tion programs—invites retaliation and is not fruitful.

3) "Oil deficits" can be offset over the next several years only through compensatory capital flows, *not* on trade account.

4) The "oil surpluses" will constitute about 7 to 10 percent of new debt issuance in the OECD countries and by 1980 might accumulate to 2 to 4 percent of global financial markets (excluding real estate).

These higher prices do entail real transfers of real resources of purchasing power from oil consumers to oil exporters, but the global economy does not appear to be untowardly burdened. The relatively small magnitudes facilitate adjustment. The key question, therefore, is not one of magnitudes, but of whether the surpluses can be rechanneled back to the debtor countries with minimum friction.

International financial markets are both deep enough and deft enough to absorb the volumes of recycled funds that are projected. It remains to be seen whether national governments will foster or impede these adjustments, but it is clear that the adjustment process will be minimally painful for those economies that prove best able to respond quickly.

Notes

1. The new extra oil import bill would have to be subtracted from the pre-October 1973 basic trade balance to estimate the rate at which reserves would actually be drawn down, but the "coverage" figures do illustrate the precariousness of the present situation.

Applications of Input-Output Analysis to Energy Problems

Anne P. Carter

This year there is rising interest in the application of input-output analysis to energy problems. Input-output computations have been used by government and private agencies to assist in forecasting shortages of fuels and other industrial inputs during the oil embargo. They are also being used to assess how various changes in energy technology might affect the economy in the long run. These problems require a detailed systems approach because they involve many interdependent industries and consumers. Studies of new technologies must bridge the gap between technical specifications that call for particular inputs—steel, construction, computers, and instruments—and production and employment in all sectors.

Input-output analysis is the only method now available for dealing with these large-scale multisectoral problems empirically. However, there is a danger that the elegance and convenience of the approach will blind users to its limitations. Input-output analysis does not supply instant economic planning. The U.S. data base is substantial and rapidly improving but still modest as compared with those of countries where the system has been used more in energy and other applications (*1*). Some of the information needed to solve current problems is not yet available. Those who take input-output seriously will continue to emphasize the importance of additional information, judgment, ingenuity, and luck.

In this article I present a brief outline of the U.S. input-output system and data base and discuss two kinds of applications: (i) estimating the impact of this year's petroleum shortages on output, employment, and prices; and (ii) analyzing the long-term economic effects of prospective changes in energy technology. The coverage is illustrative rather than exhaustive. I regret that I cannot discuss the many regional input-output studies now under way.

Framework and Data

An input-output table gives a detailed picture of the flow of goods and services that individual industries buy from and sell to each other in a particular year. Table 1 is a 1958 input-output table for the United States, aggregated to only eight sectors for illustrative purposes. Each horizontal row gives the amounts that a particular industry sold to all sectors, including itself, and to the "final demand" or final users categories: households, government, foreign trade, net inventory change, and gross private capital formation. Transactions are measured in dollars, although they occasionally are measured in physical units (kilowatt-hours, tons, number of automobiles, and so on). The materials industry, for example, sold \$276 million of its output to the mining industry, \$8565 million to itself, and \$3994 million to final demand. Individual vertical columns indicate how much each sector purchased as inputs from other sectors. Column 1 shows that the materials industry purchased \$8565 million of materials, \$1505 million of metalworking products, and \$506 million of agricultural products to produce 1958 output. The next to the bottom row of Table 1 gives the "value added" for each sector, which is the sum of its payment to labor and of its capital charges, profits, direct taxes, and miscellaneous disbursements.

Input-output coefficients are obtained by dividing the entries in a column, which are an industry's inputs, by that industry's output. In other words, coefficients show the amounts that an industry purchased from all other industries and from value added per unit of its own output.

A column of coefficients thus gives a detailed quantitative description of the technique of production used by a sector, a sort of recipe for its output with specifically enumerated inputs as ingredients. Because an input-output coefficient table includes a column of input-output coefficients for every sector, it gives a comprehensive structural description of the entire economy for a particular year.

