Recent Changes in Energy Use

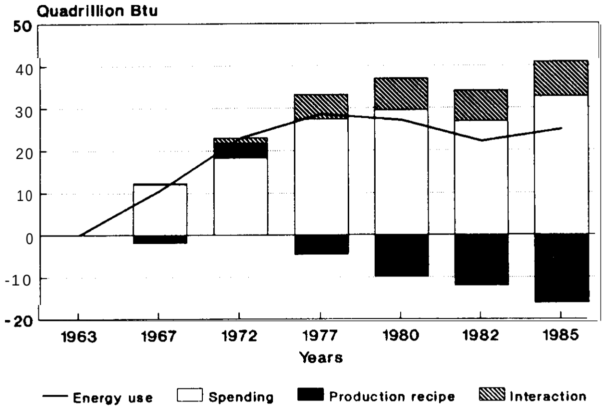
TRACING THE CHANGE IN ENERGY USE

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

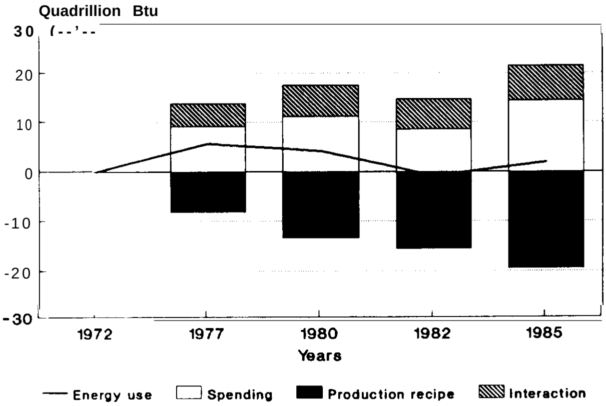


The solid line shows that U.S. energy use increased by nearly 30 quadrillion Btu (quads) from 1963 to 1977 and then declined so that by 1985 energy use had increased by 25 quads from 1963. Spending (and the interaction between spending and production recipe) caused energy use to increase in every year. 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)

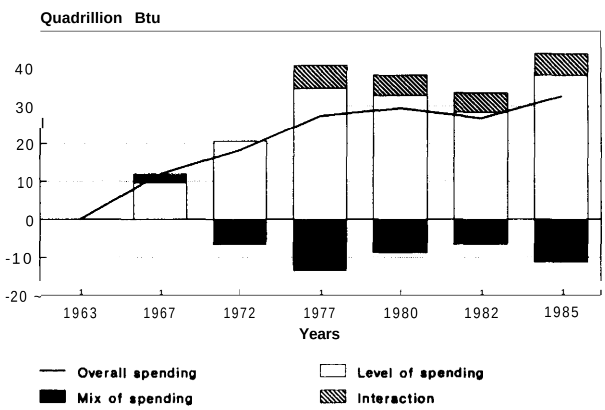
	Level	Mix	Inter-action	Total
Coal	4.6	–2.4	1.5	3.7
Crude oil & gas	11.6	-4.2	0.1	7.4
Refined petroleum	–1.2	–1.9	1.7	–1.3
Primary electricity	2.2	2.4	-0.8	3.9
Utility gas	0.4	0.3	–0.0	0.7
Total	17.7	-5.8	2.5	14.4

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.

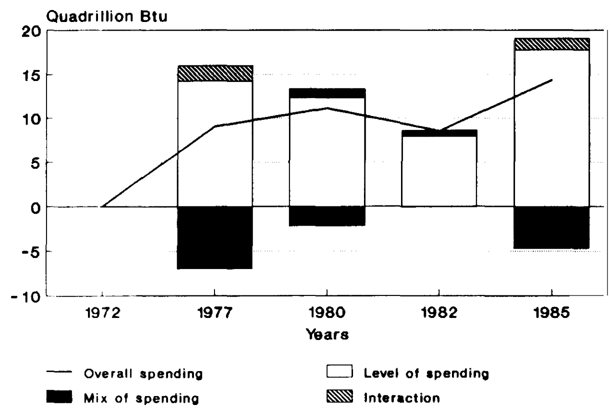
Figure 7-Changes in U.S. Energy Consumption Due to Spending, 1963-85



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.

