting the energy output associated with 1972 demand (using the 1985 production recipe) horn the output generated using 1985 demand (using the 1985 production recipe). By doing this to every component and subcomponent, the change in energy use can be attributed to different factors. In some cases, this decomposition of the change was not due to a single factor, but was instead due to two or more factors changing simultaneously causing an interaction which affected energy use.

Table 14-Comparison of OTA Energy Consumption Estimates With Estimates Published by the Department of Energy (DOE)
(quadrillion Btu)

	OTA	DOE	Percent difference
1963	50.08	48.32	3.6
1967	60.66	57.57	5.4
1972	73.03	71.26	2.5
1977	78.60	76.29	3.0
1980	77.19	75.96	1.6
1982	72.22	70.84	1.9
1985	74.94	73.94	1.4

SOURCE: Office of Technology Assessment Energy Model; and U.S. Department of Energy, Energy Information Agency, Annual Energy Review, May 19SS, table 4.

Unlike a residual in regression analysis, the interactive factor is not unexplained variance; rather, it is accurately allocated to an identifiable, but difficult to interpret factor that is the simultaneous change of two (or more) variables. For example, an interactive change may have occurred in the case where the substitution of plastics for steel in an automobile to decrease weight caused both a change in the production recipe, and a change in the mixture of spending as more fuel-efficient autos required less gas and thus realigned the mix of products a consumer bought.

Interactive factors are common to all types of shift-share analyses, although many of those reported are of a smaller magnitude than the one calculated in this study.[151] The interaction term that exists when the change in the product of two or more variables is decomposed into individual effects is present because data are measured over discrete versus infinitesimal time changes. The use of input-output analysis precludes an annual time series, instead breaks between data points tend to be 2 to 5 years in length. In particular, the 5-year span in data from 1972 to 1977—a period of tremendous turmoil in terms of energy use because of the first oil shock—was the period that generated nearly two-

[xxxii]The very fact that imported energy enters the United States in both primary and secondary forms eliminates the need to adjust for double counting.

thirds of the total interactive effect registered between 1972 and 1985. Not surprisingly, over 85 percent of the interaction between spending and production recipe was in crude oil& gas.

In decomposing factors responsible for change, interactive factors emerge from the basic algebra of difference equations. To better understand the issues involved, consider the change in energy use from 1972 to 1985 ($E_{85}–E_{72}$), as being the result of changes in the production recipe ($P_{85}–P_{72}$), spending ($S_{85}–S_{72}$), and the interaction of changes in the production recipe and spending, where Δ represents the change from 1972 to 1985:

$$1)\ E_{85}-E_{72} = [P_{85}(S_{85}-S_{72})] + [(P_{85}-P_{72})S_{85}] + [(P_{85}-P_{72})(S_{85}-S_{72})]$$

A in energy use	A in spending	A in production recipe	interaction of production recipe and spending

The interaction term, $[(P_{85}–P_{72})(S_{85}–S_{72})]$, is totally independent of the change in S given P and the change in P given S. Similar equations can be derived for each of the decompositions such as separating the energy effect from the nonenergy effect in changes in the production recipe:

$$2)\ E_{85}-E_{72} = [(P_{e85}P_{n85})(S_{85}) - (P_{e72}P_{n85})(S_{85})] + [(P_{e85}P_{n85})(S_{85}) - (P_{e85}P_{n72})(S_{85})] + [(P_{e85}-P_{e72})(P_{85}-P_{n72})]$$

Δ in energy use	Δ in the energy portion of the production recipe	Δ in the non-energy portion of the production recipe	interaction of energy and nonenergy production recipe

where P_e is energy portion of the direct requirements table and P_n is the nonenergy portion of the direct requirements table which are then combined and as hontief's "A" and converted to a total requirements matrix.

The decomposition of the change in spending into increases in the level of spending and changes in the mix of spending would look like:

$$3)\ E_{85}-E_{72} = [P(_{85})(S_{l85}-S_{l72})] + [(P_{85})(S_{m85}-S_{m72})] + [(S_{l85}-S_{l72})(S_{m85}-S_{m72})]$$

Δ in energy use	Δ in the level of spending	Δ in the mix of spending	interaction of changes in the level and mix of spending

where S_1 is the level of spending and S~ is the mix of spending.

The size of the **interaction effect is a function of the magnitude of the effect attributed to identified variables. Since both spending and the production recipe were found to have a large impact on energy use, it is not surprising that the interaction of these two factors was also large. Because of the longer time period being analyzed, the wider range of sectors being included, and the unavailability of a** 1985 input-output table, the fact that the interactive factor is larger than those reported in other studies is to be expected.1[52]

In models of structural decomposition, treatment of this effect varies and no consistent set of standards seems to apply in dealing with it. For example, as seen in the recent literature, Wolff[153] ignores the interaction term, Feldman et al.[154] and Boyd et al.[155] allocate it equally among the other sources of change, while Casler and Hamon,[156] Roop,[157] and the Department of Energy 158 treat it separately and report its magnitude. Given that the interactive term is a unique factor that affects energy use, we decided to keep it as a separate variable and report its value.

Calculation of Energy Intensities

The primary energy intensities presented in table 9 were calculated using gross output or shipments, not value-added, in the denominator of the ratio. Neither measure of output is free of methodological problems, but gross output is more appropriate given the analysis being undertaken.

Gross output data reflect the value of the whole product, which consists of components made by other businesses (suppliers) and the value added to those components by the producing business. Value--added is just the additional value supplied by the firm in its conversion of raw inputs into a final output. Businesses can boost their gross output simply by ''out-sourcing'' more intermediate parts-in some cases the whole product can be out-sourced.[159] When aggregated across sectors or the whole economy, shipments data reflect a lot of double counting since both the supplying firm and the buying firm count the same product as output.[160] The double counting makes calculating shares of output by industry and a shifting mix of the economy horn gross output data problematic.

