The 1973 Nobel Prize for Economic Science

For over two decades, Wassily W. Leontief, Henry Lee Professor of Economics at Harvard University, has been recognized as having made major advances in economic analysis and technique through his development of the input-output method. It was almost predictable then that his name would be added to the distinguished ranks of the Nobel laureates in economic science.

The awarding of this year's Nobel Prize to Leontief represents a recognition of the importance of the rigorous empirical implementation of economic theory. Whereas last year's recipients, Sir John Hicks and Kenneth J. Arrow, were cited for their theoretical advancements in the area of general equilibrium, Leontief's contributions have largely consisted of translating that theory into practice, as well as further developing it. His input-output system represents the empirical approximation of the interdependencies of all behaving units in the economy as set forth in general equilibrium theory.

Leontief's academic career began at an early age. Born in Leningrad in 1906, he began his studies at the University of Leningrad at the age of 15 and, by the time he was 22, had received his Ph.D. from the University of Berlin. In 1929 he was appointed economic adviser to the Chinese government at Nanking and in 1931 became a research associate of the National Bureau of Economic Research in New York. In the same year he joined the faculty of Harvard, where he has been professor of economics since 1946. During World War II, Leontief was chief of the Russian Economic Subdivision for the Office of Strategic Services. He organized the Harvard Economic Research Project in 1948 and since then has served as its director.

Leontief's ideas on the workings of the economy, later to be developed into input-output analysis, were clearly starting to emerge as early as 1925, when he wrote "Die Bilanz der Russischen Volkswirtschaft–Eine methodologische Untersuchung" (*1*). However it was not until the 1930's that they were rigorously formulated; and then they were resisted for many years. It was not until W. Duane Evans and Marvin Hoffenberg at the Bureau of Labor Statistics joined forces with Leontief during the World War II years and subsequently, in developing detailed input-output tables for the United States, that the technique became recognized as having a solid base and a tremendous potential for application.

Long a critic of abstract economic theory and modeling, in and of itself, Leontief has always stressed the importance of theory buttressed with economic observation and measurement. This emphasis on the empirical explains his strong drive for gathering and analyzing data in attempts to understand the workings of the economy. Leontief is also well known for his high standards of academic inquiry and for the extreme rigor of his criticism of the work of students and colleagues. When the first author presented to him ideas for the development of an interregional input-output model, accompanied by the outline of a table, his response was, "Where are the numbers?" He believes that model-building is at best half the job; only after empirical implementation and testing can work be considered completed.

Although adhering to the strictest tenets of scientific investigation, Leontief has been a leader among economists in attacking important social problems. He has given much time and thought to the economic problems of disarmament. He was also among the first to recognize the need to attack our current environmental problems, and to direct research efforts into that area.

Leontief's work picks up on ideas first set forth by the 18th-century economist François Quesnay, who attempted, in his *Tableau Économique* (*2*), to show the interrelations of a simple three-sector economy. The basics of the input-output model, which Leontief developed for an economy consisting of many sectors, can be presented in several ways. One way is to view the output X_i of any sector i $(i = 1, \ldots, n)$ as a pie to be sliced up. For example, if sector i is the coal mining industry, coal is then to be allocated to the intermediate demand of every sector j $(j = 1, \ldots, n)$ which uses coal as input into its production, as well as to final demand, Y_i, which covers: (i) the demand for coal by household consumers and government; (ii) the requirements for exports and for effecting investment in new plant and equipment; and (iii) the addition to or depletion of inventories. Letting x_{ij} represent the allocation (or deliveries) of this output to every sector j (including sector i which may need to consume some of its own product), we have

$$X_i - x_{i1} - \ldots - x_{ii} - x_{ij} - \ldots - x_{in} = Y_i \qquad i = 1, \ldots, n$$

