Part V
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, $(I-A)^{-1}$, 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 $(I-A)^{-1}$ 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	1.0000
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

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.

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.

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.[152]

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 adjustment for imported intermediate inputs whose price changes might not be accurately reflected in deflators 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.l[G3] In an effort to address some of these issues, the Bureau of Economic Analysis is revising its constant dollar value-added by industry series,l[a] making it currently unavailable.l[G5]

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,[ii] and there is a delay of 6 to 8 years between the year the data was collected and its release as input-output data.l[fi] 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.l[G7] 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.

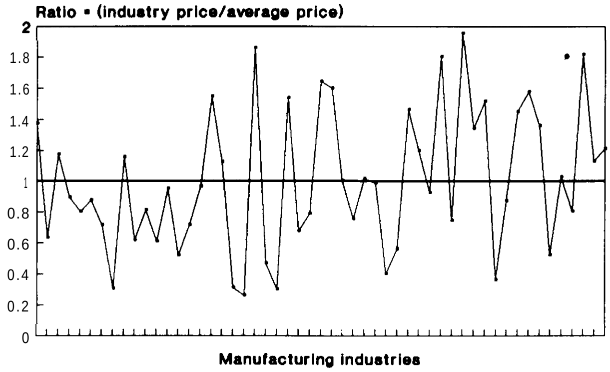
Lastly, the input-output method of analyzing change in energy use does not force the researcher to constantly view energy use as a ratio where it is always entangled with some other variable such as value-added or output.[196] Thus, actual quantities of energy use are reported as opposed to quantities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

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of Economic Growth, "Sectoring Plan for Employment and Output Series of Economic Growth and Employment Projections," unpublished, June 1987.

[184]U.S. Department of Labor, Bureau of Labor Statistics, "Historical Input-Output Time Series Data Base," unpublished, January 1989.

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of Economic Growth, "Sectoring Plan for Employment and Output Series of Economic Growth and Employment Projections," unpublished, June 1987.

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

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

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

[189]Jack 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.

[190]See 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.

[191]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, p. 5.

[192]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, pp. 26-28.

[193]Ibid., app. B.

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

[195]See 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).

[196]For 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.

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

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

[199]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), p. 7.

[200]Edward 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.

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

[202]Culter 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.

[203]Researchers 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.

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