Unlike gross output, constant dollar value-added by industry[161] is a residual of a "double-deflation" process where deflated intermediate inputs are subtracted horn deflated gross output.[162] This proc--ess requires extensive intermediate input data and deflators for each industry, including services where such data is limited. It also necessitates an adjust-ment for imported intermediate inputs whose price changes might not be accurately reflected in defla-tors based on domestic products, such as the Producer's Price Index (PPI. Depending on how these adjustments are made, significant changes in

Table 15-OTA Energy Model Data Sources and Coverage

Item	Source	Coverage						
Energy flows	NEA	1963,	1967,	1972,	1977,	1980,	1982,	1985
Energy demand	NEA	1963,	1967,	1972,	1977,	1980,	1982,	1985
Nonenergy demand	BEA	1963	1967,	1972,	1977,	1980,	1982	
	NIPA & BLS							1985
Input-output tables	BEA	1963,	1967,	1972,	1977,	1980,	1982	
Industry output	BLS							1985
Deflators	BLS	1963,	1967,	1972,	1977,	1980,	1982,	1985

ABBREVIATIONS: BEA (Bureau of Economic Analysis), BLS (Bureau of Labor Statistics), I-O (Input-Output), NEA (National Energy Accounts), NIPA (National Income and Product Accounts).

SOURCE: Office of Technology Assessment, 1990.

industry- and sector-level constant dollar value--added can occur.[163] In an effort to address some of these issues, the Bureau of Economic Analysis is revising its constant dollar value-added by industry series,[164] making it currently unavailable.[165]

DATA SOURCES

The construction of this model required four key data components for each year: input-output tables, final demand, energy use, and deflators.

Input-Output

As described in box G, **input-output (I-O) tables provided a snapshot of the inputs required to make the economy's outputs in a particular year. Because energy is primarily an intermediate rather than a final product, I-O tables are particularly well-suited for this type of analysis. I-O tables are unique in that they incorporate data from nearly every Federal statistical agency and numerous private sources, allowing a comprehensive, consistent treatment of the** whole economy. Nevertheless, the data intensive nature of I-O tables means that "benchmark" I-O tibles, which incorporate quinqennial economic census data such as the Census of Manufactures are only issued once every 5 years,[xxxiii] and there is a delay of 6 to 8 years between the year the data was collected and its release as input-output data.[166] To alleviate this problem, the Department of Commerce's Bureau of Economic Analysis (BEA) issues annual tables that are updates of the more rigorous benchmark tables.[167] In addition to updating the input-output relationships between commodities and industries for changes in the prices that have occurred since the release of the benchmark table, the annual updating process also incorporates new survey data such as the Annual Survey of Manufactures, the Annual Survey of Retail Trade, and the Service Annual Survey as well as data from the Internal Revenue Service and the Securities and Exchange Commission.[168] The annual updates have a lag of 5 to 6 years.

The model developed for this analysis uses "benchmark" tables for 1963, 1967, 1972, and 1977, and "annual" tables for 1980 and 1982 (see table 15).[169] Due to definitional and methodological changes, these tables had to be modified to achieve consistency. OTA contracted for this work and the development of the energy data to Stephen Casler who has participated in the development of several hybrid input-output energy models.[170] The accompanying report to this contract describes not only the modifications that were made to achieve consistency between industry classifications over time, but also methodological issues, such as the handling of scrap and noncomparable imports.[171]

The endpoint of 1985 referred to in this analysis does not use a complete 1985 annual table issued from BEA, but is instead BEA's 1982 direct requirements table, which has had the energy sectors updated to 1985 with 1985 National Energy Accounts (NEA) data and the 1985 estimates of gross output calculated by the Bureau of Labor Statistics.[172] This technique assumes that the use of nonenergy inputs by industries did not change between 1982 and 1985. This assumption does create some limitations, especially in calculating the effect of nonenergy production recipe changes on energy use. Nevertheless, this mixture of 1982 and 1985 data generates an aggregate level of energy consumption of 74.9 quadrillion Btu for 1985, only

[xxxiii] Benchmark I-O tables are issued for years ending in 2 or 7.

1.4 percent above that reported by the Department of Energy.[173]

This technique of just updating the energy portion of the input-output tible has been shown by other researchers to be more accurate than not making the modification.[174] Accurate results are more likely if the updating occurs over a short period of time, such as the 3-year span between 1982 and 1985,[175] because changes in input-output coefficients occur gradually for many sectors of the economy.[176]

Final Demand

Final demand was available for every year except for 1985 horn the corresponding input-output tables. Since a 1985 I-O table does not currently exist, 1985 final demand by I-O commodities was estimated by converting demand as reported in the National Income and Product Accounts (NIPA)[177] into demand by I-O commodity. The conversion of demand horn NIPA categories into demand by I-O commodities is accomplished through use of 'bridge' tables produced by BEA. In the case of households (personal consumer expenditures or PCE)[178] and business investment in personal durable equipment (PDE),[179] the bridges are published along with the 1977 input-output table.[180] For the remaining categories of domestic demand—government[181] and business investment in structures[182]-unpublished versions of these bridge tables were obtained from BEA.[xxxiv]

Import and export data for 1985 were obtained in unpublished form from the Bureau of Labor Statistics' Office of Economic Growth and Employment Projections in their 222 sectoring scheme and were converted to the BEA's input-output classifications using a BLS sectoring plan.[183]

Adjusting for Changes in Prices

The **analysis of change in the economy over time requires that each year's final demand and associated input-output tables be based in the same set of prices-allowing a consistent comparison overtime. This process of establishing a constant set of prices corrects not only for the effects of inflation on a product's price, but also for quality changes that have occurred in the product over time,** such as the addition of a turbocharger to an engine. The common name for this process is *deflation* because the current price of a product is deflated to some price in the past, although the reverse also occurs. Currently, 1982 is the most up-to-date base year. This issue was discussed in box F and in the upcoming section of strengths and weaknesses.

