Essays of an Information Scientist, Vol:9, p.272, 1986
Current Contents, #37, p.3-12, September 15, 1986

Current Comments®

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Wassily Leontief: Pioneer of Input-Output Analysis

Number 37 September 15, 1986

"It is a capital mistake," observed that master logician Sherlock Holmes, "to theorize before one has data."[1]

With this working principle economist Wassily Leontief would surely concur.

For Leontief, currently University Professor at New York University's Institute for Economic Analysis, explanations of economic systems must be grounded in facts. Theory follows as an instrument that helps explain facts. Leontief's dedicated preference for what can be observed rather than what can be imagined, coupled with an insistence on practical applications, led him to his greatest achievement—the invention and elaboration of input-output analysis (IOA).

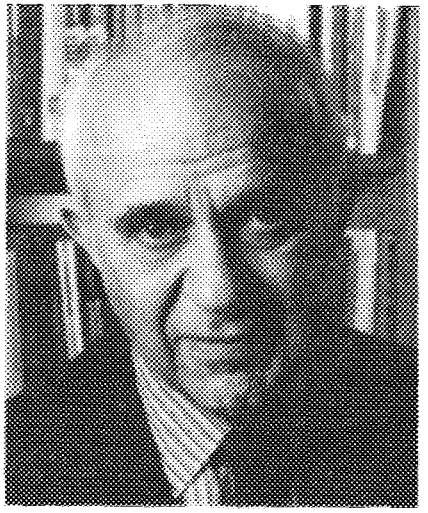
In the hands of Leontief and his many students and followers, the tool of IOA has shaped our knowledge of how and in what measure the constituent parts, or sectors, of an economy interact. More than a tool of analysis, it can also reveal what combination of resources (raw material, labor, capital)—called inputs—is required to achieve desired production goals—called outputs. IOA, therefore, plays a central role in planning and even in prediction. Today, more than 60 nations and countless businesses construct input-output tables to guide them in making economic decisions.

In recognition of the importance of IOA, Leontief was awarded the Nobel Prize in economic sciences in 1973. Japan, the world leader in the use of IOA, presented Leontief with its highest civilian honor in 1984. These are only two of the many awards he has received for his contributions to economics.

Over the years I have had relatively little professional contact with economists. Fritz Machlup, a pioneer in the economics of information and the idea of intellectual capital, was one exception.[2] The work of Leontief, however, has been recommended to me frequently. Many colleagues in the social sciences, including the sociologist Robert K. Merton, Columbia University, urged me to make his acquaintance. They all rightly anticipated that Leontief's input-output technique could have practical application in information science, and so it has.[3-5] Unaware that I was doing so, I have been using a type of input-output methodology in my citation analyses of journals and in ISI®'s annual *Journal Citation Reports®*. It was Merton in particular who saw the connection between Leontief's technique and our analyses. We now plan to use Leontief's matrix structure, in an essay next year, to present data on the "stocks and flows" of citations in and among economics journals.

It was not until early May of this year, however, that I met Professor Leontief. We met at one of his favorite restaurants in New York, on the north side of Washington Square, not far from his office at the institute.

"There is a great difference between evidence and inference," he told me as we began lunch. "I have always looked for evidence."[6]



Wassily Leontief

Early Years, Travels, Adventures

Wassily Leontief was born in Leningrad (then St. Petersburg) on August 5, 1906. His father was a professor of labor economics at the University of St. Petersburg. His grandfather owned a successful textile mill in the city.

In 1921 Leontief entered the University of Leningrad and read the classics of political economics, while all around him the Russian Revolution was radically transforming the economics and politics of the country. As a noncommunist socialist (a Menshevik), he often and bluntly criticized the new regime, and for this he was often jailed. "Some time in prison, some time at the University—it was a good education," he has remarked.[7] (p. 85)

Despite these troubles with the authorities, Leontief was graduated from the University of Leningrad in 1925. Within six months he departed the Soviet Union for the University of Berlin, where he studied for his PhD in economics. Leontief published his first article, "The balance of the economy of Russia: a methodological investigation," in 1925;[8] it, and his 1928 doctoral thesis, *The Economy as a Circular Flow*,[9] anticipated his invention of IOA. Degree in hand, Leontief, then 22, joined the Institute for World Economics at the University of Kiel, where he was engaged in research on problems of supply and demand.