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Table 1. Eight-sector input-output table for 1958. Each entry gives the volume of sales (in millions of 1947 dollars) by the sector named at left to the sector numbered at top. The sector numbers across the top correspond to the sectors numbered and named in the table. [Source: table 1.1 in (3)]

Sector	Sectors								Final demand	Gross domestic output
	1	2	3	4	5	6	7	8		
1. Materials	8,565	8,069	8,843	3,045	1,124	276	230	3,464	3,994	37,608
2. Metalworking	1,505	6,996	6,895	3,530	3,383	365	219	2,946	19,269	45,100
3. Construction	98	39	5	429	5,694	7	376	327	39,348	46,322
4. Transportation equipment and utilities	999	1,048	120	9,143	4,460	228	210	2,226	22,625	41,059
5. Services and transportation	4,373	4,488	8,325	2,729	29,671	1,733	5,757	14,756	137,571	209,404
6. Mining	2,150	36	640	1,234	165	821	90	6,717	− 653	11,199
7. Agriculture and so forth	506	7	180		2,352		18,091	26,529	8,327	55,992
8. All other	5,315	1,895	2,993	1,071	13,941	434	6,096	46,338	82,996	161,080
Value added	14,097	22,522	18,320	19,877	148,614	7,344	24,923	57,777		313,475
Total inputs	37,608	45,100	46,322	41,059	209,404	11,199	55,992	161,080	313,475	921,240

Input-output coefficients are used to form a system of linear equations connecting the outputs of all industries. Each equation gives the output, X_i, of a given sector i as the sum of the sector's sales to all other sectors and to final demand, Y_i.

$$X_i - \sum_j a_{ij} X_j = Y_i \qquad (1)$$

where a_{ij} is the input coefficient that tells requirements of the product of sector i per unit of output of sector j. The system has as many equations as there are industries.

From this system of equations we can compute the effects of any particular change in final demand on the outputs of all sectors—the effect, for instance, of a reduction in automobile purchases by consumers on the outputs of the automobile, steel, plastics, coal, and insurance sectors. Alternatively, we can compute the effects of any particular changes in coefficients on all outputs. Other sets of variables such as labor inputs can be added to the equations.

Input-output tables at 83- and 375-sector detail are constructed as a regular part of the U.S. national accounts. The most recent table, for 1967, has just been completed, and the Bureau of Economic Analysis of the Department of Commerce is now committed to a regular program of updating the 83-sector table annually. Auxiliary information on labor coefficients (man-years per dollar of output of each sector, by job category), capital coefficients (stocks of investment goods in dollars per dollar per year of capacity), and special purpose data such as pollution emissions and abatement coefficients are beginning to be assembled by other agencies to match the Department of Commerce categories. These permit us to tie employment, pollution, and so forth into the equations of the input-output system. For energy studies, coefficients for coal, natural gas, electricity, and petroleum in British thermal units have been published for 375 sectors by the University of Illinois Center for Advanced Computation (2). More recently, the Bureau of Economic Analysis has broken down the data in the petroleum row of the 83-sector input-output table so as to distinguish jet fuel, gasoline, distillate fuel oil, residual fuel oil, and other petroleum products.

The success of a particular application hinges on whether the coefficients are realistic, or realistic enough for the purpose. Users often complain that U.S. input-output coefficients are, at best, "7 years old." For the most part, however, input-output coefficients change gradually (3), and those willing to make the necessary effort (4) can generally update the coefficients satisfactorily on the basis of engineering data or published statistics. When supplies of some inputs are sharply curtailed, as seemed possible in the present "crisis," it becomes more difficult to estimate coefficient changes as precisely as the situation demands.

Unemployment from the Oil Embargo

Understandably, projections of unemployment due to the oil shortage have attracted more attention than the other energy-oriented input-output studies. Because these projections lean heavily on guesses about the size and management of the shortage, they are highly speculative. Estimates of the prospective impact of the energy shortage on this year's industrial output and employment have ranged from my own gloomy view that unemployment might be raised by anywhere from 3 to 8 percent to Clopper Almon's optimism that effects on employment would be negligible (5). The Bureau of Economic Analysis estimated that the effect on gross national product would be less than 1 percent. Differences arose primarily from different assumptions about the size of the shortfall and allowances for industrial adaptations within the basic input-output system.