The deflators used in this analysis are based in 1982 and were obtained from the Bureau of Labor Statistics "Historical Input-Output Time Series Data Base,"[184] and were aggregated to the BEA sectoring scheme using current dollar weights of output in accordance with the BLS sectoring plan and unpublished worksheets from BLS.[185] A deflator was derived for each nonenergy commodity. Since energy commodities are valued in quantities (Btu), no deflation was necessary.

Comparisons to Gross National Product (GNP)

Since the sum of all components of final demand is GNP, a preliminary check of the bridging process from NIPA to I-O commodities and the deflators is to compare the deflated total of GNP as derived through this process with the constant dollar GNP figures published by BEA in the *Survey of Current Business.* Table 16 shows that the difference between the two series averages less than 1 percent. This difference can probably be attributed to revisions in the National Income and Product Accounts that are not incorporated in the input-output tables and the use of different deflators. Comparisons of constant dollar final demand at the commodity level can not be made because BEA does not produce a constant dollar final demand series in commodity categories.

Measures of Economic Activity

No one statistic can adequately reflect economic growth or changes in a country's standard of living. This is especially true as an economy develops, incomes rise, and greater concern is directed towards the costs associated with economic activity such as pollution, depletion of natural resources, and traffic congestion that are typically not accounted for in economic indicators like GNP.[186] Nevertheless, GNP was never intended to be a proxy for economic development; rather, it is an estimate of ". . . the

[xxxiv] Changes in business inventories are also a part of domestic demand. The aggregate total for inventories was obtained from NIPA and distributed across input-output commodities using the 1977 distribution of inventories. The year 1977 was used for scaling the 1985 inventory change total instead of 1980 and 1982 because of the similarity of positions in the economic cycle.

Table I6--Comparison of OTA GNP Estimates With Estimates Published by the Bureau of Economic Analysis (millions of constant 1982 dollars)

	OTA GNP	BEA GNP	Percent difference
1963	1883.9	1873.3	0.6
1967	2286.9	2271.4	0.7
1972	2638.9	2608.5	1.2
1977	2946.3	2958.6	-0.4
1980	3140.2	3187.1	-1.5
1982	3190.7	3166.0	0.8
1985	3622.6	3618.7	0.1
Average			0.2

SOURCE: Office of Technology Assessment Energy Model; and U.S. Department of Commerce, Bureau of Economic Analysis, *Survey of Current Business*, July 1988 and July 1989, table 1.2.

market value of goods and services produced by labor and property supplied by residents of the United States,''[187] which some people construe to be economic development. In the sense that GNP is an estimate of production, it is well-suited as an economic indicator used to analyze energy use since energy is a basic input to production.

A component of GNP, Gross Domestic Product (GDP) is used throughout this report. The difference between GNP and GDP is the net return on capital located abroad but owned by U.S. residents minus the income from capital owned by foreigners but located in the United States-a category called "Rest of World" (RoW).[188] The category does not reflect actual output, but rather the returns (wages, profits, interest) associated with that output. For example, the dividends received by a U.S. investor in a European company and the interest paid to Japanese holders of U.S. Treasury bonds would both be counted in RoW.

Historically, the RoW category has been a small accounting adjustment made to the national accounts. Over the time period being analyzed (1963 to 1985), the RoW category grew in size and became erratic, hitting a high of 1.74 percent of GNP in 1980 and a low of 1.00 percent in 1985. In 1980, these payments were equal to 86 percent of the contribution made to GNP by the farming sector. Because these accounts do not represent tangible output of a good or service, they do not affect energy use; but because of their volatility, their inclusion does affect estimates of GNP, which in turn affects calculations of energy intensity that use GNP in the denominator. To avoid this problem, GDP is used.

Energy Flow Data[xxxv]

The energy flow data were obtained for each of the 7 years from the National Energy Accounts (NEA) developed by Jack Faucett Associates, Inc. for the Department of Commerce.[189] The accounts show the flows of 34 different energy products being consumed by 122 industries and 8 categories of final demand. The OTA energy model aggregated these 34 energy products into 5 broad categories (coal, crude oil & gas, refined petroleum, primary electricity, and utility gas) and collapsed the industries into a list of 88 (see table 17).[190] Final demand was aggregated into six sectors: households, government, business investment, changes in business inventories, exports, and imports.

NEA is regarded as the best estimate of energy use by industry, aside from the newly (1986) created Manufacturing Energy Consumption Survey (MECS).[191] Nonetheless, construction of NEA is based on incomplete indicators of energy consumption, such as transportation mileage estimates and census surveys. The conversion of energy quantities (tons, cubic feet, barrels, kilowatt-hours) into Btu is based on Department of Energy conversion factors published in the *Monthly Energy Review*.[192] For example, it is assumed that 1 kilowatt-hour of electricity consumption is equal to 3,412 Btu.[193] Nuclear and hydroelectric power are converted to Btu using the prevailing ratios for fossil fuel steam electric plants.