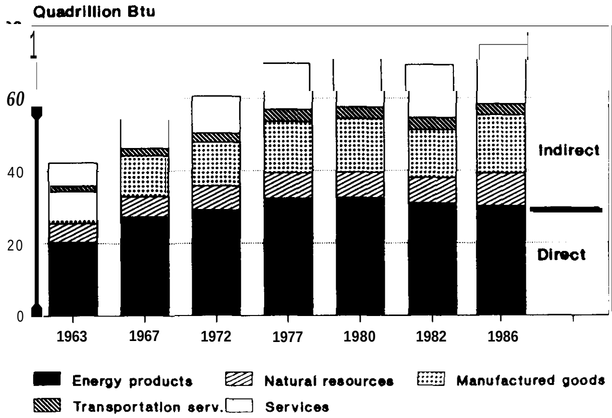
Direct purchases of energy products by final consumers have been constant or falling since 1977 (see figure 9). Only 1.1 quads of the overall 1972-85 total 14.4-quad increase in energy use due to spending came from direct demand for energy products. This would not seem to be small if the share of the 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**

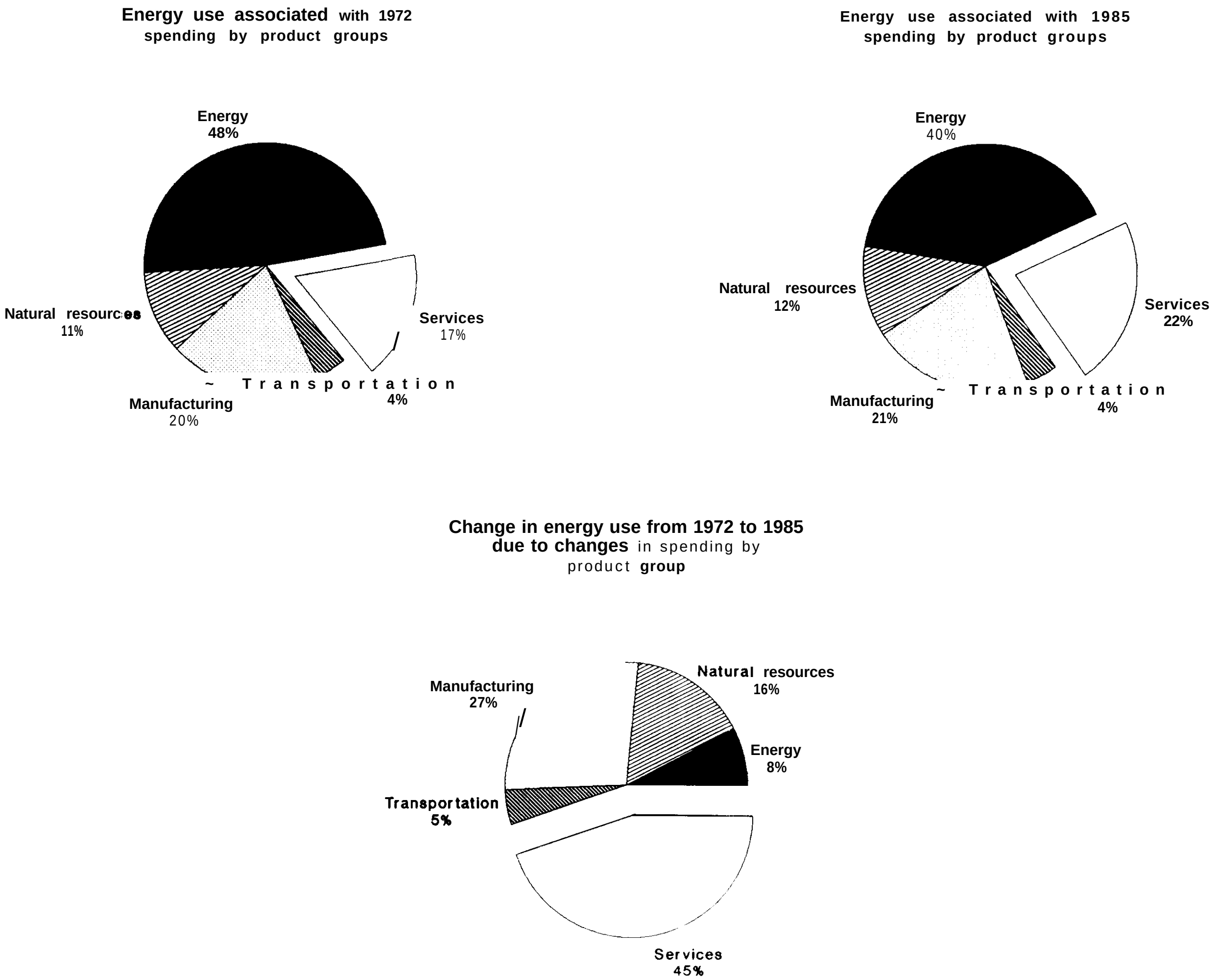
Consumers of final products area heterogeneous group, composed of households, Federal, State, and local governments, businesses,[xvii] and international tcade.[xviii] The overall consumption of a particular product is calculated by summing the expenditures made on that product from each of these sources. 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)

