Appendix C Historical Notes on the Development of Leontief's Input–Output Analysis

C.1 Conceptual Foundations

The original idea of developing a detailed accounting of interindustry activity in an economy is certainly much older than Leontief's model. Leontief himself describes input–output as an analytical formalization of basic concepts set forth over a century and three quarters earlier by the French economist François Quesnay. Quesnay, in turn, was heavily influenced by earlier eighteenth century economists dating back to the beginning of that century. Perhaps the key precursor idea was the recognition of the concept of a "circular flow" of productive interdependences in an economy, which is a notion that can be traced to as far back as the early perspectives of Sir William Petty in the mid seventeenth century. We begin the story of input–output with this "pre-history."

When British forces led by Oliver Cromwell invaded Ireland in the 1650s, Sir William Petty, a physician and Oxford professor of anatomy accompanying the British army, was assigned the task of assessing the spoils of war. In the history of economic thought Petty is often described as the first econometrician, since he portrayed his thinking as "political arithmetick," although the term econometrics was not adopted until well into the twentieth century.[1] Petty's account, documented in Petty (1690, 1691), described the characteristics of production, distribution, and disposal of the wealth of a nation as closely *interconnected*, and the problem of assessing the value of that wealth as properly reflecting the interrelationships among these characteristics.[2] He also recommended in this work that "just accounts might be kept of the People, with the respective increases and decreases of them, their wealth and foreign trade," which led to the first reported estimates of national economic accounts (Stone, 1973, p. 143).

[1] The term *econometrics* was first coined in the 1920s by Ragnar Frisch, the winner of the very first Nobel Prize in Economic Science awarded in 1969 (Frisch died in 1973, the year Leontief won the Nobel Prize). The Econometric Society was founded in 1930, at the initiative of Frisch and Yale economist Irving Fisher.

[2] This is reported in the interpretation of Kurz and Salvadori (2000a). Davenant (1699) as reported in Stone (1973) described Petty's "political arithmetick" as "the art of reasoning by figures upon things related to government."

Petty was a pupil of philosopher Thomas Hobbes[3] and became known as one of the so-called *Mercantilists* who dominated economic thinking during a substantial period of what is usually referred to as *Pre-Classical* economics (1500–1676). The Mercantilists believed that a nation's wealth came primarily from the accumulation of gold and silver. The Mercantilist view held that nations without native sources of such resources could obtain them only by selling more goods than they bought from abroad and, hence, the political leaders of such nations must intervene extensively in the marketplace, imposing import tariffs and subsidizing exports to improve the competitiveness of domestically produced goods abroad. In this sense, mercantilism represented the earliest elevation of commercial interests to the level of national policy interest, which, of course, remains an essential element of modern economic policy today. Among the most enduring concepts of the Mercantilists was Petty's concept of chronicling the details of the interdependence of industry, which Charles Davenant (Davenant, 1699), a contemporary of Petty's and a fellow Mercantilist, described as the following:[4]

> And perhaps this art alone can show the links and chains by which one business hangs upon another, and the dependence which all our various dealings have upon each other. (Pyatt, 2000, p. 426.)

While Petty was a Mercantilist in his perspectives and policies, his work included the first rudiments of what would later become the so-called *labor theory of value*. Richard Cantillon, a disciple of Petty and an Irish financier who lived in Paris in the early eighteenth century, wrote that the intrinsic value of a commodity

> is the measure of the quantity of land and of labor entering into its production, having regard to the fertility or produce of the land and to the quality of labor (Cantillon, 1755, p. 29).

However, Cantillon argued even further that market prices may deviate from the intrinsic value of a commodity due to a mismatch of demand and availability of that commodity. He attributed the gross product of an economy to proprietors of land, farmers, and artisans, emphasizing, for the most part, that all of society subsists on the basis of the production from the land. Hence, he reasoned, essentially breaking with the Mercantilists, that the source of any surplus that could account for increasing economic value can only be attributable to agriculture.