Adventure intervened. Leontief spent the year 1929 in China as an economic consultant to the Ministry of Railroads. He organized an aerial survey to gather data on agricultural production. This information showed the Chinese government where to build new rail lines. In an interview with Leonard Silk, Leontief recalled:

> I rode on trains that came under fire from bandits; I remember lying down on the floor. There was fighting in the north with the Russians. The Russian planes bombed the Chinese with watermelons. They threw watermelons down on them. This was an idyllic world, you see.[10]

In 1930 Leontief returned to the institute in Kiel, but he was not to remain there long. His publications, including two articles describing his thesis work,[11,12] attracted attention in the US. In 1931 Leontief accepted an offer of employment from the National Bureau of Economic Research in New York, an outstanding research institution organized by Wesley C. Mitchell. A lecture by Leontief at Harvard University some few months later brought yet another offer, with further support for his own research project—a quantitative investigation of intersectoral flows in the US economy. He accepted and began his 44-year tenure as a member of the Harvard faculty.

What Is Input-Output Analysis?

Leontief published the first input-output table 50 years ago.[13] He began this work shortly after assuming his new post at Harvard, but it was a difficult undertaking, and Leontief and his assistant needed nearly four years to complete their work.

An input-output table is a model of the interindustry relationships in an

economy.[14] The structure of the table is a matrix that lists economic sectors, in the same sequence, both vertically and horizontally. On the left-hand side of the table, each row is preceded by the name of a sector; the numbers appearing to the right show where and in what quantity the sector's output is dispersed. Across the top of the table, each column is headed by a sector's name; the numbers appearing below the column heading show whence and in what quantity that sector derives its inputs. Thus, any sector can be analyzed in terms of the direction and amount of its production or the origin and amount of its intake.

A greatly simplified example of an input-output table appears in Figure 1. In this example, the economy is defined in terms of three sectors: agriculture, manufacturing, and households. (Actual input-output tables are drawn up with hundreds of sectors—the more sectors, the more detailed the analysis or projection.) The numbers in the table are given in units of currency (here it is dollars) but could also be expressed as actual units—for example, tons of steel or kilowatt hours of electricity. In Figure 1, of the $200 output of the agricultural sector, $50 is the intermediate output that flows back into and is consumed by the agricultural sector, $40 flows to manufacturing, and $110 flows to the household sector. On the input side, the manufacturing sector, for example, takes in $40 from the agricultural sector, $30 from its own sector, and $180 from the household sector (a total input of $250) to produce its total output of $250. From these actual numbers Leontief derives coefficients, or ratios, of the quantitative relationship of one sector to another. The coefficients are fixed by the current technology; by using these coefficients, it is possible to project how changes in input or output of individual sectors will affect all other sectors because of the strict proportionality assumption for input-output relationships. As technology changes, coefficients change also.[15]

Figure 1: Example of an input-output table (in dollars).

From \ Into	Sector 1: Agriculture	Sector 2: Manufacturing	Sector 3: Households	Total output
Sector 1: Agriculture	50	40	110	200
Sector 2: Manufacturing	70	30	150	250
Sector 3: Households	80	180	40	300
Total input	200	250	300	

(From "Input-Output Analysis" by Wassily Leontief. In *International Encyclopedia of the Social Sciences*, David L. Sills, editor. Volume 7, p. 346. Copyright © 1968 by Crowell Collier and Macmillan, Inc. Reprinted by permission of the publisher.)

In a recent address before the US Census Bureau Conference in Washington, DC, Leontief used a familiar metaphor to describe the special ability of IOA to bring together micro- and macroeconomics:

> It has often been said that in economics one must make a choice between detailed description of individual trees or aggregative description of the entire forest. Input-output analysis is an application of the modern systems approach that permits us to describe the forest in terms of individual trees. It provides the means for observing and analyzing simultaneously the quantitative relationships between hundreds and even thousands of variables while preserving throughout all the operations the identity, the name and address, of each of them.[16]

The numbers for Leontief's first table, with 42 sectors, were drawn from the 1919 US Census of Manufactures (the 1929 census was not yet available when the project was begun in 1932).[13] None knew better than Leontief the many refinements needed for future input-output tables; nonetheless, the achievement must have been satisfying: he had united hard data—real numbers—with a theoretical structure and simultaneously drawn the "big picture."