The NEA include only those energy products that are produced and sold on an establishment basis.[xxxvi] Thus, the cogeneration of electricity sold to a utility is reflected in the data. On the other hand, if the cogenerated electricity was used within the business establishment, it would not be reflected in NEA data; only the purchased energy required to generate the electricity, such as natural gas, would be counted. Similarly, the energy associated with coke gas used in the production of steel would not be counted, but the coal required to make the coke would be recorded. If this convention was not followed, a

[xxxv]This section is based on the OTA contractor report prepared by Stephen D. Casler, ''Energy Flows Through the U.S. Economy, 1980, 1982, and 1985,'' December 1989.

[xxxvi]A distinction is drawn between an *establishment*, which is an individual corporate unit like a branch plant or a one-establishment business, and an *enterprise*, which refers to the complete corporate structure of a company that can consist of thousands of establishments.

Table 17—Listing of Broad Sectors and Individual Industries/Commodities in the OTA Energy Model

Energy sector	
1	Coal mining
2	Crude petroleum and natural gas
3	Petroleum refining and related industries
4	Electric utilities
5	Gas utilities
Natural resources sector	
6	Livestock and livestock products
7	Other agricultural products
8	Forestry and fishery products
9	Agricultural, forestry, and fishery services
10	Iron and ferroalloy ores mining
11	Nonferrous metal ores mining, except copper
12	Stone and day mining and quarrying
13	Chemical and fertilizer mineral mining
14	New construction
15	Maintenance and repair construction
Manufacturing	
16	Ordnance and accessories
17	Food and kindred products
18	Tobacco manufacturers
19	Broad and narrow fabrics, yarn, and thread mills
20	Miscellaneous textile goods and floor coverings
21	Apparel
22	Miscellaneous fabricated textile products
23	Lumber and wood products, except containers
24	Wood containers
25	Household furniture
26	Other furniture and fixtures
27	Paper and allied products, except containers
28	Paperboard containers and boxes
29	Printing and publishing
30	Chemicals and selected chemical products
31	Plastic materials and synthetic materials
32	Drugs, cleaning and toilet preparations
33	Paints and allied products
34	Paving
35	Asphalt
36	Rubber and miscellaneous plastic products
37	Leather tanning and finishing
38	Footwear and other leather products
39	Glass and glass products
40	Stone and clay products
41	Primary iron and steel manufacturing
42	Primary nonferrous metals manufacturing
43	Metal containers
44	Heating, plumbing, and structural metal products
45	Screw machine products and stampings
46	Other fabricated metal products
47	Engines and turbines
48	Farm and garden machinery
49	Construction and mining machinery
50	Materials handling machinery and equipment
51	Metal working machinery and equipment
52	Special industry machinery and equipment
53	General industrial machinery and equipment
54	Miscellaneous machinery, except electrical
55	Office, computing, and accounting machines
56	Service industry machines
57	Electrical industrial equipment and apparatus
58	Household appliances
	Electric lighting and wiring equipment
59	Radio, TV, and communication equipment
61	Electronic components and accessories
62	Miscellaneous electrical machinery and supplies
63	Motor vehicles and equipment
64	Aircraft and parts
65	Other transportation equipment
66	Scientific and controlling instruments
67	Optical, ophthalmic, and photographic equipment
68	Miscellaneous manufacturing
Transportation services	
69	Railroad
70	Local transport
71	Motor freight transport
72	Water transportation
73	Air transportation
74	Pipe lines, except natural gas
75	Transportation arrangements
Services	
76	Communications, except radio and television
77	Radio and TV broadcasting
78	Water and sanitary services
79	Wholesale and retail trade
80	Finance and insurance
81	Real estate and rental
82	Hotels: personal and repair services (excluding auto)
83	Business services
84	Automobile repair and services
85	Amusements
86	Health, education, social services, and nonprofit organizations
87	Federal Government enterprises
88	State and local government enterprises

SOURCE: Office of Technology Assessment, 1990.

double counting of energy consumed would occur. The energy associated with both the sale and captive use of wood are not included. Lastly, purchases of energy products that are used as feedstocks, such as the petrochemical industry's use of petroleum, are included in the NEA energy flows.

STRENGTHS AND WEAKNESSES OF THE OTA ENERGY MODEL

Economic models like the one used for this analysis are simulations of reality and thus suffer from being unable to completely reflect all facets of a real economy. The power of models lies in the fact that "what if" questions can be asked that reveal knowledge that would be difficult, dangerous, or impossible to obtain from the real economy the model emulates. In this sense, all models have their strengths and weaknesses and the results obtained should be interpreted with attention to these traits. The following section outlines some of the character strengths and flaws of the OTA energy model.

Strengths

There are two major strengths of the model: 1) it is based in input-output data and analysis, and 2) the hybrid nature of the model.

Input-output

Input-output tables reflect the state of the economy at a particular time-a snapshot. The strength of this analytical technique is that it is rooted in real data that is the bedrock of the national accounting system used for estimating the performance of the economy. No economic activity that occurs in the formal marketplace escapes this accounting. Because I-O plays this critical role in the U.S. statistical system, the data are unusually complete and internally consistent, and cover every sector of the economy.[194] As a result, the OTA energy model encompasses the whole economy, not just individual or aggregated sectors such as manufacturing. As can be seen from the analysis in part III, the service sector is an important component of the U.S. energy equation. These features make I-O analysis an invaluable tool in examining how the structure of the economy has evolved.1[95]

In addition to its data intensiveness, another strength of I-O analysis is the ability to capture the interrelationships and linkages that exist between sectors of the economy. By being able to trace the direct and indirect links, input-output lets the researcher calculate the complete energy required to make a product from raw material all the way to the retail outlet. These interconnections allow not only a tracing of the direct energy associated with some economic activity, but also the indirect energy embodied in specific goods and services. Seemingly low energy-intensity products such as water & sewage treatment use a lot of energy when the direct and indirect effects are included. As an increasing number of products are part of complex production systems that extend beyond U.S. borders, this ability to calculate the energy embodied in a product is important and is unique to I-O models.