We thus obtain the system

$$\begin{array}{rcccl} X_1 - x_{11} - x_{12} - \ldots - x_{1j} - \ldots & & - x_{1n} & = & Y_1 \\ -x_{21} + X_2 - x_{22} - \ldots - x_{2j} - \ldots & & - x_{2n} & = & Y_2 \\ \vdots \qquad\qquad \vdots & & \vdots & & \vdots \\ -x_{n1} \qquad - x_{n2} - \ldots - x_{nj} - \ldots & & + X_n - x_{nn} & = & Y_n \end{array} \qquad (1)$$

in which we have many more unknowns than equations. To solve this system, input-output method makes the basic assumption of constant production coefficients. By surveying, for example for this year, an economic sector j, say steel, operating under normal circumstances, we are able to obtain data on its total output and total input of coal (produced by sector i) and to observe that it requires say 0.67 tons of coal per ton of output. We then may reasonably assume that in the next year the steel sector, whose output X_j is unknown, will still require 0.67 tons of coal per ton of output. Thus for next year, we may state deliveries of coal to the steel sector, or x_{ij}, to be $0.67X_j$; or designating the number 0.67 by a_{ij}, we have $x_{ij} = a_{ij}X_j$, where a_{ij} is termed a constant production coefficient. By similar reasoning we eliminate all the x_{ij}'s in Eqs. 1 to obtain

$$\begin{array}{rcccl} (1 - a_{11})X_1 \qquad - a_{12}X_2 - \ldots - a_{1j}X_j - \ldots & & - a_{1n}X_n & = & Y_1 \\ -a_{21}X_1 + (1 - a_{22})X_2 - \ldots - a_{2j}X_j - \ldots & & - a_{2n}X_n & = & Y_2 \\ \vdots \qquad\qquad & & \vdots & & \vdots \\ -a_{n1}X_1 \qquad - a_{n2}X_2 - \ldots - a_{nj}X_j - \ldots & & + (1 - a_{nn})X_n & = & Y_n \end{array} \qquad (2)$$

Or using vector and matrix notation

$$(I-a)X=Y$$

where X and Y are $(n \times 1)$ column vectors, I is an $(n \times n)$ identity matrix, and a is the $(n \times n)$ constant production coefficients matrix

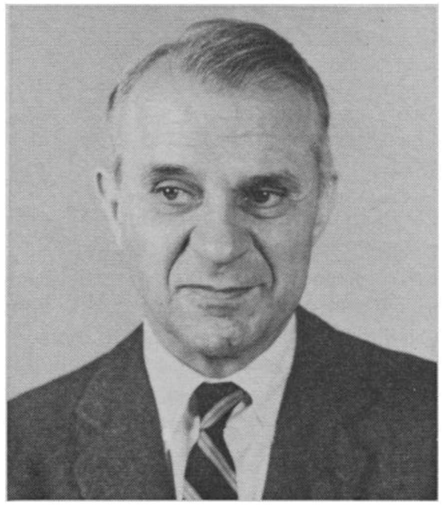
$$a=\begin{bmatrix} a_{11}, \ldots, a_{1n} \\ \cdot \quad\quad \cdot \\ \vdots \quad\quad \vdots \\ \cdot \quad\quad \cdot \\ a_{n1}, \ldots, a_{nn} \end{bmatrix} \tag{3}$$

With the use of the inverse matrix $A \equiv (I-a)^{-1}$, and given the conditions under which a meaningful economy normally operates, we obtain the solution

$$X=AY \tag{4}$$

Equations 4 thus project (forecast) the output of any sector, whether it be agriculture, textiles, chemicals, or housing, on the basis of the given final demand vector Y. If any component of this vector changes, say the final demand for steel, Y_j, increases, the consequences for the output of every economic sector, including steel, are given by Eqs. 4. Aside from the direct requirement for more steel which requires an expansion of the steel industry, the inverse matrix A captures the numerous indirect effects. All industries which supply inputs directly to steel must also expand as steel expands, thus yielding a first round of indirect effects. But the expansions of these industries mean more inputs into their operations, producing a second round of indirect effects. And so forth. After a number of rounds, these indirect effects on each industry, for a properly constructed a matrix, converge to zero. The summation of the direct effect and all the round-by-round indirect effects is what is embodied in the use of the inverse matrix A.

Given high-speed computers, the usefulness of such a system in economic planning is tremendous. For example, consider a nation or region with very limited capital resources that is in the process of development. This region or nation needs to examine the impact of alternative development projects—say a food products plant, a textile operation, or tourist facilities. By employing the input-output framework with additional studies relating to import requirements, it can approximate (depending on the adequacy of its existing and "borrowed" data base) the expansions in output, employment, and new income generated in each of the various sectors.