The idea of constructing a network of interindustry flows came to Leontief early. As a student he had pored over the classics of political economics in Rus-

sian, French, and German. However, he acknowledges a special debt at the beginning of his input-output article,[13] and throughout many of his publications, to the physician-turned-economist François Quesnay and his *Tableau Économique* (1758).[17] Quesnay, a leader of Physiocratic thought, divided the French economy into three sectors (farmers, manufacturers, and landowners) and demonstrated how the production of farmers (whom the Physiocrats saw as the source of all wealth) was distributed among themselves and the other two groups in a circular flow.

Another source of inspiration was Léon Walras and his description by sophisticated equations of an economy in general equilibrium, in which a balance is struck between supply and demand.[18] Robert Dorfman, Harvard University, observes that Leontief simplified Walras's equations to make them "empirically implementable." He continues:

> Whereas Walras had subordinated the whole question of intermediate goods, the purchases of the various industries from each other emerged as the central set of equations in Leontief's system. What began as a bold simplification ended as a basic shift in the emphasis of the whole system.[19]

In 1941 Leontief published a more nearly complete exposition of IOA, with full theoretical and empirical apparatus, in *The Structure of American Economy, 1919-1929*.[20] By this time the US Census of Manufactures for 1929 was available and its data were included. This book and its second edition[21] (published in 1951 and including data from the 1939 census) have received over 175 citations in the *Science Citation Index®* (*SCI®*), 1955-1985, and the *Social Sciences Citation Index®* (*SSCI®*), 1966-1985 (see Table 1).

A Tool of Planning for a Time of Planning

During World War II, a division of the US Bureau of Labor Statistics charged with studying the impact of the eventual transition from a wartime to a peacetime economy, and especially its effect on levels of employment, turned to IOA.

Leontief served as a consultant to the bureau and, with a small group of researchers at Harvard, constructed a 90-sector input-output table, based on 1939 data. A second table, with 42 sectors, was built later and proved its worth as a tool of prediction. Many then expected a steep decline in demand for steel after the war. IOA predicted otherwise—that demand would remain heavy. Few believed this, but that is exactly what took place as the pent-up demand of consumers was unleashed for durables, such as refrigerators and automobiles, that were made from steel. IOA had served well, but in the late 1940s support from the government fell away. On this subject Leontief told me,

> In this country it is considered somewhat dangerous.... Politically, it smells of planning and such things.... [the US] government is most conservative in how the economy should be run, or rather, not interfered with. As a matter of fact, why should you know anything about the economy, if the competitive system is automatically making adjustments?[6]

Input-output research did continue at the bureau, but on a much smaller scale. Meanwhile, Leontief received private support to establish the Harvard Economic Research Project, a "laboratory" with a mission to explore the potential applications of IOA. In 1953 the group published *Studies in the Structure of the American Economy*.[22] Leontief contributed four chapters in which he reviewed the fundamental concepts of IOA; explored the effects of changes in the technical coefficients, or ratios, from 1919 to 1939; examined the possibilities of dynamic versus static models (those over time rather than those for a single year); and showed how interregional analyses could be conducted. Other chapters cover the potential of the input-output paradigm for analyses of capital structure, consumption and final demand, aggregation, and specific in-

Table 1: Leontief's works most cited in the *SCI*, 1955-1985, and in the *SSCI*, 1966-1985, arranged in descending order according to number of citations. A = total number of citations. B = bibliographic information. Those items accompanied by an asterisk were reprinted in one of the three volumes listed at the end of the table; the counts for asterisked items do not include citations to reprints of the articles. The identifying numbers of 1983-1985 *SCI/SSCI* research fronts that include core works by Leontief are given in parentheses after the bibliographic reference.