C.2 Quesnay and the Physiocrats

The primacy of agriculture became a central tenet of the Physiocrats, who were a group of eighteenth century French philosophers known in their time as *les economists* – the first economic thinkers to call themselves economists. *Physiocracy* (tr. "the rule of nature"), as their school of thought became known, was deeply influenced by "natural law." The American economist George Soule describes the Physiocrats as the first

[3] The seventeenth century political philosophy of Thomas Hobbes asserts that men in a state of nature, i.e., without civil government, are in "a war of all against all in which life is hardly worth living." Hobbes's solution to such a dismal state of affairs was to fashion a social contract that establishes the authoritarian state to keep peace and order (see Routh, 1975).

[4] As discussed in Pyatt (2000).

school of economic thinkers to consider their craft a science, i.e., to "regard their theory as objectively scientific and to develop a complete and self-contained view of the economic order as a whole" (Soule, 1952, p. 33).

The Physiocrats were led by French court physician François Quesnay.[5] The Physiocrats opposed the Mercantilist policy noted earlier of promoting trade at the expense of agriculture because they believed that agriculture was the sole source of wealth in an economy, which they termed *produit net*, or the net product of the economy. Instead of heavy government intervention advocated by the Mercantilists, the Physiocrats, like their contemporary Cantillon, advocated a policy of *laissez-faire*, which called for minimal government interference in the economy.[6]

As the Physiocrats continued to develop their economic theories into the middle of the eighteenth century, Quesnay, in 1758, conceived his seminal *Tableau Économique*, subsequently published in Quesnay (1759), which depicted income flows between economic sectors. The *Tableau* is most remembered for its diagrammatic representation of how expenditures can be traced through an economy in a systematic way (see Figure C.1). Quesnay illustrated his thinking by describing how a landowner who receives a sum of money as rent spends half of this sum on agricultural products and half on products of artisans. In turn, farmers buy industrial products, artisans buy food and raw materials, and so on.

Many of Quesnay's and the Physiocrats' views were considered quite controversial in their time. For example, as their ideas developed, they stubbornly held to the idea that the wealth of a nation lies in the size of its *produit net,* and, as a result, that manufacturing and commerce added no value to the economy, referring to them as "sterile expenditures." This meant that the value of the output of manufacturing and commerce was equal only to the value of their inputs. In modern parlance this would mean that there was no "value added" attributable to such enterprises. Virtually all economic theorists have since concluded that *produit net* is flawed reasoning. Nonetheless, one concept of lasting value advanced by the Physiocrats is the idea of the economy as a circular flow of income and output among economic sectors as reflected in Quesnay's *Tableau*. Even the *Tableau* was controversial, however, perhaps because of its association with the collection of the Physiocrats' controversial ideas, and there were mixed reactions among economic theorists for the next century and a half, ranging from "genius" (Mirabeau, 1766, and Marx, 1905) to ignoring it entirely, as it was by most economists for decades, or opining that "it should be reduced to an embarrassed footnote" (Gray, 1931). As it turned out, the key to recognizing the lasting value of the notion of circular flow and the *Tableau* lay in finding a way to express the underlying ideas mathematically.

[5] For most of his life Quesnay was a physician, including serving as the court physician to King Louis XV and his mistress, the Madame de Pompadour. Quesnay's interest in economics arose late in his life, at 63 in 1756, when he was asked as a respected physician and scientist to prepare several articles on the role of agriculture in the economy. Quesnay drew on the work of Cantillon and many others to advance his ideas. In 1757, his admirers included the Marquis de Mirabeau and Samuel DuPont de Nemours among others, who continued to champion his work for many years thereafter (Taylor, 1960, and Meek, 1965).

[6] The Physiocrats slogan, often repeated in summarizing their views, was "*Laissez faire et laissez passer, le monde va de lui-même*" or, essentially, "don't interfere, the world will take care of itself" (Soule, 1952).

