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Wassily Leontief: In appreciation

William J. Baumol and Thijs ten Raa

1. Introduction

His date and place of death are not controversial: Wassily Leontief died on 5 February 1999 at the New York University Medical Center. His date of birth was presumed to be 5 August 1906, but after the collapse of the Soviet Union Leontief apparently first found out, and reported with much amusement, that it was precisely one year earlier, in 1905. Hence he was 93 years old. His gravestone in Connecticut (next to that of Schumpeter) states that Wassily was born in St Petersburg, while his birth certificate, issued by the municipality of Munich, states correctly that he was born in Munich.[1] Leontief not only spanned the twentieth century, he was also one of its most creative economists. He was the first to put to use the concept of the economic system as a working aggregation of interrelated parts, in which all the parts have their place. His model of the economy is a fine instrument that enabled him to hold it in his hand, to examine it, and understand its workings. He emphasized that microeconomic and macroeconomics are different depictions of the same system, different parts of which are studied in fields of specialization such as economic growth, spatial and environmental economics, and monetary economics. His

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1 For more on Leontief's life and further discussion of his work, see the 2006 special issue of *Economic Systems Research* 18 (4). His birth certificate is posted on the web (available at http://www.wassily.leontief.net/docum/certifG.jpg). His father was a Munich graduate (Kaliadina and Pavlova 2006).

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representation of the economy as a complex system with many dimensions enables us to interrelate all this, to unite pure theory with policy issues and to connect micro data with national statistics. Leontief's invention of input–output analysis has facilitated both national accounting and applied equilibrium analysis.

Although Leontief, entirely by himself, constructed an operational framework that is now used throughout the discipline and all over the world, his work fits in with that of a chain of predecessors, as will be reviewed in Section 2. Section 3 describes some of Leontief's earlier work, which was preponderantly theoretical. This enabled him to pursue the lines of inquiry that he deemed of primary importance. Section 4 describes the revolutionary advance of his basic analysis over that of his predecessors. Section 5 outlines his later work, which was influential, but also controversial, for his relationship with mainstream economists had not been easy.

2. Leontief and the chain of historical predecessors

Wassily Leontief's work can be seen as the culmination of a sequence that runs from the beginnings of a systematic economic literature to the end of the twentieth century. One way of looking at the antecedents of input–output analysis is to take it as an end point of the strand that began with Léon Walras and continued through the writings on general equilibrium up until the onset of the Great Depression, for in Walras and in Leontief the different sectors of the economy and their interrelations play a central role. Leontief (1937: 111; 1944: 299; 1949: 275) expressed this point of view,[2] but he (Leontief 1936c) and others also linked him with a much earlier contribution, the physiocratic *Tableau Économique* (1758–1759), the work of that early economist physician, François Quesnay. (Actually, Quesnay was not the first medical doctor to make a major contribution to the economic literature. Both William Petty and Bernard de Mandeville

2 He wrote 'This is the same type of relation which was originally used by Walras in his first formulation of the general equilibrium theory,' 'An attempt to approach the empirical analysis of the American national economy from the point of view of general equilibrium, i.e. treating it as a completely determined system, is presented in my Structure of the American Economy, 1919–1929, Cambridge, 1941,' and 'This is the relationship that Walras describes in terms of his production function, his coefficients of production, each coefficient describing the amount of any particular input necessary to produce one unit of the final output,' respectively.

were physicians. See Kuczinsky and Meek (1972) for an authoritative compilation of the various editions of the *Tableau*. See Phillips (1955) for an early analysis of the relationship between the Tableau and Input–Output.) And here there is a linkage considerably more continuous than is generally recognized.

The *Tableau* is often taken to have more or less disappeared from the economic literature half a century after Du Pont de Nemours left France for the United States,[3] until it was rediscovered by Marx; see his noted letter to Engels of 6 July 1863 and his characterization of the Tableau as 'incontestably the most brilliant idea of which political economy had hitherto been guilty,' as cited in Sweezy (1942: 75). Marx translated the logic of the Tableau into his structure of 'simple reproduction' under capitalism, and then used it in attempting to solve what he called 'the transformation problem' (derivation of the numerical relationships between his two concepts, value and surplus value, and the price and profit variables of standard economic analysis).