Wassily W. Leontief

The input-output method is also very useful for highly industrialized nations like the United States. In the early 1960's, when there was great concern over the unemployment that might be generated by reductions in military expenditures, Leontief (with his associate Hoffenberg) examined the impact of cuts in these expenditures, when they were coupled with offset programs. The projected effects on different sectors of the economy were quite different and also varied from one offset program to another. For example, if the offset program were primarily economic aid to underdeveloped countries, and if there were a \$1 billion cut in military purchases, roughly 16,500 jobs might be lost in the aircraft and aircraft-parts sector, while some 4,200 might be gained in textiles. Over all business sectors, there might be an increase of 11,600 jobs, which, however, would be more than offset by release of uniformed and civilian personnel directly employed by the Department of Defense (*3*).

The input-output method has also had important applications in regional analyses, through the development of many kinds of regional and multiregional models. One of these models, the pure interregional model, can be directly derived from Eqs. 3 and 4 by making explicit a set of regions $J,K=A, \ldots, U$, and by redefining X and Y as $(Un \times 1)$ column vectors with respective components X_i^J and Y_i^J, I as an $(Un \times Un)$ identity matrix, and a as an $(Un \times Un)$ constant production coefficients matrix where the coefficient a_{ij}^{JK} represents the output of sector i in region J required per unit output of sector j in region K $(i,j=1, \ldots, n)$.

By the disaggregation of the national economy into a set of interdependent regional economies, the impact of any change in final demand, such as in military expenditures, can be traced out upon each sector not only of the national economy but also of each of its regions. Also, input-output analysis has become a very useful tool in metropolitan planning, where planning agencies and political leaders are increasingly required to estimate the likely impacts of the construction of different facilities or of contractions of different industries.

Finally, an extremely important application of input-output analysis, again anticipated by Leontief (*4*), is in the management of the environment of the world and its diverse regions and nations. This application involves an extension of the set of coefficients so as to associate with the unit of output of each economic sector the amount of different pollutants generated—air pollutants (such as SO_2 and particulates), water pollutants (such as biological oxygen demand), solid wastes, noise, and so forth. Imagine that we build up a set of such coefficients, covering say 60 different kinds of pollutants, so that we have a pollution coefficients matrix p $(60 \times n)$ (*5*). Then for any solution X we can calculate a (60×1) column vector $P=pX$ listing the total amount of each of the 60 pollutants generated by the system. Of course, the set of economic activities must be extended to cover treatment (depollution) activities so that the P vector would represent *net* rather than *gross* pollution generated. Several ways to effect this extension are currently being explored.

Although the practical applications of input-output analysis have mushroomed over the years, the model continues to receive criticism on several important counts. Many have questioned the validity of the input-output model's basic assumption of constant production coefficients. While for small changes in output, the assumption may be valid, in cases where output changes are large, such as a 10 percent cut in military expenditures or the introduction of a new industry into a developing economy, change may well occur in the proportions of inputs used. Or when tables are expressed in terms of cents-requirements of inputs per dollar of output, rather than in physical requirements, changes in the relative prices of inputs may lead to substitution of inputs, the less expensive tending to replace the more expensive.

Further, because each sector in the model is an aggregation of many individual firms, the coefficients derived for any one sector represent an average over the production operations of firms which may differ greatly in size, efficiency of operations, and other factors. Thus the constant production coefficients may lead to inaccuracies when changes in final demand affect firms differently, as is often the case. In addition, because changes in technology are inevitable for the future, the use of constant base-year production coefficients for projections can also lead to major errors.

Moreover, in its nondynamic form the input-output model assumes the existence of unused capacity and resources, to allow for expansions when required. But often the sectors of a system may already be operating at capacity. In more recent and sophisticated models, however, capacity-building activities are being successfully introduced to help overcome this shortcoming.

An additional point concerns the applicability of input-output analysis for developing regions where little, if any, basis exists for collecting, processing, and borrowing data. How can the input-output method be used without the appropriate empirical base?