The construction of input-output tables allows a separation of changes in energy use due to what is being purchased (spending) and how that product was produced (production recipe), a feature that is distinctive to input-output analysis. Because spending (final demand) is an identifiable component of input-output tables, it allows a researcher the ability to focus on different aspects of demand, analyzing how different products or sources (households v. government) affect energy use. Similarly, experiments such as how much of the change in energy use associated with the production recipe comes from energy inputs and how much horn nonenergy inputs can be run. This level of detail and the ability to separate direct energy use horn indirect energy use is a valuable feature associated with input-output analysis.

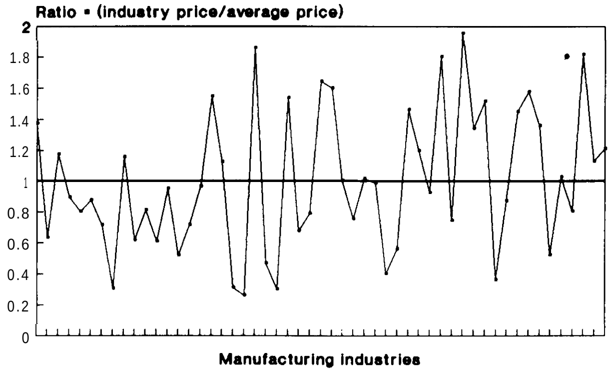
Lastly, the input-output method of analyzing change in energy use does not force the researcher to constantly view energy use as a ratio where it is always entangled with some other variable such as value-added or output.[196] Thus, actual quantities of energy use are reported as opposed to quantities contingent on some economic variable.

Construction of a Hybrid I-O Table

Modifying an I-O table so that energy is expressed in quantities such as Btu instead of dollars (a hybrid model) creates numerous methodological advantages. First, valuing a good in Btu rather than dollars eliminates the need to adjust for changing prices over time, eliminating a possible source of error. Second, through the mathematics of input-output, energy intensities (Btu per dollar of output) are a byproduct of calculating energy consumption. Third, the hybrid method avoids the need to convert dollar-based energy output into energy quantities, such as Btu, using a simple conversion ratio (Btu per dollar of energy output or implicit price). Since the price paid for different types of energy by different industries varies significantly, using an average price for all industries can introduce a significant distortion (see figure 19).[197] Thus, the OTA model implicitly uses a unique price for each fuel type for every industry.

Lastly, only through using a hybrid I-Omodel can the production recipe be divided into its energy and nonenergy portions. Use of conversion ratios like

Figure 19-implicit Price Paid per Btu of Refined Petroleum



SOURCE: U.S. Department of Energy, Energy Information Agency, *Annual/Energy Review, 1988 (DOE/EIA41364(66)),* May 1969, table 27, p. 65.

those described above would not capture the direct and indirect changes associated with the inversion of the matrix.1[98]

Limitations

Data

While I-O accounts have a number of advantages, they do suffer from data and methodological limitat-ions. Because the model is based on observed data, there tends to be a long lag time between the collection of data and the availability of I-O tables. A' 'benchmark' table for 537 business categories is published following publication of the industrial censuses, which are conducted every 5 years. The benchmark table for the 1977 I-O tables became available only in 1984. A 1982 benchmark table has not yet been released. Asaresult,a"revision' of the 1977 benchmark, updated to 1982 and aggregated to 85 business categories, is the latest I-O table used in this analysis. Although 85 industries provide suffi-cient detail for the a broad study of the economy, more detail is necessary for pinpointing changes and avoiding biases associated with aggregation. For example, what appears to be a change in the steel industry's (SIC 331) production recipe resulting in less energy use per unit of output might have little to do with technology and instead be attributable to a shift in production from pipes and tubes (SIC 3317) to wire and nails (SIC 3315).

The sporadic nature of benchmark I-O accounts means that a continuous time series is impractical to assemble. A weakness of this analysis is that it relies on six I-O tables to explain changes in energy use that occurred over a 22-year period-temporal peculiarities can skew the findings. This limitation means that turning points, such as the first year that the energy intensity began to decline, 1971, are in some cases missed. The lack of a continuous series restricts any connection between business cycles and energy use to causal observances because annual trends cannot be plotted.

Only four of these six I-O tables (1%3, 1967, 1972, and 1977) were the more detailed and accurate benchmark tables; the 1980 and 1982 tables were annual updates of the 1977 benchmark. Given the severe economic recession of 1982, its use as a datapoint, especially an endpoint, is questionable. This problem is reduced through the updating of the energy and final demand components to 1985. Although no set of endpoints are typical, 1972 and 1985 are at relatively the same point in the economic cycle.

Other than the input-output data, the other data sources employed, deflators and the NEA, also have their share of weaknesses. By and large, deflators used in this analysis are of good quality: a unique deflator is used for each industry and the same series can be used over the whole time period being studied. Nevertheless, the significance of deflators as a source of error and distortion is frequently overlooked. The main weakness associated with deflators is that it is very difficult to make quality adjustments for service products where the output is inherently hard to measure and for products experi-encing rapid technological change such as comput-ers.1[w] In particular, the accuracy of the computer deflator has been debated.[2m] Whether corrector not, its effect on economic analysis is substantial, and additional work needs to be done to test the sensitivity of the findings presented in this report to changes in the deflators used.