A	B
176	**Leontief W.** *The structure of American economy, 1919-1929.* Cambridge, MA: Harvard University Press, 1941. 181 p.; and *The structure of American economy, 1919-1939.* New York: Oxford University Press, 1951. 264 p.
151	**Leontief W.** *The future of the world economy.* New York: Oxford University Press, 1977. 110 p. (83-0221; 84-8233; 85-6680)
116	**Harvard Economic Research Project.** *Studies in the structure of the American economy.* New York: Oxford University Press, 1953. 561 p.
109	*__Leontief W.__ Theoretical assumptions and nonobserved facts. *Amer. Econ. Rev.* 61:1-7, 1971. (83-4380)
104	*__Leontief W.__ Environmental repercussions and the economic structure: an input-output approach. *Rev. Econ. Statist.* 52:262-71, 1970. (85-6680)
89	*__Leontief W.__ Introduction to a theory of the internal structure of functional relationships. *Econometrica* 15:361-73, 1947.
72	*__Leontief W.__ Factor proportions and the structure of American trade: further theoretical and empirical analysis. *Rev. Econ. Statist.* 38:386-407, 1956.
61	*__Leontief W.__ Domestic production and foreign trade; the American capital position re-examined. *Proc. Amer. Phil. Soc.* 97:332-49, 1953.
40	*__Leontief W & Strout A.__ Multiregional input-output analysis. (Barna T, ed.) *Structural interdependence and economic development. Proceedings of an International Conference on Input-Output Techniques*, September 1961, Geneva, Switzerland. London: Macmillan, 1963. p. 119-50.
35	**Leontief W.** Quantitative input and output relations in the economic system of the United States. *Rev. Econ. Statist.* 18:105-25, 1936.
	**********
158	**Leontief W.** *Input-output economics.* New York: Oxford University Press, 1966. 257 p.
32	**Leontief W.** *Essays in economics. Vol. 1. Theories and theorizing.* White Plains, NY: International Arts and Sciences Press, 1966. 252 p.
23	**Leontief W.** *Essays in economics. Vol. 2. Theories, facts and policies.* White Plains, NY: Sharpe, 1977. 161 p.

dustries (cotton textiles, air transportation). The book has received over 115 citations in the *SCI*, 1955-1985, and the *SSCI*, 1966-1985 (see Table 1).

A few years earlier, Leontief published an article on the basics of IOA in *Scientific American*.[23] He has consistently published articles in this journal and in other publications designed for wider audiences than economists alone; he believes strongly in the importance of reaching out to other fields and bringing the results of his labors to the general public.

Sharpening the Tool

Since the early 1960s, Leontief has applied his analytical tool to specialized problems: the economic effects of disarmament and military spending,[24-27] the costs of pollution,[28-30] the depletion of nonfuel mineral resources,[31,32] the impact of automation on workers,[33-37] and projections of the world economy to the year 2000.[38] This last study was supported by the United Nations and was inspired by Leontief's 1973 Nobel lecture, entitled "Structure of the world economy: outline of a simple input-output formulation."[39] The UN study, a massive undertaking, describes a number of possible scenarios for the future economic state of the world. In particular, *The Future of the World Economy*[38] shows how and in what measure aid to developing countries might be most efficiently

distributed. This book has received over 150 citations in the *SCI*, 1955-1985, and the *SSCI*, 1966-1985. It is characteristic of Leontief's interests and intellect that, in refining and elaborating IOA, he concurrently sought to analyze and solve practical problems.

A recent book by Ronald E. Miller and Peter D. Blair, University of Pennsylvania, Philadelphia, entitled *Input-Output Analysis: Foundations and Extensions*, is an up-to-date review of the current uses and applications of "Leontief matrixes," as they are often called.[40]

Leontief has written few books. "Rarely have I written a book to write a book," he told me. "Usually, I work on a problem, write an article, and when I have enough articles, I publish a book."[6] *Input-Output Economics*, published in 1966,[41] is one such book. It gathers together Leontief's most important articles on IOA; this year a greatly enlarged second edition appeared.[42] Other volumes of collected papers include *Essays in Economics, Volume 1* and *Volume 2*.[43,44] These two volumes include articles on many topics, including the use of mathematics in economics, matters of political economics, and criticisms of Keynesian theory.