Marx himself suggested that his solution was imperfect (*Capital* Volume 3, Chapter IX, 1894, reprinted 1909) and the task of providing the first fully defensible way of dealing with the problem was left to Ladislaus von Bortkiewicz (1868–1931), a distinguished Polish mathematical statistician who was born in St Petersburg and went on to teach at the University of Berlin; see von Bortkiewicz (1907).

von Bortkiewicz is relevant here for two reasons. First, the logic of his solution of the transformation problem rested directly on the Marxian model of simple reproduction, based, as Marx indicated and as we have just seen, on Quesnay. Second, when Leontief came to the University of Berlin as a postgraduate student, since his primary thesis advisor admitted that he could not follow Leontief's (1928) mathematics, it was von Bortkiewicz who was appointed as Leontief's second advisor as Leontief recounted with some delight to one of the present authors (in that conversation, the name of Werner Sombart as his other adviser did not come up; see Kaliadina and Pavlova 2006: footnote 17). Thus, the chain was complete – Quesnay to Marx to von Bortkiewicz to Leontief.

The story is delightful, but, as we will argue later, it is rather misleading because it puts Leontief in the position of a writer who merely carried previous traditions one step further. This grossly undervalues his revolutionary contribution – which, although he himself noted that it was built

3 However, an anonymous reviewer draws our attention to the relevant writings of Isnard to Lang and Buquoy. For more on this see Kurz and Salvadori (2000, 2006).

upon such distinguished predecessors, took him a giant step further, well beyond anything that the previous links in the historic chain had provided.

3. Early work: pure theory and the closed model

If one was to ask a student of economics whether the national product should include all outputs of all sectors of activity, he/she would probably answer 'yes.' The first publication of Leontief (1925) shows that this is erroneous, and that the Soviet statistical office made this mistake. It is now called 'the problem of double counting (an issue not new to the literature).' Outputs are distributed between intermediate demand (industries) and final demand (such as households), and Leontief argued that only the latter should be included. This paper is considered the first input–output study, particularly by the Soviets after Stalin, when input–output analysis was no longer viewed as a 'bourgeois' tool but – by somewhat creative extension – as a Russian invention. Leontief always kept his distance from such petty matters; his closest approach was in Leontief (1960). Dobb (1965: 200) assesses the status of the 'first input–output study' as follows: 'From this seminal idea [the dissolution of double counting], simple and unarresting it may appear when one first meets it, the whole system of input-output analysis evidently derives.' Thus Leontief (1925) can reasonably be interpreted as the predecessor to input–output analysis.

The year 1925, when this first publication appeared, was also the year that Leontief moved to Berlin, then the center of academic life. During the next 10 years Leontief was a prolific source of valuable papers, all highly theoretical, and none of them dealing with input–output analysis, such as his papers on elasticities and indifference curves in foreign trade (Leontief 1932, 1933). In hindsight he regarded this period as an antebellum that was a necessary step in establishing himself, playing down his contributions. Modern price index theory, however, still makes use of his first publication in *Econometrica* (Leontief 1936a). And modern macroeconomics – with its emphasis on dynamics – has reflected Leontief's (1936b) critique of Keynes. In particular, Leontief emphasized that Keynes underplayed the importance of the role of investment, and that it should be viewed as a productive input, and not just as a component of demand.

His purely theoretical work continued after the appearance of his first true input–output study (Leontief 1936c). Modern macroeconomists' use of game theory has roots in his model of wage bargaining (Leontief 1946). His deepest theoretical work, however, deals with the structure of functional relationships (Leontief 1947). Leontief was motivated here by production analysis. The economy is a system that transforms resources into final goods and services, in which he considered whether it is possible to distinguish stages of a production process. In other words, can distinct sectors of activity be identified? And, if so, what principles should guide the classification?