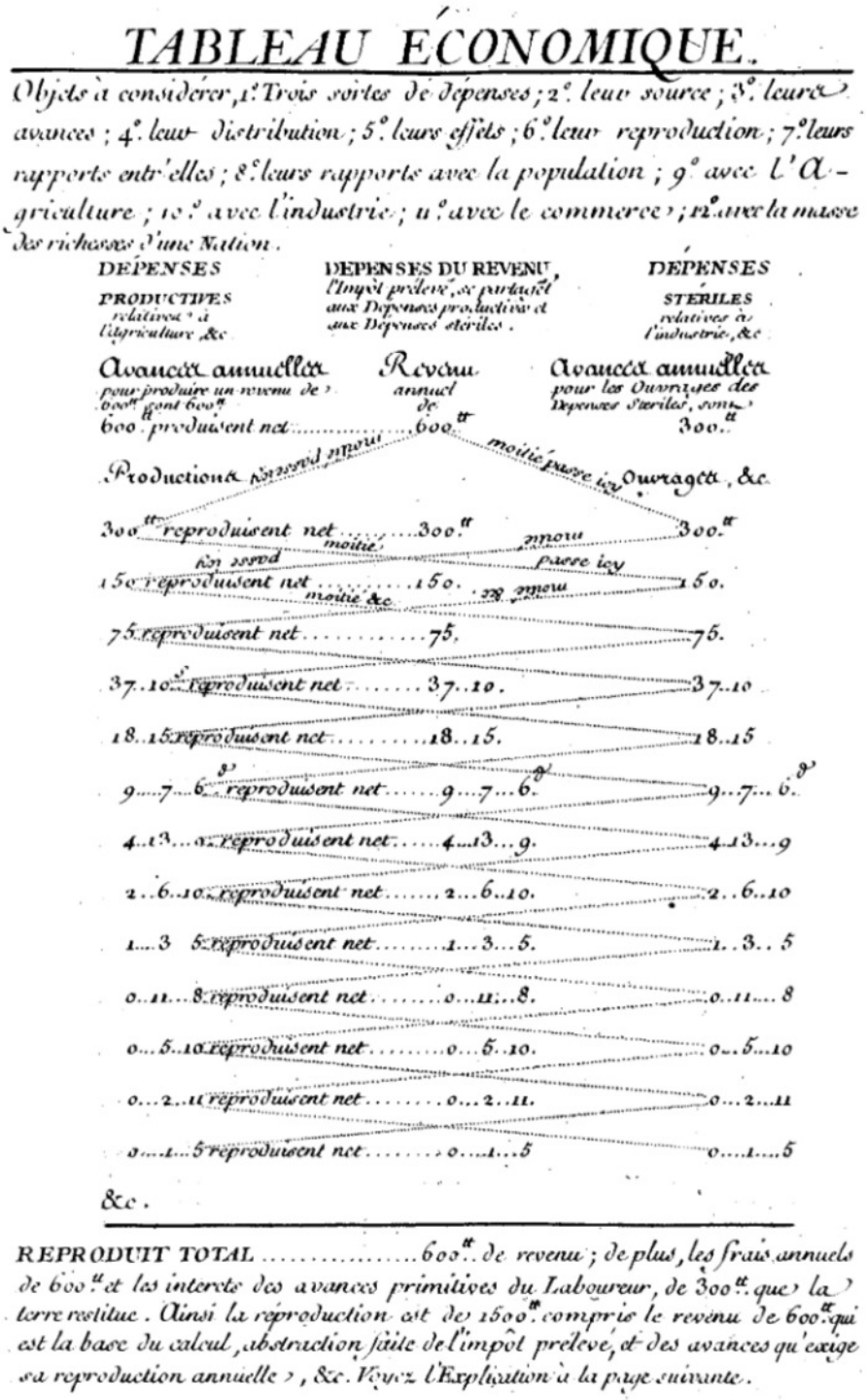

TABLEAU ÉCONOMIQUE.

