

1 Introduction and Overview

1.1 Introduction

Input–output analysis is the name given to an analytical framework developed by Professor Wassily Leontief in the late 1930s, in recognition of which he received the Nobel Prize in Economic Science in 1973 (Leontief, 1936, 1941). One often speaks of a Leontief model when referring to input–output. The term *interindustry analysis* is also used since the fundamental purpose of the input–output framework is to analyze the interdependence of industries in an economy. Today the basic concepts set forth by Leontief are key components of many types of economic analysis and, indeed, input–output analysis is one of the most widely applied methods in economics (Baumol, 2000). This book develops the framework set forth by Leontief and explores the many extensions that have been developed over the last 85 years.

In its most basic form, an input–output model consists of a system of linear equations, each one of which describes the distribution of an industry’s product throughout the economy. Most of the extensions to the basic input–output framework are introduced to incorporate additional detail of economic activity, such as over time or space, to accommodate limitations of available data or to connect input–output models to other kinds of economic analysis tools. This book is an updated and considerably expanded edition of our earlier versions of this textbook (Miller and Blair, 1985, 2009).

In this chapter we introduce the basic input–output analysis framework and outline the topics to be covered in the balance of the text. Appendix C provides a historical account of the work leading up to Leontief’s formulation and its subsequent development and refinement. More detailed historical accounts of the early development of input–output analysis and input–output accounts are given in Polenske and Skolka (1976, chapter 1) and Stone (1984). An extensive history of applications of input–output analysis since Leontief’s introduction of it is provided in Rose and Miernyk (1989). In the present text we cover many of the developments in input–output since its widespread application as an analysis tool began in the early 1950s. Leontief himself participated in a number of these developments and applications, as will be evident throughout this text (see also Polenske, 1999, 2004).

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The widespread availability of high-speed digital computers has made Leontief's input–output analysis a widely applied and useful tool for economic analysis at many geographic levels – local, regional, national, and even international. Prior to the appearance of modern computers, the computational requirements of input–output models made them difficult and even impractical to implement. Today, in the USA alone, input–output is routinely applied in national economic analysis by the US Department of Commerce, and in regional economic planning and analysis by states, industry, and the research community. The model is widely applied throughout the world; the United Nations has promoted input–output as a practical planning tool for developing countries and has sponsored a standardized system of economic accounts for constructing input–output tables. Also, interactions among nations of the world are promoted by various international organizations such as the Organization for Economic Co-operation and Development, the Asian Development Bank, the Institute of Development Economics, IDE-JETRO, and research consortia, such as the World Input-Output Database, the Global Multi-region input–output Database known as EORA, the global multi-regional environmentally extended supply and use / input–output database known as EXIOBASE, or the emerging collection of intercountry input–output tables, Full International and Global Accounts for Research in Input–Output Analysis known as FIGARO, being prepared by the European Commission agency, Eurostat.

Input–output has also been extended to be part of an integrated framework of employment and social accounting metrics associated with industrial production and other economic activity, as well as to accommodate more explicitly such topics as international and interregional flows of products and services or accounting for energy consumption and environmental pollution associated with interindustry activity. In this text, we present the foundations of the input–output model as originally developed by Leontief, as well as the evolution of many methodological extensions to the basic framework. In addition, we illustrate many of the applications of input–output and its usefulness for practical policy questions. Throughout the text, we will review some of the current research frontiers.

1.2 Input–Output Analysis: The Basic Framework

The basic Leontief input–output model is generally constructed from observed economic data for a specific geographic region (nation, state, county, etc.). One is concerned with the activity of a group of industries that both produce goods (outputs) and consume goods from other industries (inputs) in the process of producing each industry's own output. In practice, the number of industries considered may vary from only a few to hundreds or even thousands. For instance, an industrial sector title might read “manufactured products,” or that same sector might be broken down into many different specific products.

The fundamental information used in input–output analysis concerns the flows of products from each industrial sector, considered as a producer, to each of the sectors,

itself and others, considered as consumers. This basic information from which an input–output model is developed is contained in an interindustry transactions table. The rows of such a table describe the distribution of a producer’s output throughout the economy. Each column describes the composition of inputs required by a particular industry to produce its output. These interindustry exchanges of goods constitute the shaded portion of Table 1.1. The additional columns, labeled *Final Demand*, record the sales by each sector to final markets for their production, such as personal consumption purchases and sales to the federal government. For example, electricity is sold to businesses in other sectors as an input to production (an interindustry transaction), and also to residential consumers (a final-demand sale). The additional rows, labeled *Value Added*, account for the other (non-industrial) inputs to production, such as labor, depreciation of capital, indirect business taxes, and imports.

The formulation of analytical models using the basic input–output data as just described is the principal purpose of this text. There is considerable literature devoted to assembling the basic data used in input–output models from surveys or interpretation of other primary and secondary sources of economic data. Some of this literature is referenced in Chapter 4, but, for the most part, in this text we focus on the formulation of models using available data or on methods to compensate for the lack of available data.