Let us denote capital, labor and mineral resources by K, L and M, and the final goods and services by Y, all scalars, for simplicity of exposition. Let the transformation be given by

$$Y = G[F(K, L), M] \tag{1}$$

Obviously, there are two stages of production: first K and L are combined and then their combination is commingled with M. Leontief noted that the marginal rate of substitution between K and L is independent of M. The demonstration is straightforward. Partial differentiation of Equation (1) with respect to K and L, respectively, yields their marginal products:

$$Y_K = G_F \cdot F_K, Y_L = G_F \cdot F_L \tag{2}$$

Here we use subscripts to denote partial derivatives by subscripting, without inserting primes. The ratio of the two marginal products yields the marginal rate of substitution between K and L. By Equation (2),

$$MRS^{K,L} = Y_K/Y_L = F_K/F_L \tag{3}$$

This, by Equation (1), is a function of K and L only. In other words, the marginal rate of substitution between the inputs used in a stage of production is independent of the other inputs (M). Then he *proved* that this condition is not only necessary but is also sufficient for the determination of the internal structure of the overall function, as given by Equation (1), without making any assumption. This theoretical result is strikingly general and continues to be used extensively in modern utility theory. Thus, the widely employed 'separability conditions' all go back to Leontief's theory.

Leontief's first input–output study presented what is called the *closed model* (Leontief 1936c). All outputs are also used as inputs. Industries produce commodities using commodities as well as factor inputs. Households produce these factor inputs using commodities. This, of course, is very much in the spirit of the contemporaneous work of von Neumann (1945). Leontief's *tour de force* was his breakthrough in relating general equilibrium theory to the data for an economy. The input–output matrix encompasses the data for all branches of the economy, including consumption coefficients.

This model was also used to analyze pricing. Assuming perfect competition, the zero-profit condition determines the prices as a row eigenvector of the matrix. However, since this vector is determined only up to a scaling vector, it is only relative prices that are thereby determined.

The weak element in the closed model is its treatment of investment. It is represented in a manner similar to household consumption – which can indeed be treated appropriately as an instantaneous activity. von Neumann circumvented the problem by assuming balanced growth, but Leontief was not content to proceed in this way. His solution was to assume fixed and given capital coefficients. Changes in output, in this approach, imply rigidly predetermined changes in the quantities of capital required and, hence, determinate quantities of investment. The model of the economy thus becomes a system of differential equations. Another more pragmatic solution was to separate out the matters that engendered problems. Leontief felt at ease modeling production sectors by means of equations using intermediate input coefficients. The difficult final demand sector could then be left exogenous.

4. Later work: the open model and applications

Although he obviously felt deeply about the contribution of input–output analysis and, as we will note, used its logic imaginatively and creatively in a variety of applications that were far from obvious, Leontief might perhaps have emphasized more explicitly its consistency with the principle that guided his views about his discipline. Although a strong believer in the essential role that must be played by theory, as who among us is not, he was passionate about the trap into which, he believed, much of the work in the arena had fallen. His ire was aroused by the types of abstract theoretical work that he considered to have no foundation in reality, to lack applicability and that provided no handle for empirical testing. In his view, such endeavors followed a dead-end path onto which standard teaching in the graduate schools was determinedly leading the next generation of economists. (See his Presidential Address to the American Economic Association; Leontief 1971.) This was a position he held passionately and it was, arguably, the source of his one failure, for it did not discernibly move either the journals or the graduate schools in the direction for which he called. Yet he has left heirs in this endeavor, some who had made major contributions of a sort that may have induced other colleagues to avoid the directions Leontief deplored.