Objets à considérer, 1°. Trois sortes de dépenses; 2°. leur source; 3°. leurs avances; 4°. leur distribution; 5°. leurs effets; 6°. leur reproduction; 7°. leurs rapports entr'elles; 8°. leurs rapports avec la population; 9°. avec l'Agriculture; 10°. avec l'industrie; 11°. avec le commerce; 12°. avec la masse des richesses d'une Nation.

DÉPENSES PRODUCTIVES relatives à l'Agriculture &c

DEPENSES DU REVENU, l'Impôt prélevé, se partagent aux Dépenses productives et aux Dépenses stériles.

DÉPENSES STÉRILES relatives à l'industrie, &c

Avances annuelles pour produire un revenu de 600 tt sont 600 tt

Revenu annuel de 600 tt

Avances annuelles pour les Ouvrages des Dépenses Stériles, sont 300 tt

600 produisent net ..... 600 tt

Productions moitié passe ici Ouvrages, &c

300 tt reproduisent net ..... 300 tt — 300 tt

150 reproduisent net ..... 150. — 150.

75 reproduisent net ..... 75. — 75.

37..10 reproduisent net ..... 37..10. — 37..10

18..15 reproduisent net ..... 18..15. — 18..15

9...7...6 reproduisent net ..... 9...7...6. — 9...7...6.

4..13...9 reproduisent net ..... 4..13...9. — 4..13...9

2..6..10 reproduisent net ..... 2..6..10. — 2..6..10

1...3...5 reproduisent net ..... 1...3...5. — 1...3...5

0..11...8 reproduisent net ..... 0...11...8. — 0...11...8

0...5..10 reproduisent net ..... 0...5..10. — 0...5...10

0...2..11 reproduisent net ..... 0...2..11. — 0...2...11

0...1...5 reproduisent net ..... 0...1...5 — 0...1...5

&c.

REPRODUIT TOTAL ..... 600 tt de revenu; de plus, les frais annuels de 600 tt et les interets des avances primitives du Laboureur, de 300 tt que la terre restitue. Ainsi la reproduction est de 1500 tt compris le revenu de 600 tt qui est la base du calcul, abstraction faite de l'impôt prélevé, et des avances qu'exige sa reproduction annuelle, &c. Voyez l'Explication à la page suivante.

Figure C.1 François Quesnay's *Tableau Économique*
Source: Alexander Gray. 1931. *The Development of Economic Doctrine*. London: Longman's, Green and Co. Reproduced here with permission of the publisher.

C.3 Mathematical Formalization

Achille-Nicholas Isnard, a well-known French engineer and another contemporary of the Physiocrats, was among the strongest critics of the doctrine that only agriculture was productive. In supporting his position, Isnard (1781) further developed the concept of production as a circular flow, referring to surplus value as "disposable wealth." As reported in Kurz and Salvadori (2000a), who provide detailed accounts of these developments, Isnard wrote:

> In the whole of riches, and setting aside values, there are in reality two parts, one required in production, the other destined to enjoyments …. The latter is the noble part of goods and the part which is nobly enjoyed by the proprietors. (Kurz and Salvadori, 2000a, p. 159, from Isnard, 1781, pp. 35–36.)

This notion that the accumulation of wealth depended upon the technical condition of production as well as the "exigence of nature" challenged the conclusion that industry is generally not productive. In addition, and most importantly for present purposes, Isnard was perhaps the first to represent the circular flow of income and expenditure as a system of simultaneous algebraic equations.

The framework advanced and formalized by Isnard contributed to the conceptual thinking of English classical economists Adam Smith (1776) and David Ricardo (1810–1824) in the late 1700s and early 1800s, but it was a contemporary of Ricardo's, Robert Torrens, who, in 1820, seemed to set the stage for Leontief's eventual breakthroughs. Torrens was a British army officer and owner of the influential London Globe newspaper who wrote extensively on economics and was an independent discoverer of Ricardo's principle of "comparative advantage" in international trade. Torrens (1820, 1821) postulated that the concept of economic surplus provides the key to an explanation of the share of income attributable to sources other than wages and the rate of profit.