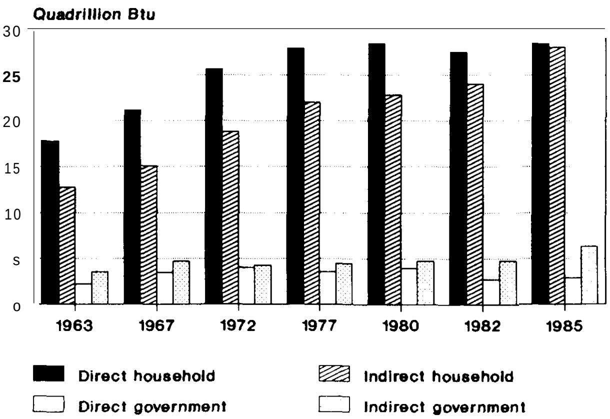
	Energy	Natural resources	Manufacturing	Transportation services	Services	Total
Coal	0.5	0.5	1.0	0.0	1.6	3.7
crude oil & gas	0.5	1.3	1.8	0.5	3.3	7.4
Refined petroleum	-1.6	0.1	0.1	0.0	0.1	–1.3
Primary	1.6	0.3	0.8	0.0	1.1	3.9
utility gas	0.1	0.1	0.2	0.0	0.2	0.7
Total	1.1	2.3	3.9	0.7	6.4	14.4

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]

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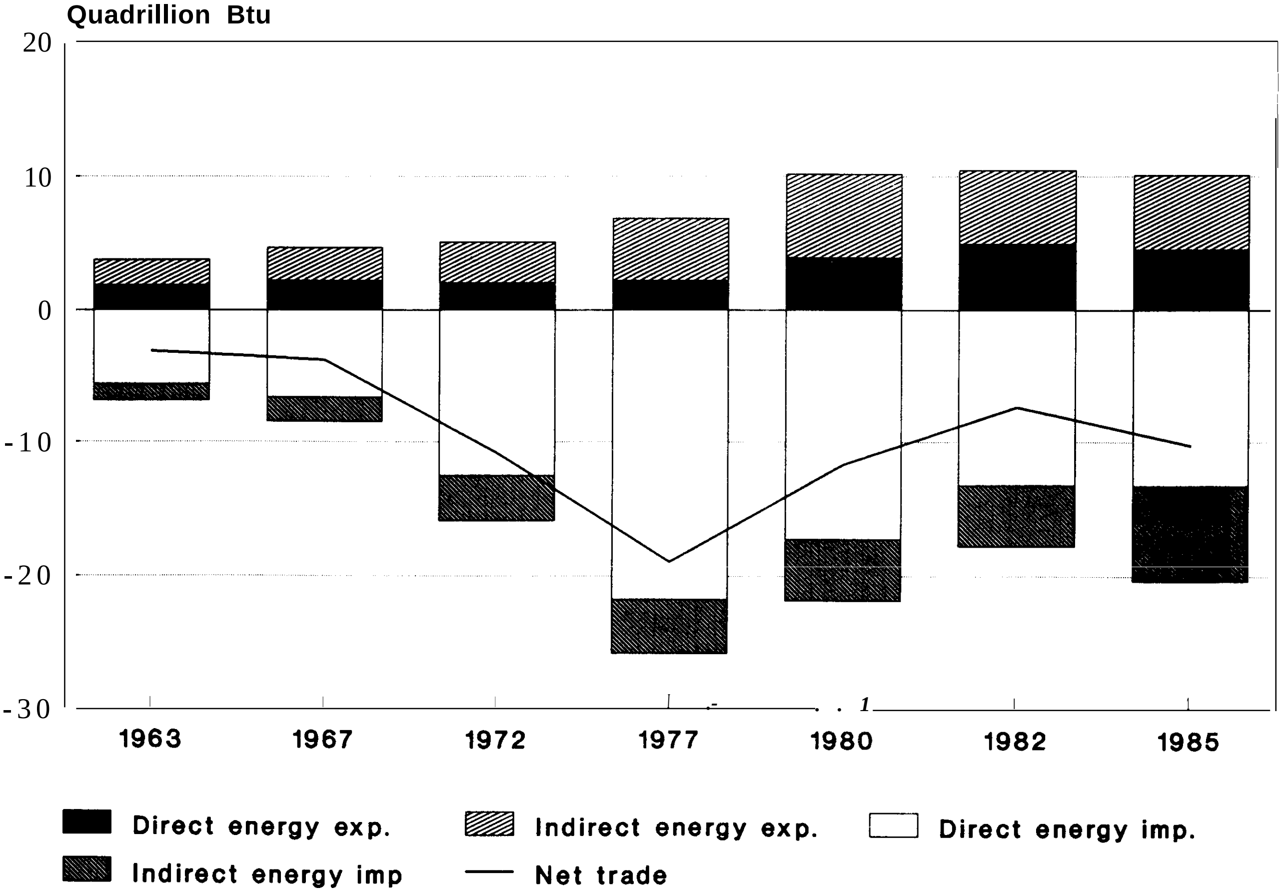
Figure 12—Direct and Indirect Energy Use Associated With Imports and Exports