NEA data are the only source for consistent energy use data by industry overtime. Nevertheless, the accounts suffer horn a lag of roughly 4 years: the 1985 data were released in 1989. The lag associated with NEA and the I-O tables limits the analysis to 1985, leaving a gap in trying to explain the more recent, 1985 to 1988, increase in energy use. A limiting assumption associated with the NEA is that the economic value of all types of energy are equal-a Btu is a Btu regardless of the type. This conversion of energy type into a common unit, Btu, conceals the fact that different forms of energy have unique properties and are not equivalent replacements for each other.[20]1 Some analysts argue that when the quality of a particular energy type is taken into account, the decline in the energy intensity in the 1970s and early 1980s is much smaller.[m]

Methodology

The most important assumption made in I-O analysis is that of "linear," or fixed, economies of scale. Calculations that estimate the energy directly and directly associated with a product assume that the same mix of inputs, the process employed, and the relative prices of goods and services are the same for making one product as they are for making 10,000. Many of the calculations used in this analysis such as the energy associated with manufactured v. service products, the primary energy intensities associated with a product, and the energy associated with household v. government expenditures rely on this assumption.

Another methodological assumption made in this analysis was that all imported products could be made in the United States and that the U.S. production recipe for making these imported products is an exact proxy of the recipe used overseas. Some products like coffee or chrome, cannot be made in this country. Other products, like cars, that do have a domestic counterpart are made much differently overseas than in the United States. Thus, estimates of the energy embedded in imported products are rough approximations.

The production recipe only includes nondurable inputs, such as steel and rubber, that are completely used up in the production of output. Inputs of a more durable nature that depreciate over time, such as machine tools or the actual physical plant (capital goods), are not included in the production recipe, but are instead thought of as business investment and are included in final demand.[203] This assumption results in an underestimate of the indirect energy associated with a product if the complete demand vector, including all of business investment, is not part of the calculation. For example, the indirect energy associated with making a car would not include the energy required to make the stamping presses or the conveyor belt. (Nevertheless, the nondurable input of electricity needed to drive this equipment would be included.) This assumption would affect estimates of the energy embodied in manufactured products, the individual energy intensities, and the energy associated with household expenditures. This failure to include capital in the production recipe results in an underestimate of the energy embodied in products that ranges from 2 to 17 percent depending on the product. The unweighed average underestimate is estimated to be 9 percent.[204]

Lastly, the OTA model was constructed primarily to address the question of how much of the change in energy use was due to efficiency gains and how much was due to a changing mix in the industrial composition of output. To make this comparison, it is important that the value of output be converted to a constant set of prices since a million dollars' worth of output in 1963 had a much different value that a million dollars' worth of output in 1985. This requires that price, an important factor in energy use, beheld constant by creating a constant-dollar model. In this sense, the model can isolate the change due to efficiency but not why that efficiency change occurred. Examples of likely causes of the change are frequently cited in the analysis, but their inclusion is anecdotal, not conclusive.

ENDNOTES FOR PART V

148 U.S. Department of Commerce, Bureau of Economic Analysis, "Annual Input-Output Accounts of the U.S. Economy, 1984," *Survey of Current Business*, November 1989, p. 39.

149 For a more detailed explanation of hybrid input-output analysis and some of its extensions see R. Miller and P. Blair, *Input-Output Analysis: Foundations and Extensions* (Englewood Cliffs, NJ: Prentice Hall, Inc., 1985), ch. 6; and S.D. Casler and S. Wilber, "Energy Input-Output Analysis," *Resources and Energy*, No. 6, 1984; C. Bullard and R. Herendeen, "The Energy Costs of Goods and Services," *Energy Policy*, December 1975; C. Bullard and R. Herendeen, "Energy Impact of Consumption Decisions," *Proceedings of the IEEE*, vol. 63, No. 3, March 1975, pp. 484-493; S. Casler and A. Afrasiabi, "Input Composition and the Energy Output Ratio," draft, June 1989; S. Casler, A. Afrasiabi, and M. McCauley, "Decomposing Change in Energy Input-Output Coefficients," draft, n.d.

150 The conversion ratio for electricity represents the fossil fuel required for the production of nuclear, hydroelectric, and geothermal electricity per unit of electricity. Therefore, when multiplied against the electricity input for some sectors the product represents the Btu of fossil fuel that would be required if nuclear, hydroelectric, and geothermal electricity were produced with fossil fuels. For example, in 1985, the fossil fuel equivalent for primary electricity (mainly nuclear and hydroelectric power) is 3.07 Btu. For one unit of electricity, it would require 3.07 units of fossil fuel. Of all the electricity produced in 1985, 27.38 percent was primary, thus the conversion ratio is derived by multiplying 0.2738 x 3.07 = 0.8401.

151 For example, the occurrence of an interactive factor in a divisia analysis is noted in 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. 32. Casler and Hannon, Roop, and the U.S. Department of Energy all report interactive factors. See S. Casler and B.

Hannon, "Readjustment Potentials in Industrial Energy Efficiency and Structure," *Journal of Environmental Economics and Management*, vol. 17, 1989, p. 106; J. M. Roop, "Energy Implications of Structural Change in the United States Economy," paper delivered to the IEA-Energy Demand Analysis Symposium, Oct. 12-14, 1987, Paris, France; and U.S. Department of Energy, *Energy's Role in International Trade: Structural Change and Competitiveness*, Office of Policy Planning and Analysis, July 1989, p. A-1.