This incomplete list of criticisms, as well as others, can only be tempered by a recognition of what input-output analysis has accomplished, despite its shortcomings, and by a caveat as to how the model must be properly employed. First, we note that if nothing else, the input-output framework has been a tremendous boon to quantitative economics, in that it has required consistent, orderly, and comprehensive collection of economic data. The necessity for uniform accounting procedures and precise definitions of sectors and commodities has forced the many data collection agencies of a number of nations to coordinate their efforts, and the results have facilitated comparative studies across nations. Furthermore, input-output analysis is unequaled in its ability to describe the structure of an economy—to provide a comprehensive snapshot—for any given base year for which data have been systematically and properly collected.

When it comes to making projections and forecasting impacts, input-output analysis can still be extremely useful, despite its extensive use of constant production coefficients, provided it is supplemented with additional analyses and relevant data. It should be used by an analyst who has sufficient knowledge of the intricate workings of the economy being studied, so that he is able to modify production coefficients when necessary, such as in response to expected technological changes, or changes in input proportions because of changing relative prices, or in the light of the findings of other partial studies and data analyses which might be available.

In short, criticism of input-output work is criticism of work which has largely stemmed from the mechanical use of the model by those who fail to take account of the dynamics of a real-life situation. Input-output used as a computer plaything is a simple technique, requiring little more talent than a knowledge of intermediate algebra. Only a sophisticated analyst can do justice to the input-output model, by knowing how and where and when—and when not—to use it. Sophistication and skill will be even more crucial when we attack the problems of environmental management with the input-output model—which will inevitably happen, as it is the only technique we currently have or are likely to have in the near future for comprehensively probing the intricate interdependencies of the joint economic-ecologic system.

As plans go forward for the sixth International Conference on Input-Output Techniques in Vienna, cosponsored by the United Nations, it appears that input-output analysis is becoming a stable element of world culture. Like Adam Smith and *The Wealth of Nations*, Marshall and *Principles of Economics*, and Keynes and "The General Theory," Leontief and "Input-Output" are becoming permanent words in the economics vocabulary.

WALTER ISARD
University of Pennsylvania, Philadelphia 19104

PHYLLIS KANISS
Cornell University, Ithaca, New York 14850

References and Notes

1. W. Leontief, *Weltwirtsch. Arch.* **22** 338 (1925). It was subsequently translated as "The balance of the economy of the USSR" in *Foundations of Soviet Strategy for Economic Growth, Selected Short Soviet Essays 1924–1930*, N. Spulber, Ed. (Indiana Univ. Press, Bloomington, 1964), pp. 88–94.
2. F. Quesnay, *Tableau Économique* (1758).
3. W. Leontief and M. Hoffenberg, "The economic effects of disarmament," *Sci. Am.* **204** 34 (April 1961).
4. See, for example, W. Leontief, "Environmental repercussions and the economic structure: An input-output approach," *Rev. Econ. Stat.* **52**, 262 (1971).
5. Many of these coefficients are already being developed at the Regional Science Research Project, Center for Urban Development Research, Cornell University, Ithaca, N.Y.

merely to meet current social needs: the future is usually different from what it was once predicted to be, and only a broadly diversified science and technology will be ready to manage this kind of future.

The final panelist, Gerard Piel, publisher of *Scientific American*, implied that the economic development kit upon which Dyson speculated was already at hand in the form of the technology and resources available today from the developed countries, and he said it was time to use it. Piel contended that, at its present rate, the growth of the world's population would soon result in a population too large for the available resources to support a decent life for everyone. Moreover, he said that all the evidence appears to indicate that population growth slows only when the ratio of income per capita reaches a high value comparable to that in the industrialized countries. Finally, there is insufficient time left to permit the underdeveloped nations to progress at their own rate, because the world population will have become too large in the meantime. Hence, in order to attain the goal of a "human life for every human being," economic intervention is required on the part of the developed nations in the form of resources and technological know-how. Piel added that, while the resources and technology may be here, the wisdom to use them has yet to appear. But scientific, objective knowledge could be the source of such wisdom by making obvious, among other things, "the brotherhood of man."

Many people, of course, would not wish all aspects of heavily industrialized societies on anybody, and thus Dyson's warning may be at least partially applicable to Piel's plan for upgrading the world's standard of living. Auger may have been right after all: perhaps the best ways to use science and technology would become clearer, if everyone had double his present brain capacity.—ARTHUR L. ROBINSON