But the bulk of his contributions were successful and influential. As is true of any creative scholar's work, there is no comfortable way to classify his contributions and place them into neat boxes. Yet, it is possible to argue that these are, roughly speaking, of three main types, all interconnected. First, there is, of course, the theory of input–output analysis, which is, in itself, a major leap forward from the work of the predecessors who led up to Leontief's analysis (as summed up in Leontief 1966, particularly ch. 7). The advance here was formulation of the structure of the interdependencies of an economy in a way that was less abstract and far more operational than anything that had appeared before. Second, he was able to quantify the models with the aid of empirical data for an economy, enabling the model to serve as a guide to concrete policy decisions as well as contributing to pure understanding. (The open input–output model appears in *The Structure of the American Economy* – see Leontief (1941) – but only in the second edition. The model was launched in Leontief (1944) and was studied in Leontief (1977).) In dealing with a substantial set of such simultaneous economic interrelationships, nothing like that had ever been done before. Third, while some of the areas of application of the quantified input–output models are obvious, as, for example, their use as a guide to central planning, Leontief took the applications far beyond that, sometimes in totally unexpected directions. Thus, Leontief's (1970) application to environmental issues was, surely, far from obvious – although once it had been carried out, it does seem an evident and natural way to go about analysis of its subject. Perhaps his most striking and unexpected application was that to international trade (Leontief 1953), where 'the Leontief paradox' has, for evident reasons, generated a stream of literature seeking to shed light on the puzzling result and to draw out its implications for the field. Again, none of the predecessor works offered anything like this degree of flexibility and rich diversity of application.

It should be added that one of the most significant features of this last accomplishment is that, in addition to the applications that Leontief himself was able to provide, the analysis left the way open for others to find unexpected applications of the analysis, taking off in still other and very different directions. There evidently can be no clearer demonstration of the power and value of a scholarly contribution such as this.

5. Input–output analysis: the great step beyond predecessors

We have already noted the historic roots of input–output theory. But what input–output added to the work of any predecessor was truly revolutionary. The directly pertinent work of Quesnay, Marx and von Bortkiewicz in each case had its limited and specific purpose, and none had any empirical connection. Quesnay used his table largely to support the view that manufacturing is a sterile activity and that only agriculture offers a surplus. Marx explicitly translated Quesnay's work into a static two-sector model, his 'simple reproduction' concept (of course, he does offer some unsystematic remarks on a more dynamic [expanded reproduction] construct; see the last chapter of Marx *Capital*, Volume 2). The static analysis provides one immediate conclusion: that in a balanced and stationary economy divided into a sector that produces consumption goods and one that supplies producers' goods, the producers' goods used by the consumption sector must be equal in value to the consumption goods that go to the capital goods sector. Finally, as we have seen, von Bortkiewicz used the Marxian reproduction scheme just to solve Marx's transformation problem. The solution was the last stage in the pre-Leontief story. Each step in this pre-Leontief saga, it will be noted, pursued its author's immediate objective, *and was not designed to lead to applications distant from the initial topic of discussion.*

In contrast, input–output offers us a tool with a vast array of uses. The techniques, as just noted, have been applied to subjects as heterogeneous as international trade, economics of the environment, and productivity. It is not merely *capable* of using data; rather, it is designed for the purpose. Just to make the point – how such theory of our century permits both application and use of facts – we provide a single illustration selected because it is so far afield from the topics to which input–output is commonly applied. The topic is energy conservation and the various projects intended to be energy-saving, among them public transportation by rail (subways), recycling of oil, and the use of solar energy and other new energy sources (see Baumol and Wolff 1981). As advocacy of such measures grew in intensity in the 1970s, dispassionate observers noted that these processes all *used up* energy resources, as well as providing or saving energy. For example, the agricultural products that are employed to produce biomass may be transported in trucks that use up gasoline, and the digging of subway tunnels also consumes enormous amounts of power. Seeking to analyze the issue systematically, engineers invented the concept of 'net energy' in which the energy used up by a proposed activity is subtracted from the energy it is expected to contribute. But it soon became clear that the engineers' calculations had at least one major shortcoming. No account was taken of the fact that it requires inputs to make inputs – that the trucks carrying the biomass themselves had to be built and used energy in the process of their construction, and that the same was true of the assembly line used to build the trucks, and so on *ad infinitum.* Clearly, there was a Leontief process at work. In the usual notation, if we let D represent the vector of energy consumed per unit of output, and A is the Leontief matrix, then the proper measure of energy consumed is