[152]Roop is the only researcher whose results, because they are reported in Btu, are directly comparable to those in this study. In his analysis of the 1972-82 change in energy use across the whole economy, he found that the overall interactive term was a positive effect at 2.7 quads. See U.S. Department of Energy, "Energy's Role in International Trade: Structural Change and Competitiveness," Office of Policy Planning and Analysis, July 1989, p. 1-4. His analysis of the industrial sector from 1972 to 1982 generated "cross products" that summed to –3.1 quads. See J.M. Roop, "Energy Implications of Structural Change in the United States Economy," paper delivered to the IEA-Energy Demand Analysis Symposium, Oct. 12-14, 1987, Paris France.

[153]E.N. Wolff, "Industrial Composition, Interindustry Effects, and the U.S. Productivity Slowdown," *The Review of Economics and Statistics*, LXVII, 1985, p. 272.

[154]S. Feldman, D. McClain, and K. Palmer, "Sources of Structural Change in the United States, 1963-1978: An Input-Output Perspective," *The Review of Economics and Statistics*, LXIX, 3, 1987, p. 505.

[155]G. Boyd, D.A. Hanson, and M. Ross, "The Market in U.S. Manufacturing, 1959-1981: Effects of Sectoral Shift and Intensity Changes," draft, prepared for the Energy Modeling Forum No. 9, September 1987, p. 31.

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

[157]J.M. Roop, "Energy Implications of Structural Change in the United States Economy," paper delivered to the IEA-Energy Demand Analysis Symposium, Oct. 12-14, 1987, Paris, France.

[158]U.S. Department of Energy, Office of Policy Planning and Analysis "Energy's Role in International Trade: Structural Change and Competitiveness," July 1989, p. 1-4.

[159]"The Hollow Corporation," *Business Week*, Mar. 3, 1986, p. 57.

[160]See B. Gelb, "The Measurement of Output," The Conference Board, *Energy Consumption in Manufacturing* (Cambridge, MA: Ballinger Publishing, 1974), p. 80.

[161]Also referred to as Gross Product Originating. Milo F. Peterson, "Gross Product by Industry, 1986," *Survey of Current Business*, April 1987.

[162]Ibid.

[163]Researchers who have made these adjustments estimate a lower rate of growth in manufacturing value-added than that reported by the Bureau of Economic Analysis from 1979 to 1985. See U.S. Congress, Office of Technology Assessment, *Technology and the American Economic Transition: Choices for the Future*, OTA-TET-283 (Washington DC: U.S. Government Printing Office, May 1988), p. 173; Lawrence R. Mishel, "The Late Great Debate on Deindustrialization," *Challenge*, January-February 1989, p. 40.

[164]"Gross Product by Industry: Comments on Recent Criticisms," *Survey of Current Business*, July 1988, p. 132.

[165]"National Income and Product Accounts Tables," *Survey of Current Business*, July 1989, p. 78.

[166]For example, the 1977 I-O table was released in May of 1984. See "The Input-Output Structure of the U.S. Economy, 1984," *Survey of Current Business*, May 1984.

[167]M.A. Planting, "The History and Development of the U.S. Annual Input-Output Accounts," paper presented at the International Meeting on Problems in the Compilation of Input-Output Tables, Baden, Austria, March 1988.

[168]Ibid., p. 6.

[169]Sources for input-output tables referenced is as follows—1963: U.S. Department of Commerce, Bureau of Economic Analysis, "The Input-Output Structure of the U.S. Economy, 1963," *Survey of Current Business*, November 1969; 1967: U.S. Department of Commerce, Bureau of Economic Analysis, "The Input-Output Structure of the U.S. Economy, 1967," *Survey of Current Business*, February 1974, 1972: P.M. Ritz, E.P. Roberts, and P.C. Young, "Dollar-Value Tables for the 1972 Input-Output Study," *Survey of Current Business*, April 1979; 1977: U.S. Department of Commerce, Bureau of Economic Analysis, "The Input-Output Accounts of the U.S. Economy, 1977," *Survey of Current Business*, May 1984; 1980: U.S. Department of Commerce, Bureau of Economic Analysis, Input-Output Accounts of the U.S. Economy, 1980, unpublished; 1982: U.S. Department of Commerce, Bureau of Economic Analysis, "Annual Input-Output Accounts of the U.S. Economy, 1982," *Survey of Current Business*, April 1982.

[170]See S. Casler and B. Hannon, "Readjustment Potentials in Industrial Energy Efficiency and Structure," *Journal of Environmental Economics and Management*, vol. 17, 1989; S. Casler and A. Afrasiabi, "Input Composition and the Energy Output Ratio," draft, June 1989; S. Casler, A. Afrasiabi, and M. McCauley, "Decomposing Change in Energy Input-Output Coefficients," draft, n.d.; Stephen D. Casler, "The Effects of Changing Industry Mix on Air Pollution Output," draft, n.d.; S.D. Casler, and S. Wilber, "Energy Input-Output Analysis," *Resources and Energy*, No. 6, 1984.

[171]S. Casler, "Energy Flows Through the U.S. Economy, 1980, 1982, and 1985," contractor report prepared for the Office of Technology Assessment, December 1989.

[172]U.S. Department of Labor, Bureau of Labor Statistic, "Historical Input-Output Time Series Data Base," unpublished, January 1989.

[173]U.S. Department of Energy, Energy Information Administration, *Annual Energy Review, 1987* (Washington DC: Energy Information Administration, May 1988), table 4, p. 13.

[174]Casler and Hannon, op. cit., endnote 22, p. 27.

[175]S. Casler, A. Afrasiabi, and M. McCauley, "Decomposing Change in Energy Input-Output Coefficients," draft, n.d., p. 4.