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.

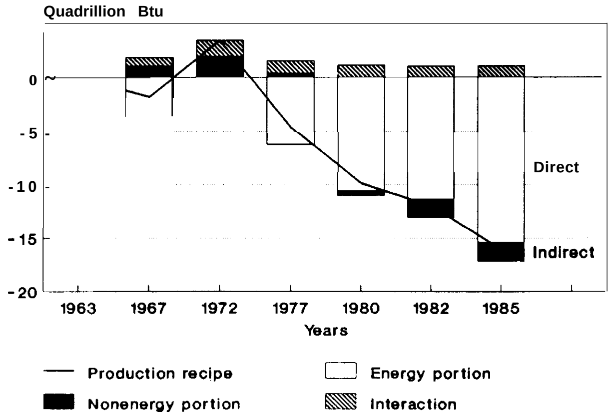
After 1972, the economy's energy efficiency improved dramatically. Changes in the energy portion of the production recipe led to a 15.4-quad drop in energy use from 1972 to 1985 (see figure 14). This change was responsible for over three-quarters of the entire decline due to production recipe changes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

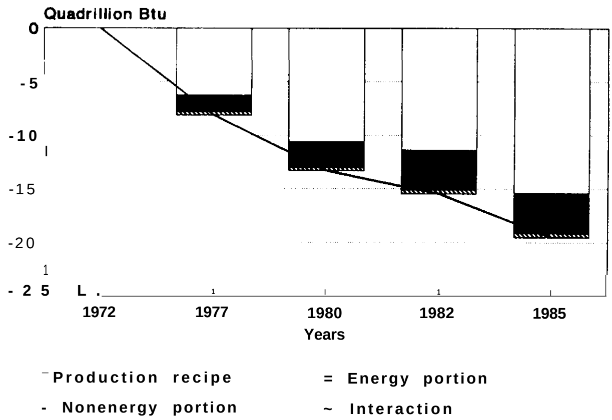
Figure 13-Changes in U.S. Energy Use Due to Changes in Production Recipe, 1963-85



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.[w] 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.

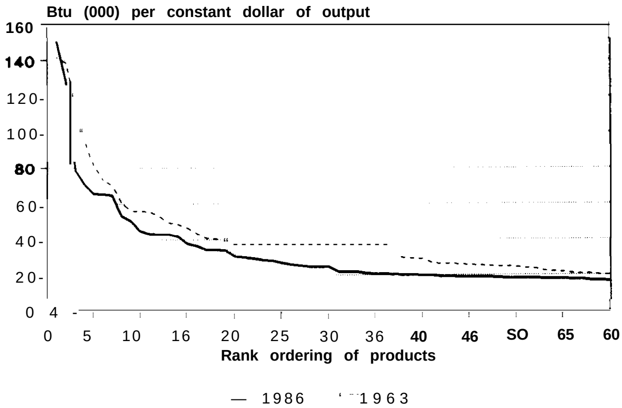
different products roughly compare, what the distribution of energy intensity across products looks like, and where some of the biggest declines in energy intensity have occurred.

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 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-

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.