$$D + DA + DA^2 + \ldots + DA^n + \ldots \tag{4}$$

But most of the engineers carrying out the net energy studies were considering only D as the measure of energy use. Some studies were more sophisticated and used $D+DA$ as their energy consumption measure. A small number of net energy studies even subtracted DA^2, but none went beyond that, thereby in effect assuming $DA^3 + \ldots = 0$. A full input–output calculation, using the standard data on the US economy offered rather startling conclusions. The usual approach that takes into account only the energy of the directly used input overlooks, on average, over 60% of the true quantity of energy used. Even if a second round – the inputs used to make the direct inputs – is taken into account, some 28% of the total energy consumption is omitted. Thus, investments in what are deemed to be energy-saving measures that project, say, a 20% net energy yield were shown by the input–output calculation as more likely, in fact, to use up more energy than they provide.

6. Enfant terrible in the neoclassical mainstream

Surely Leontief's work placed him in the mainstream of economic research. However, he found himself increasingly isolated from that mainstream.

His career in the universities of the United States reached its apex when Schumpeter invited him to Harvard University, where Leontief became *the* mathematical economist and a primary influence on neoclassical economists such as Paul Samuelson and Robert Solow. But he was dissatisfied with the directions in which his students and others were taking the field. In his view, they were providing theory without measurement, and he considered that to be mere speculation at worst and applied mathematics at best.

Leontief was skeptical not only about contemporary theoretical work, but about that in econometrics as well. He was a fervent detractor of much of time-series analysis. In his opinion, the bulk of that work would be unhampered 'if you feed it weather reports instead of economic statistics.' He considered it measurement without theory. And, unlike physics, the time span in which the results of economic investigation retain their validity is very short. His favorite example was the lack of constancy of input–output coefficients. His attitude toward structural econometrics was, however, milder.

Another attribute that helps to explain his drift from the neoclassical mainstream is his style. He did not choose to ally himself closely with any mainstream group, enjoying his independence and resenting authority that he did not consider intellectual. Radical economists naturally evinced some sympathy for his ideas and positions, but the relationship was no more than a marriage of opportunity.

Many neoclassical economists criticized input–output analysis as excessively mechanical. The open input–output model comprises a system entailing both physical quantities (interrelating final demands and gross outputs) and a value system (interrelating prices and factor rewards). But this raised the question of whether interdependence of these two sides of the workings of the economy should not be dealt with more explicitly. Some neoclassical economists took the position that their analysis explains the interaction between prices and quantities, and that Leontief's does not.

We will argue that this is a misunderstanding. Leontief (1937: 116–17) did begin to provide an explanation of the determination of prices and quantities that deals with them simultaneously, using his closed model. He deliberately truncated the connection to free himself from assumptions such as the zero-profit condition that restricted application of the model. But the framework is still there and remains effective.

Neoclassical economists use the market values of labor and capital to assess their productivities and to commingle them in total factor expressions. In a sense, they take at face value what they are supposed to measure. This approach is legitimate for perfectly competitive economies, but Leontief believed that such economies inhabit textbooks rather than the real world. Input–output analysis can resolve this problem.[4]

7. Conclusion

The main implication of the preceding discussion is clear. Leontief possessed a strikingly creative mind that was guided by a desire for relevance. His work opened up entirely new and highly fruitful directions to the practitioners of our discipline. We have also shown that there is no basis for the occasionally voiced perception that Leontief was a narrow-minded

4 In ten Raa and Mohnen (2002), productivity growth is measured without recourse to observed factor values, by disaggregating output and calculating the production prices that would emerge under perfect competition – but do not necessarily prevail in our more complex economy. Leontief's apparatus is thus used simultaneously to account for input and output component growth rates and their valuations. This example underscores the general equilibrium nature of input–output analysis.

proponent of an unexciting planning tool. His contributions are far wider than input–output analysis and, moreover, his techniques can be used to analyze problems of value determination, including those that evade standard neoclassical tools.

Because of Leontief's contributions, the literature of economics has been affected profoundly and is far more illuminating and useful as a result. We economists are indeed all deeply indebted to him.

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Abstract

In this paper we briefly review the work of Wassily Leontief, in respect for his memory and appreciation of his accomplishment. His work encompasses and redirects the entire field of economics, including pure theory.

Keyword

Leontief