The impact of the oil embargo depends, first of all, on the size of the overall petroleum deficit. After months of debate and measures to augment and clarify available information, there is still no convergence of government estimates, nor is it clear by how much lifting of the embargo will change supplies of refined petroleum, given limits on domestic refining capacity and exportable refined products abroad. Second, any attempt to appraise the impact of the shortage must take account of petroleum-saving measures that will change the coefficients in individual industrial and final sectors and also take account of limits on supplies of or conversion to other fuels. Particularly if the shortfall is large, the specific approach that the government takes to managing the allocation of scarce energy supplies could also be crucial.

Petroleum Coefficients and the Energy Shortage

Taken literally, input-output coefficients set requirements for each specified input as a fixed proportion of output. Under such a strict interpretation, a 10 percent reduction in petroleum products available to a given sector would entail a 10 percent reduction in its output; in general, the curtailment of supply to each sector would reduce output proportionately. This interpretation is unrealistic for energy coefficients today. For a long time, energy prices have been so low that there was little incentive to trim waste. Now that energy is scarce and expensive, firms and final users are finding ways to reduce their consumption without necessarily curtailing their levels of operation. Coefficients used in input-output computations should be reduced accordingly.

Generally there is more opportunity to trim consumption of energy for space heating and lighting than for process uses. Judgment is still required to translate the savings into input coefficients. Statistics for energy use are not subdivided into space heating, lighting, and process uses for detailed industrial sectors, nor is it easy to anticipate the felicitous reductions in process requirements that engineers can sometimes make when they set their minds to it. However sophisticated, economic analysis alone cannot produce realistic estimates of energy-saving adaptations in industry because there is no relevant historical experience on which to base them. In our computations at Brandeis University (*6*), my colleagues and I assumed that savings of 15 percent in energy from all sources could be made in service industries (such as finance and insurance, business services, and hotels) and that savings of 2 percent were possible in other industries. Subsequent experience has shown these allowances to be conservative.

While coal, oil, natural gas, and electricity are supplied by different sectors in the input-output table, some of them are interchangeable in particular industrial uses. In some sectors such as food processing, electric utilities, and pulping mills, the same process functions are performed alternatively by oil, natural gas, and, to some extent, coal or electricity. Depending on historical and geographical circumstances, individual plants with similar outputs are at present committed to different energy sources. The effects of petroleum shortages on a sector's performance will be mitigated in situations in which other fuels contribute a substantial proportion of sectoral energy requirements. The University of Illinois energy coefficients indicate that the food sector gets 41 percent of its energy from natural gas and 28 percent from oil. In estimating the food industry's response to the oil embargo, we assumed that a 10 percent reduction in the industry's consumption of petroleum products would result in at most a 2.8 percent shortfall in its energy requirements. In effect, in cases in which different forms of energy are used interchangeably, we can combine their coefficients. Decisions about which energy coefficients to combine have been based on some consultation with specialists, but they still involve much guesswork.

The availability of alternative forms of energy also affects petroleum requirements. If coal or natural gas supplies were unlimited, electric utilities could switch fuels and liberate petroleum for use in internal combustion engines. However, this year's natural gas supplies are short, and significant switching to coal is delayed because of time lags in stepping up coal mining, shortages in coal transport capacity, and pollution regulations requiring low-sulfur fuels. Information on lags, substitutions, and other adaptations is not part of the input-output or any other economy-wide data system. Still, these factors must be dealt with in any realistic analysis. It is easy to modify the analytical framework to incorporate these factors, but it is not easy to assemble the factual basis for doing so.