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]

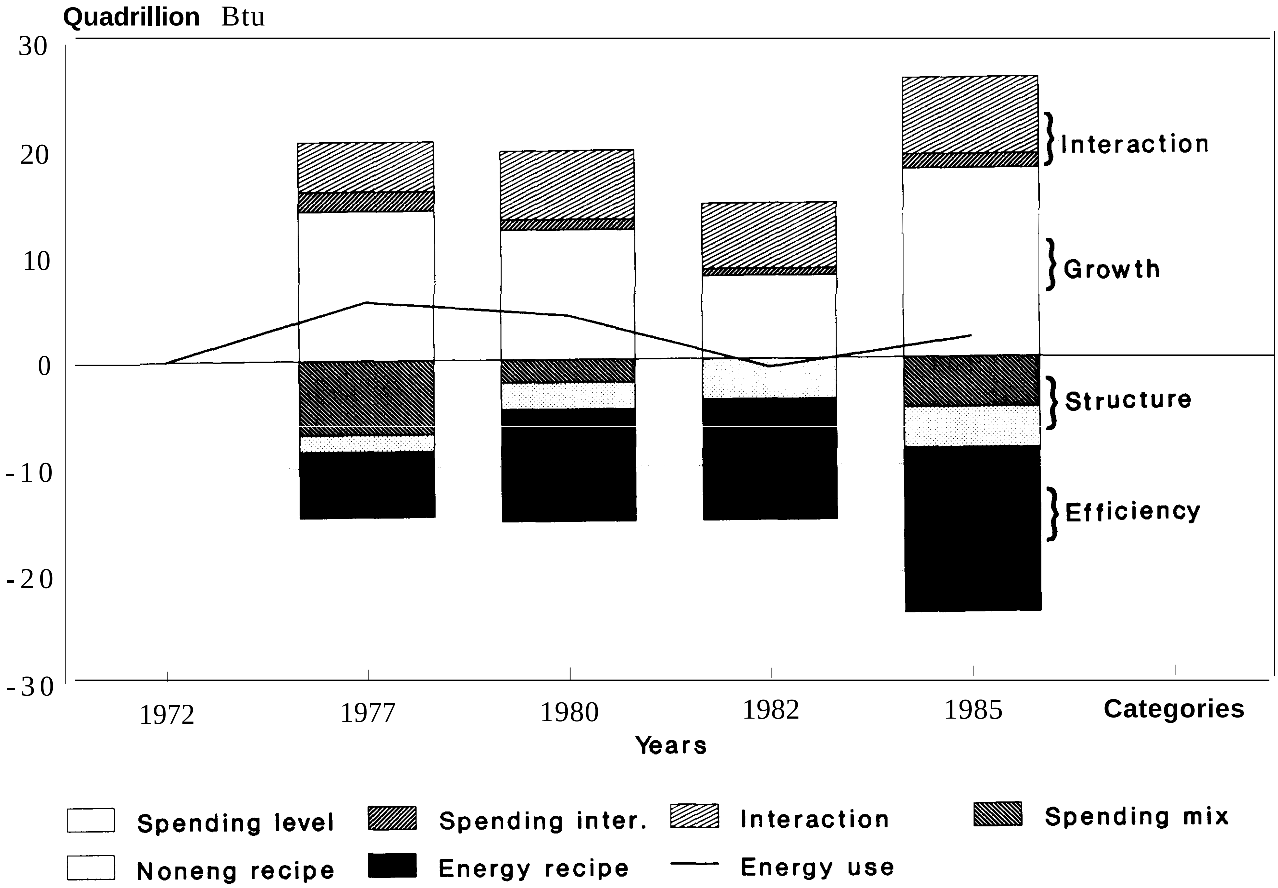
ENDNOTES FOR PART III

[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.

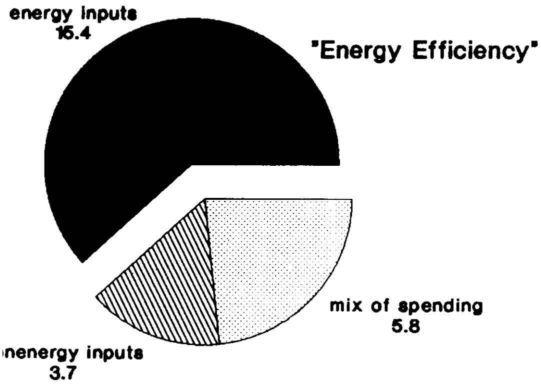
[26]This finding is in agreement with the results reported by Hannon and the Department of Energy. See Hannon (1982), op. cit., footnote 23, p. 266; and U.S. Department of Energy, *Energy's Role in International Trade: Structural Change and Competitiveness*, Office of Policy Planning and Analysis, July 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 Efficiency"
energy inputs
15.4
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