For present purposes, the key concept in Torrens's work, described in his essay on the corn trade (Torrens, 1820), was that when one defines the agricultural rate of profit in physical terms as the ratio between net corn output and corn input (corn used as seed and consumed as food for workers) that "the exchange value of manufactured goods relative to corn is adjusted such that the same rate of profit obtains in manufacturing" (Kurz and Salvadori, 2000a, p. 161). Showing this relationship, perhaps ironically, on the one hand, essentially debunked the Physiocrats' *produit net* theory while, on the other hand, refined the analytical connection between profits and various factors of production as depicted in the *Tableau Économique*.

Later on in the century, now more than a century after Quesnay's work and nearly half a century since Torrens's ideas were put forth, another French economist, Léon Walras, applied concepts of Isaac Newton's mechanics of motion in developing the early notions of a theory of what we call today *general equilibrium* in economics, although some historians of economic thought credit Quesnay's *Tableau* as "the first

method ever devised in order to convey an explicit conception of the nature of economic equilibrium" (Schumpeter, 1954, p. 217).

Walras's work, presented mostly in Walras (1874), utilized a set of production coefficients that related the quantities of factors required to produce a unit of a particular product to levels of total production of that product. Walras's ideas were heavily influenced by Isnard's earlier algebraic formulation.

At the turn of the twentieth century the published work of Karl Marx (probably the most influential socialist thinker to emerge in the nineteenth century but whose work was largely published posthumously near the turn of the century), revealed that Marx was an outspoken champion of the Physiocrats' theories in perhaps another twist of irony in this historical path – a socialist espousing *laissez-faire*. Marx considered the Physiocrats to be "the true fathers of modern political economy" (Marx, 1894 and 1905, with additional discussion in Kurz and Salvadori, 2000a). Marx argued that the concept of the *Tableau* was unduly neglected by the classical economic theorists for most of the nineteenth century and essentially resurrected it in his own work.

Marx developed a sequential or what he termed "successivist" procedure for determining profits and then prices, which was ultimately proved flawed by Russian mathematical economists Vladimir K. Dmitriev (1898) and Ladislaus von Bortkiewicz (1907), who demonstrated that the rate of profit and prices must be determined *simultaneously* rather than *successively*, consistent with the emerging ideas that would ultimately become the modern concept of *general equilibrium*.

Von Bortkiewicz, born in St. Petersburg but of Polish ancestry, was among the most ardent critics of Marx's work. He spent much of his career teaching economics and statistics at the University of Berlin, where one of his students was the young Wassily Leontief. Von Bortkiewicz (1907) was instrumental in demonstrating the concept of general equilibrium, contradicting Marx's view, and most importantly expressing his framework mathematically in an algebraic form. In particular, he assumed that commodities are produced from a fixed level of each input for each unit for commodity output, i.e., what we now often refer to as a *linear* production function.

C.4 Leontief and the "Economy as a Circular Flow"

Wassily Wassilievich Leontief was born in 1905 in Munich into an intellectual Russian family and spent his childhood in St. Petersburg during the years leading up to the Russian Revolution in 1917. In 1921, at the age of fifteen, he was arrested for opposing the communist dictatorship as it was emerging. The young Leontief was a brilliant student and was released to enter the University of Leningrad that same year to study economics following in the footsteps of his father. Following surgery on his jaw in 1925, he was permitted to leave Communist Russia under an exit visa to obtain follow-up diagnosis and treatment in Berlin (Samuelson, 2004, and Kaliadina and Pavlova, 2006).