Problems in Allocating Scarce Petroleum

A few months ago the fuel shortage loomed larger than it does now, and the President announced the following guidelines for mandatory cutbacks in petroleum consumption by industry:

Space heating, commercial and industrial users	25 percent
Industrial process use	10 percent
Utilities	10 percent
Transportation other than air and private auto	10 percent

Proportional across-the-board cutbacks for broad groups of sectors are politically feasible because they seem objective and fair. If petroleum input coefficients were truly fixed, a given percentage of reduction in petroleum would reduce each sector's output by the same proportion; across-the-board cutbacks would simply scale down all production and final deliveries proportionally. At the time the cutbacks were announced, the administration was counting on industry to trim consumption without seriously reducing output.

Actually, however, a petroleum cutback of a given percentage is likely to curtail production of some sectors more than that of others because some rely on alternative energy sources or can effect energy savings more readily than others. A multiregional input-output system would be required to take geographical differences in fuel supplies into account. Even when petroleum deliveries to all sectors and regions are reduced uniformly, output reductions may in fact be far from uniform. Thus, the danger of secondary shortages was substantial, and some did materialize.

If a set of guesses is made about fuel savings and substitutions in individual sectors, input-output computations can uncover potential bottlenecks in any particular allocation scheme. According to our computations, dangers of unemployment due to secondary shortages would have been smaller if, instead of proportional cutbacks, more petroleum had been allocated to transportation, mining, and chemicals and less to construction and some manufacturing sectors. However, it would be politically difficult to implement a program that seems to "discriminate" among firms in different sectors. Furthermore, the proposed changes in energy coefficients were rough estimates, and hence the computed allocation would have been difficult to defend under pressure. Finally, even a very detailed input-output model cannot pinpoint shortages of all specialized products.

As luck would have it, the wisdom of the Administration's allocation scheme was never put to the test. A mild winter, a leaky embargo, and mysterious inventory cushions kept the shortage to manageable proportions. In addition, consumer demand for automobiles fell in response to the gasoline shortage, and this led to decreases in the outputs of many of the industry's supplying sectors. Those, in turn, automatically reduced industrial demand for fuels. The amount of petroleum released by the 30 percent reduction in automobile purchases and a 25 percent reduction in consumer purchases of travel services was close to the amount that mandatory cutbacks would have saved under the 25 November guidelines in the absence of reductions in consumer spending.

It is difficult to plan a precisely balanced allocation of fuels, and local decisions and the price system must continue to play an important role. However, government can relieve pressure on existing supplies by deliberately postponing some of its own energy-intensive purchases. Input-output computations can gauge the approximate fuel saving and employment consequences of such policies.

Figure 1 shows the total (direct and indirect) energy and labor requirements of selected types of final goods. Reducing spending on construction—for example, state and local road construction—would accomplish a given energy saving with less unemployment than would reduction in government purchases of services or computers by the same dollar amount. Reducing (or postponing) road construction would cut the demand for energy-intensive materials such as steel and cement and thus lessen the energy needs of the materials sectors.

Another important aspect of the allocation problem lies in deciding the relative amounts of gasoline, jet fuel, heating oils, and other petroleum products to be derived from a given stream of crude oil. The Department of Commerce uses input-output coefficients representing each sector's dependence on specific petroleum fractions. Their system provides estimates of the adequacy of specific petroleum products for industrial requirements.

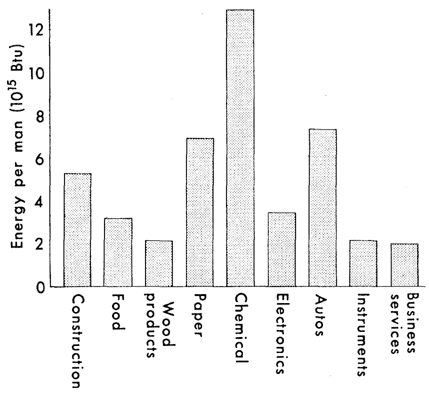

Fig. 1. Total energy-to-labor content ratios; 1 Btu = 1.06×10^3 joules.