The Trouble with Economics

At the beginning of this essay, I underscored Leontief's commitment to empirical evidence, that is, to facts; he is, however, a master at formulating theories and, indeed, throughout his career has taught theoretical economics more often than input-output techniques. He seems to emphasize data more than theory only because his union of the two stands out so sharply against the work of many of his colleagues, who, he says, fill

> page after page of professional economics journals...with mathematical formulas leading the reader from sets of more or less plausible but entirely arbitrary assumptions to precisely stated but irrelevant theoretical conclusions.[45]

He described some of his colleagues to me as behaving "like an airplane that took off, is circling, and never lands."[6]

As early as 1937, he questioned the assumptions of Keynes's *The General Theory of Employment, Interest and Money*.[46-48]

> I already saw what was happening there. Keynes was demonstrating how one can first provide the formula and then let someone else make it true. Of course, you can do it. Why not, logically? But theorizing without facts in an empirical science is very dangerous.[6]

In his presidential address to the 83rd meeting of the American Economic Association in 1970, published a year later in the *American Economic Review*,[49] Leontief systematically criticized the profession's research strategies and results. The address, "Theoretical assumptions and nonobserved facts," ranks high on Leontief's list of most-cited works, having received over 100 citations in the *SCI* and *SSCI* (see Table 1). A "journal study" by Leontief, in which he analyzed the type of methodology used for articles published in the *American Economic Review*, appeared in 1982 in *Science*.[45] He found that over half of the articles published by the journal fall into the category of "mathematical models without any data." The nature of Leontief's entire "output" underscores his firm and long-held opposition to "implicit theorizing," and, as he told me, his commitment "to finding out how the world works."[6]

Recent Years

Although now entering his ninth decade, Leontief seems to have slackened his pace very little in the search for how the world works. In 1975, after 44 years of teaching at Harvard University, he departed for New York University, where he assumed the post of professor of economics and, two years later, director of the Institute for Economic Analysis. During his years at Harvard, Leon-

tief taught many of the best of today's economists, including Paul Samuelson, Robert Solow, and James Duesenberry. He called for, as he still calls for, better and more systematic collection of economic data in the US. At the institute Leontief completed *The Future of the World Economy* (1977),[38] and, with Faye Duchin, the institute's recently appointed director, *Military Spending: Facts and Figures, Worldwide Implications, and Future Outlook* (1983).[50] Last year he published, again with Duchin, *The Future Impact of Automation on Workers*.[51] This work predicts a dramatic shift in the composition of the labor force, with fewer clerical workers and middle managers, but with increased numbers employed in producing the new technologies. Even under their most aggressive scenario for the integration of technology into the workplace, Leontief and Duchin believe that jobs lost in clerical and management areas will be offset by demand for workers in the manufacture of the new technologies. However, they conclude that technological unemployment remains a possibility in the long term.

Currently Leontief is working with the Italian government to redesign the country's entire transportation system (sea, air, road, and rail) through IOA. Most recently, he returned from Sapporo, Japan, where he attended the Eighth International Conference on Input-Output Techniques. The first such conference was held in The Netherlands in 1952.

After lunch we walked through the square to Leontief's office, where he showed me a new French-language publication, "very elegantly done,"[6] that reprints several of his important articles and includes a series of interviews he gave the editors; an article by Anne P. Carter and Peter A. Petri, Brandeis University, Waltham, Massachusetts, assessing his contribution to economics; and an excellent bibliography of his works.[7]

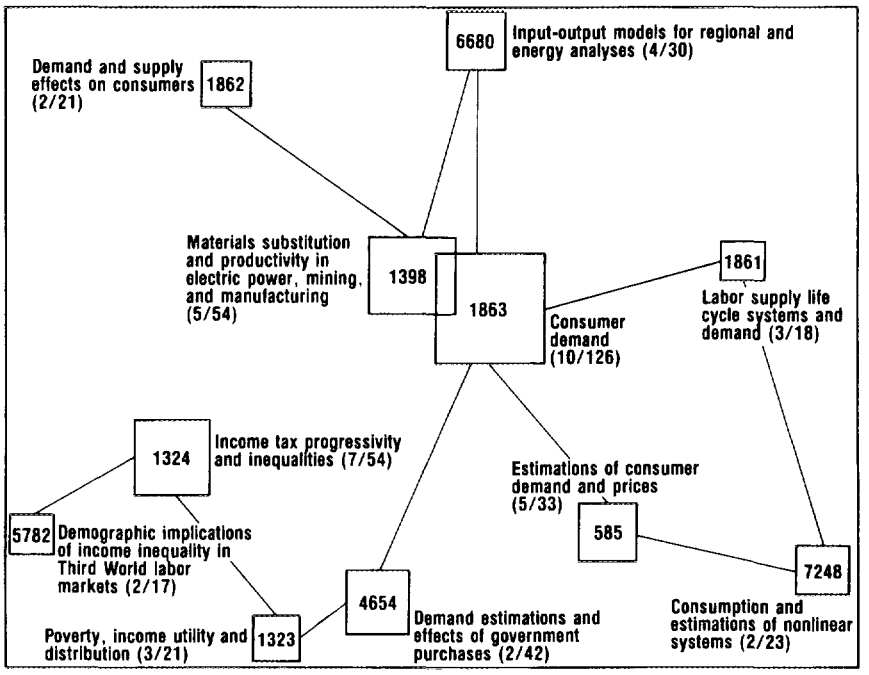
This is a special year for Professor Leontief. As noted, it is the golden anniversary of the invention of IOA. I understand that, later in the year, special sessions on IOA—honoring its inventor—will be held at the annual meetings of the Regional Science Association and the American Economic Association.[52,53]