[176]Data Resources Inc., "Structural Change in the United States: An Historical Analysis," September 1984, p. 32; and S.F. Feldman and K. Palmer, "Structural Change in the United States: Changing Input-Output Coefficients," *Business Economics*, January 1985, pp. 46-47.

[177]U.S. Department of Commerce, Bureau of Economic Analysis, *Survey of Current Business*, July 1989.

[178]U.S. Department of Commerce, Bureau of Economic Analysis, National Income and Product Accounts, table 2.4.

[179]Ibid. table 5.6.

[180]U.S. Department of Commerce, Bureau of Economic Analysis, "The Input-Output Accounts of the U.S. Economy, 1977," *Survey of Current Business*, May 1984, tables B and C, p. 46.

[181]National Income and Product Accounts, op. cit., endnote 178, tables, 3.9, 3.15, and 3.16.

[182]Ibid., table 5.4.

183U.S. Department of Labor, Office of Economic Growth, "Sectoring Plan for Employment and Output Series of Economic Growth and Employment Projections," unpublished, June 1987.

184U.S. Department of Labor, Bureau of Labor Statistics, "Historical Input-Output Time Series Data Base," unpublished, January 1989.

185U.S. Department of Labor, Office of Economic Growth, "Sectoring Plan for Employment and Output Series of Economic Growth and Employment Projections," unpublished, June 1987.

186See Robert Repetto, "Wasting Assets," *Technology Review*, January 1990.

187Carol S. Carson, "GNP: An Overview of Source Data and Estimating Methods," *Survey of Current Business*, July 1987, p. 104.

188P.M. Ritz, "Definitions and Conventions of the 1972 Input-Output Study," U.S. Department of Commerce, Bureau of Economic Analysis, July 1980, p. 28.

189Jack Faucett Associates, Inc., *National Energy Accounts*, JACK-FAU-84-316, Use File Computer Tape, Chevy Chase, MD, December 1984 and November 1989. It should be noted that the National Energy Accounts, which made this analysis possible and are the only public source of energy, use information by each industry of the economy are going to be discontinued. See E. Hirst, "Comparison of EIA Data Collections: Electricity Supply and Demand," mimeo, Energy Division, Oak Ridge National Laboratory, October 1989.

190See Casler, op. cit., endnote 171, app. C for a matching of these 88 industries to the corresponding Bureau of Economic Analysis industries and Standard Industrial Classification codes.

191J.M. Roop, "Energy Implications of Structural Change in the United States Economy," paper delivered to the IEA-Energy Demand Analysis Symposium, Oct. 12-14, 1987, Paris, France, p. 5.

192S. 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, pp. 26-28.

193Ibid., app. B.

194Carol S. Carson, "GNP: An Overview of Source Data and Estimating Methods," *Survey of Current Business*, July 1987, p. 112.

195See Anne Carter, *Structural Change in the American Economy* (Cambridge, MA: Harvard University Press, 1970); Stanley J. Feldman, David McClain, and Karen Palmer, "Sources of Structural Change in the United States, 1963-1978: An Input-Output Perspective," *The Review of Economics and Statistics*, 1987; and Peter D. Blair and Andrew W. Wyckoff, "The Changing Structure of the U.S. Economy: An Input-Output Analysis," *Frontiers of Input-Output Analysis*, Ronald Miller et al. (eds.) (New York, NY: Oxford Press, 1989).

196For example, the divisia method analyzes changes in energy use in relation to changes in output. See G. Boyd, J.F. McDonald, M. Ross, and D.A. Hanson, "Separating the Changing Composition of U.S. Manufacturing Production From Energy Efficiency Improvements: A Divisia Index Approach," *The Energy Journal*, vol. 8, No. 2, 1987, p. 93.

197Miller and Blair, op. cit., endnote 149, p. 222.

198S. Casler and A. Afrasiabi, "Input Composition and the Energy Output Ratio," draft, June 1989.

199See U.S. Congress, Office of Technology Assessment, *Statistical Needs for a Changing U.S. Economy*, OTA-BP-E-58 (Washington, DC: U.S. Government Printing Office, September 1989), p. 7.

200Edward Denison, *Estimates of Productivity Change by Industry* (Washington, DC: The Brookings Institution, 1989), p. 15; Lawrence R. Mishel, "The Late Great Debate on Deindustrialization," *Challenge*, January-February 1989, p. 38; Martin N. Baily and Robert J. Gordon, "The Productivity Slowdown, Measurement Issues, and the Explosion of Computer Power," *Brookings Paper on Economic Activity*, vol. 2, 1988; and Allan H. Young, "BEA's Measurement of Computer Output," *The Survey of Current Business*, July 1989.

201Huntington and Myers, op. cit., endnote 8, p. 7.

202Culter J. Cleveland, Robert Costanza, Charles A.S. Hall, and Robert Kaufman, "Energy and The U.S. Economy: A Biophysical Perspective," *Science*, vol. 225, August 1984, p. 893.

203Researchers have incorporated capital into input-output models, but such efforts rely on capital flows data, which suffers from a very long lag. At this date, the latest capital flows table uses data collected in 1977. For an example of incorporating capital into a model and making a dynamic input-output table, see F. Duchin and D.B. Szyld, "A Dynamic Input-Output Model With Assured Positive Output," *Metroeconomica*, vol. XXXVII, October 1985; and W. Leontief and F. Duchin, "The Impacts of Automation on Employment, 1963-2000," Final Report to the National Science Foundation, contract #PRA-8012844, April 1984, p. 3.1.

204S. Casler. and S. Wilber, "Energy Input-Output Analysis," *Resources and Energy*, No. 6, 1984, p. 146.