Effects of Rising Fuel Costs on Industrial and Consumer Prices

The Commerce Department also uses input-output analyses to estimate the effects of rising petroleum costs on industrial and consumer prices. Their estimates are not published, but my computations illustrate the logic of their procedures.

The same set of input-output coefficients a_{ij} used in Eq. 1 also form a system of equations interrelating prices in all industries. Each equation in the price system states that the costs of all inputs to a sector, including value added, must sum to its price, P_j. For each industry,

$$P_j - \sum_i a_{ji} P_i = v_j \qquad (2)$$

where $a_{ji}P_i$ is the cost of input i per unit of output of j, and v_j is value added per unit of output in sector j.

The computed effects of a 100 percent tax on petroleum products (or an equivalent increase in oil industry profits) on all industrial prices are shown in Fig. 2. The second bar of each pair depicts the price effects of a 100 percent tax on all fossil fuels. Prices were computed for all 83 sectors and then aggregated into groups. Roughly speaking, a 100 percent increase in fuel costs would add at least 8 percent to the present rate of inflation. The impact on industrial prices would range from a 14 percent increase in the chemicals industry, which is very energy-intensive, to less than 2 percent for tobacco manufacturing and some of the service sectors. As might be expected, prices of construction and manufactured products would rise more than those of service sectors, which require relatively less energy and more labor. For many years, saving labor has been the key to successful enterprise in the American economy. These price changes may well shift some of the focus to saving energy.

The computed effects of energy-induced price increases on the cost of living of four income groups are shown in Fig. 3. The impacts are regressive:

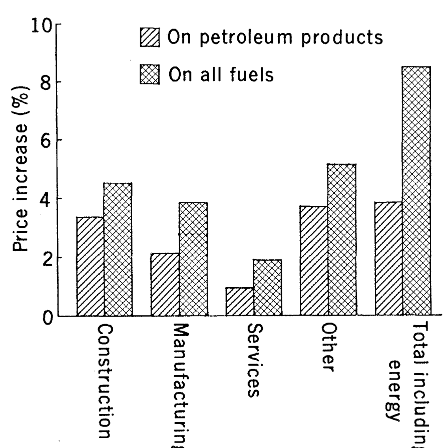

Fig. 2. Price increases due to 100 percent taxes on fuels.

energy-intensive products, those whose prices increase most, comprise a larger proportion of the budgets of lower- than of higher-income families. With the tax on petroleum alone, the cost of living increases 4 percent for the highest income group (more than $20,000 per year) and 6 percent for the lowest income group; with taxes on all energy, the cost of living increase ranges from 7 percent for the highest income group to 12 percent for the lowest.

As in the case of output and employment computations, input-output price computations can be misleading unless they take into account the changes in coefficients and in value added which are likely to accompany the energy shortages. If energy scarcity and rising prices curtail energy consumption, inflationary pressures will be lessened. Substitution of cheaper for more expensive fuels could have similar effects. None of the above-mentioned effects on energy coefficients were taken into account in the price computations presented here. However, all energy prices are rising simultaneously; therefore, allowances for fuel switching would not have a large effect on computed prices.