Leontief decided not to return to Russia and entered the University of Berlin to work with von Bortkiewicz and social scientist Werner Sombart on his doctorate, which he received in 1929.[7] In the late 1920s Leontief began to assemble the ideas for his doctoral thesis, which he described as "the national economy as a circular process," drawing on Quesnay's *Tableau* and on Walras's formalization of general equilibrium, although Leontief preferred the term "interdependence," concluding that an economy is never in equilibrium (DeBresson, 2004). In 1928 he published part of his thesis in the paper, "The Economy as a Circular Flow" (Leontief, 1928), where he set forth a two-sector "input–output" system that depicted production, distribution, and consumption characteristics of an economy as a single integrated system of linear equations. Complete exposition of his analytical framework would not come for nearly another decade in Leontief (1936).

Concepts similar to Leontief's were being conceived at the time of his original work by the Italian economist Piero Sraffa (Sraffa, 1960, and described in Kurz and Salvadori, 2000b and 2003). In addition a French mathematician, Father Maurice Potron, developed similar ideas in his writings between 1911 and 1941 (Abraham-Frois and Lendjel, 2006). Despite the somewhat parallel tracks of Leontief, Sraffa, and Potron, it was likely the intense focus on empirical implementation that ultimately led to widespread use of Leontief's framework (Kurz and Salvadori, 2006, and Bjerkholt and Kurz, 2006). Some theorists characterize Leontief's model as an approximation of the Walrasian model[8] introduced a century earlier, but with several important simplifications that allowed a theory of general equilibrium to be applied and implemented empirically. Leontief felt, even very early in his career, that economists placed far too little attention on empirical verification (DeBresson, 2004).[9]

Leontief (1941, p. 9) introduces his later empirical work by stating that "this work may be best described as an attempt to construct a *Tableau Économique* of the United States." Indeed, in Quesnay's later work (discussed in Phillips, 1955, and more recently in Steenge and van den Berg, 2007), he placed his observations about circular flow transactions in the form of a table that resembles the input–output table developed by Leontief. Quesnay's original schematic is shown as Figure C.1. However, Leontief's contributions went far beyond that of constructing the *Tableau* or the table of transactions. As can be seen in this volume, in particular, Leontief devised the analytical foundations that transformed the descriptive nature of the *Tableau* into an empirical analytical tool and, today, Leontief's input–output analysis has become one of the most widely applied methods in economics (Baumol, 2000).

[7] Some fascinating anecdotes of this impressionable time in Leontief's life are provided in DeBresson (2004).
[8] In Leontief's first book (Leontief, 1941), *The Structure of American Economy*, he referred to only three other economists' works: François Quesnay, Léon Walras, and David Ricardo.
[9] In 1971 Leontief, serving as president of the American Economic Association that year, delivered his presidential address entitled "Theoretical Assumptions and Non-observed Facts," which took the economics profession to task for failing to underscore the need for empirical verification of economic theory.

C.5 Development of Input–Output Analysis

Following his graduate studies in Berlin, Leontief joined the staff of the Institute of World Economics in Kiel in 1927 where he carried out research on derivation of statistical demand and supply curves. After a year-long assignment as an advisor to the China Ministry of Railroads, Leontief moved to New York to join Simon Kuznets at the National Bureau of Economic Research in 1931. In the following year Joseph Schumpeter brought Leontief to the faculty at Harvard University where he began work on the first input–output tables for the US economy.

With Leontief's arrival at Harvard also came the university's first mathematical lectures on economics, although he seldom included his own research in his lectures (Solow, 1998, and Samuelson, 2004). In 1936 Leontief presented the theoretical framework for input–output analysis and US interindustry transactions tables for 1919 and 1929 (Leontief, 1936), followed somewhat later by his first book on the input–output structure of the US economy (Leontief, 1941).

Beginning in 1941, just prior to US entry into World War II, Leontief in collaboration with the US Government's Bureau of Labor Statistics (BLS), began preparation of a US transactions table for 1939, which was essentially completed in 1943 (Kholi, 2000 and 2001) to be used by the War Mobilization Board for planning postwar demobilization and, in particular, analyzing the implications of decreases in war spending and increases in personal consumption through detailed projections of employment by industry in the US economy.