Citation Data

When I told Leontief that we were analyzing the more than 1,500 citations to his publications in our database, he said, "Look here: my example [in terms of publications and influence] is very untypical. Most of my connections are in other fields."[6]

A survey of 1985 citations to works by Leontief reveals an approximately 40/60-percent split between those coming from economics journals and those from other social-sciences journals, respectively. This seems to confirm Leontief's view of his own influence outside economics but also indicates no lack of interest in his work by fellow economists. In fact, two works by Leontief (*The Future of the World Economy*[38] and "Environmental repercussions and the economic structure: an input-output approach"[28]) are core to the 1985 research front "Input-output models for regional and energy analyses" (#85-6680). The other two core publications making up this cluster are *Input-Output and Regional Economics*,[54] by Harry W. Richardson, State University of New York, Albany, and "US energy policy and economic growth, 1975-2000,"[55] by Edward A. Hudson, senior economist, Data Resources, Inc., Cambridge, Massachusetts, and Dale W. Jorgenson, professor of economics, Harvard University. This research front, with 30 citing documents, is connected to mainstream economics, as is evident in the multidimensional scaling map

Figure 2: Multidimensional-scaling map for C2-level research front #85-0294, "Supply and demand economics," showing links between C1-level research fronts. The number of core/citing items are given in parentheses following the research-front titles on the map. The size of the box around the research front number indicates the relative size of the citing literature.



"Supply and demand economics" in Figure 2.

In 1984 *The Future of the World Economy*[38] and *The Future of Nonfuel Minerals in the US and World Economy*[32] made up the entire core of research front #84-8233, "Projections of the distribution of nonfuel mineral resources in the world economy," which was created from nine citing 1984 articles. And in 1983 Leontief's address "Theoretical assumptions and nonobserved facts"[49] and *Analysis and Control of Dynamic Economic Systems*,[56] by Gregory C. Chow, professor of economics, Princeton University, New Jersey, formed the core of research front #83-4380, "Interactive macroeconomic models," created from 15 articles published in 1983. A second 1983 research front, "Analyses of the political and economic problems of developing countries" (#83-0221), contains 32 core publications, including *The Future of the World Economy*,[38] and 224 citing 1983 articles. It is plain that this UN study, Leontief's second most-cited publication, has been consistently important in research articles published over the past three years.

Finally, I should emphasize that our list of Leontief's most-cited publications in Table 1 is to be read with two important cautions in mind. First, the *SSCI* file, which contains the lion's share of citations to works by Leontief, does not begin until 1966, relatively late in Leontief's career; we do not yet have a record of most citations to his works for the 40 years before this date. And, second, many of his articles that have been reprinted in monographic form are not ex-

plicitly identified in our count. We did not tackle the daunting task of determining the specific article involved when a volume of collected works was cited. An asterisk in Table 1 marks those among Leontief's most-cited articles that have been reprinted in monographs; there are more citations to these articles than the table indicates. Citations to *Input-Output Economics*[41] and *Essays in Economics, Volume 1* and *Volume 2*,[43,44] are listed at the end of the table.

* * * * *

My thanks to C.J. Fiscus, David A. Pendlebury, and Amy Stone for their help in the preparation of this essay.

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