New Technologies and Economic Growth

Some of the most promising applications of input-output analysis to energy problems concern the long-term economic impact of introducing major new energy technologies over the next 10 or 15 years. Here we can work with rough approximations, and the standards of accuracy for coefficients are less demanding than for short-term analysis. Still, assembling data is the most demanding task. Translating engineering details on individual processes into input-output industrial categories is far from simple, particularly for technologies that have barely been tested. It must be done through persistent interdisciplinary dialogue. On the basis of consultation with individuals from the Atomic Energy Commission, the Federal Power Commission, the Department of Commerce, and Bechtel, Inc., Istvan (7) has estimated sets of input-output coefficients distinguishing between current- and capital-account requirements to represent the electric utility industry of the early 1980's. In his analysis the industry consists of seven subsectors: conventional fossil fuel generation, nuclear generation, diesel and gas turbine generation, hydropower, transmission, distribution, and administration. Requirements for each subsector are represented by a column of coefficients that incorporate expected changes in technology such as pollution abatement equipment, extrahigh voltage transmission, underground distribution, and so forth. Because such a large proportion of electric power costs are for plant and equipment, Istvan specifies a full set of "capital coefficients" measuring the stocks of capital goods—boilers, transformers, buildings, and so forth—originating in each sector which are required per unit of output of each of the seven activities. Construction lags for increasing electric capacity are long, and they vary for different processes and components. He estimates the time sequences for installing each type of capital goods in each subsector. This information is combined in a dynamic input-output model (*8*) that simulates the time path of utility investment requirements and outputs of all sectors by assuming different rates of growth in power consumption. Just (*9*) has estimated input-output coefficients, also on capital and current accounts, for more speculative technologies: two processes of coal gasification and the gas turbine topping cycle. In another context, Ayres and Gutmanis (*10*) project changes in energy consumption coefficients across many industries.

A number of agencies concerned with the development of new technologies are considering the use of input-output analysis in technological assessment. In the coming decades, new energy technologies will require substantially greater stocks of capital goods per unit of output than do the techniques they might supersede. In any year, higher per unit investment requirements for energy must be met at the expense of lower current consumption or a smaller rate of economic growth.

Some fear that these costly techniques will impose too great a drain on the economy's resources. My calculations in this area deal with expected changes in electricity-generating technology, including pollution controls, into the 1980's and rough estimates of requirements for coal gasification. Requirements for specific industries and the growth potential of the economy were computed for a few scenarios. Switching to these new technologies would have only a moderate effect on the economy's growth potential provided that energy consumption coefficients for industries and the proportion of household budgets allocated to energy remain at their present levels. However, past trends show energy consumption coefficients rising at an average rate of 3 percent per year. The combined effects of increasing energy consumption coefficients and the more costly new energy technologies would place a strong drag on the economy. On the other hand, a persistent economic growth rate of 3 to 4 percent could be maintained with a moderate reduction in the proportion of current output consumed. Whether the present rate of economic growth should be maintained is a different issue.

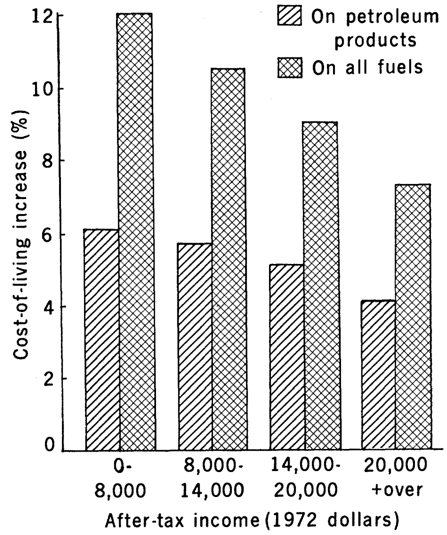

Fig. 3. Increases in cost of living due to energy taxes by income class.

Since economic growth is very sensitive to changes in final consumption, it is essential that long-range technological assessment in an input-output framework be combined with analysis and projection of future consumption patterns. Hannon and others at the University of Illinois (*11*) have measured important consumer options such as shifts from auto to bus transportation, changing kitchen design, and recycling bottles in terms of input-output categories. Their results suggest that such changes may be as important as industrial changes in shaping the course of future economic development.

A Global Input-Output Model

Despite our national program for energy self-sufficiency, global energy problems cannot be ignored. Certainly the most comprehensive of the recent input-output studies in the energy field is Wassily Leontief's worldwide input-output model. Its scope includes agriculture and other resources. The work is still at an early stage, but his system will eventually include input-output tables of 40 sectors for 15 regions of the world. Requirements for energy from various sources will be computed and considered in relation to estimated reserves accessible at various extraction costs. Given the problems of a national study, the demands of a world model may seem overwhelming. But Leontief's optimism has proved justified many times before. We should be learning a lot in the next few years (*12*).

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