Also during the war, Leontief was called upon to work for the Office of Strategic Services (OSS), an early predecessor of today's Central Intelligence Agency, to assemble a classified input–output table for Germany for war planning and, later, to analyze the issue of postwar German reparations.[10]

In implementing his empirical work Leontief made use of the first large scale mechanical computing machinery in 1935 and later the first commercial electro-mechanical computer, the IBM Automatic Sequence Controlled Calculator (called the Mark I), originally designed under the direction of Harvard mathematician Howard Aiken in 1939, built and operated by IBM engineers in Endicott, New York for the US Navy, and eventually moved to Harvard in 1944.

Following World War II, in 1948, as the Cold War loomed, a government interagency project funded by the Air Force's Planning Research Division, known as Scientific Computation of Optimum Programs (SCOOP), was initiated to update the 1939 US interindustry transactions table to 1947. In that same year Leontief founded the Harvard Economics Research Project (HERP), which focused on continuing to develop the input–output framework and applications. Project SCOOP's activities were greatly expanded as the Korean War erupted in 1950 to include analysis of possible obstructions

[10] According to Leontief's second protégé at Harvard, Paul Samuelson, the OSS involvement of Leontief's work during World War II was initiated with the help of Leontief's first protégé, Abram Bergson, who during the war had become head of the OSS Russian desk (Samuelson, 2005).

to wartime mobilization (Kohli, 2001) and much progress was made in the ability to work with large-scale input–output tables of more than 500 industrial sectors (Klein, 2001), although Leontief and others published only much more aggregated tables at the time. For example, Leontief's 1951 revision of his 1941 book (Leontief, 1951) was enlarged and expanded and included the US input–output table for 1939 (previously unpublished by BLS) and Evans and Hoffenberg (1952) published the 1947 table.

In the postwar period, input–output accounts began to be routinely developed in the United States and elsewhere around the world, although ironically for a period during the Cold War era, the US suspended work on constructing input–output tables because it smacked of communist "central planning" while, at around the same time, the Chinese Government shut down its preparation of input–output tables because it considered input–output to be a tool of capitalism (Polenske, 1999). The US Bureau of Economic Analysis (BEA) began preparing the US national input–output tables with the 1958 table published in 1964, and since then so-called "benchmark" tables have been published every five years corresponding to the quinquennial national economic census (every five years for years ending with 2 and 7, e.g., 1992, 1997, 2002, and 2007)[11], since the primary source of data for the input–output accounts is the national economic census. A key use of the input–output accounts in the United States since BEA began preparing them was and continues to be as a tool for, and a check on the accuracy and consistency of, a variety of other economic accounts (Landefeld and McCulla, 1999). Since 1957, input–output tables have also been routinely constructed in the United Kingdom, Norway, Denmark, the Netherlands, Italy, Canada, Japan and increasingly many other countries around the world.

Of particular importance in making input–output analysis a widely applied tool of economic analysis was the development of a standardized system of economic accounts built around input–output concepts developed under the direction of Richard Stone (Stone, 1961) in recognition of which he received the Nobel Prize in Economic Science in 1984 (Stone, 1997).

Further additional developments to Leontief's original model are presented in, among others, Leontief *et al.* (1953) and Leontief (1966a, 1966b, and 1974) and in volumes of proceedings of many international conferences on input–output techniques summarized in Table C.1. Summaries of many of these developments are included in Stone (1984) and Rose and Miernyk (1989).

Leontief's work as HERP's director continued until 1973 (Polenske, 1999) and, after 44 years, he left Harvard in 1975, but continued his research and teaching on input–output at New York University until his death at age 93 in 1999. Professor Leontief's legacy is rich and vast, as illustrated by the scale and scope of the topics that have followed from his original work that are described in this volume.

[11] Highly aggregated versions of these tables are included in Appendix B.