1.3 Outline for This Text

This text is organized into 15 chapters, beginning with the theory and assumptions of the basic input–output framework, then exploring many of the extensions developed over the last six decades. The text deals mostly with methodological developments, but also covers some of the practical issues associated with implementation of input–output models, including many references to the applied literature. Chapters 2–6 cover the main methodological considerations in input–output analysis. Chapters 7–14 cover many issues associated with the application of input–output analysis to practical problems. The concluding chapter, Chapter 15, sketches a range of relevant topics for which available space did not permit a more detailed treatment or that were beyond the scope of this text. The following describes the main topics covered in each chapter:

- Chapter 2 introduces Leontief’s conceptual input–output framework and explains how to develop the fundamental mathematical relationships from the interindustry transactions table. The key assumptions associated with the basic Leontief model and implications of those assumptions are recounted and the economic interpretation of the basic framework is explored. The basic framework is illustrated with a highly aggregated model of the US economy. In addition, the “price model” formulation of the input–output framework is introduced to explore the role of prices in input–output models. Appendices (some of which appear in the supplementary online resources for this text, <http://www.cambridge.org/millerandblair>) to this chapter

Table 1.1 *Input–output transactions table*

		Industry Producers as Consumers							Fin	
		Agric.	Mining	Const.	Manuf.	Trade	Transp.	Services	Other	Personal Consum Expendi
Industry Producers	Agriculture									
	Mining									
	Construction									
	Manufacturing									
	Trade									
	Transportation									
	Services									
	Other Industry									
Value Added	Employees	Employee Compensation								
	Business Owners and Capital	Profit-type income and capital consumptions allowances								
	Government	Indirect Business Taxes								

include a fundamental set of mathematical conditions for input–output models, known as the Hawkins–Simon conditions.

- Chapter 3 extends the basic input–output framework to analysis of regions and the relationships between regions. First, “single-region” models are presented and the various assumptions employed in formulating regional models versus national models are explored. Next, the structure of an interregional input–output (IRIO) model, designed to expand the basic input–output framework to capture transactions between industrial sectors in regions, is presented. An important simplification of the IRIO model designed to deal with the most common of data limitations in constructing such models is known as the multiregional input–output (MRIO) model. The basic MRIO formulation is presented and the implications of the simplifying assumptions explored along with the balanced regional model which captures the distinction between industrial production for regional versus national markets. Finally, the chapter summarizes the fast-growing range of applications of MRIO to multinational and global economic models and issues. Several appendices to this chapter provide additional development of mathematical tools helpful for conceptualizing and implementing regional models, as well as additional mathematical refinements for MRIO and balanced regional models. Additional appendices explore more detailed MRIO examples.
- Chapter 4 deals with the construction of input–output tables from standardized conventions of national economic accounts, such as the widely-used System of National Accounts (SNA) promoted by the United Nations, including a basic introduction to the so-called commodity-by-industry or supply–use input–output framework developed in additional detail in Chapter 5. A simplified SNA is derived from fundamental economic concepts of the circular flow of income and expenditure, that, as additional sectoral details are defined for businesses, households, government, foreign trade, and capital formation, ultimately results in the basic commodity-by-industry formulation of input–output accounts. The process is illustrated with the US input–output model and some of the key traditional conventions widely applied for such considerations as secondary production (multiple products or commodities produced by a business), competitive imports (commodities that are also produced domestically) versus non-competitive imports (commodities not produced domestically), trade and transportation margins on interindustry transactions, or the treatment of scrap and secondhand goods. Finally, the chapter concludes with an examination of issues associated with the level of sectoral and spatial detail in input–output models, e.g., the potential bias introduced by the level of aggregation of industries or regions. Appendices to this chapter illustrate the implications of aggregation bias using IRIO and MRIO models for Japan and the USA.
- Chapter 5 explores variations to the commodity-by-industry input–output framework introduced in Chapter 4, expanding the basic input–output framework to include distinguishing between commodities and industries, i.e., the supply of specific commodities in the economy and the use of those commodities by collections of businesses defined as industries. The chapter introduces the fundamental

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commodity-by-industry accounting relationships and how they relate to the basic input–output framework. Alternative assumptions are defined for handling the common accounting issue of secondary production, and economic interpretations of those alternative assumptions are presented. The formulations of commodity-driven and industry-driven models are also presented, along with illustrations of variants on combining alternative assumptions for secondary production. Finally, the chapter illustrates the problem encountered with commodity-by-industry models, such as non-square commodity–industry systems, mixed technology options, or the interpretation of negative elements. Appendices to this chapter provide some alternative derivations of commodity-by-industry transactions matrices, methods for eliminating negative entries in specific types of commodity-by-industry models where appearance of such entries is most common, and additional observations on non-square commodity-by-industry systems.

- Chapter 6 examines key summary analytical measures known as multipliers that can be derived from input–output models to estimate the effects of exogenous changes on (1) new outputs of economic sectors, (2) income earned by households resulting from new outputs, and (3) employment generated from new outputs, or (4) value-added generated by production. The general structure of multiplier analysis and special considerations associated with regional, IRIO, and MRIO models are developed. Extensions to capture the effects of income generation for various household groups are explored, as well as additional multiplier variants and decomposition into meaningful economic components. Chapter appendices expand on mathematical formulations of household and income multipliers.
- Chapter 7 presents the so-called supply side input–output model. It is discussed both as a quantity model (the early interpretation) and as a price model (the more modern interpretation). Relationships to the standard Leontief quantity and price models are also explored. In addition, the fast-growing literature on quantification of economic linkages and analysis of the overall structure of economies using input–output data is examined. Finally, approaches for identifying key or important coefficients in input–output models and alternative measures of coefficient importance are presented.
- Chapter 8 introduces and illustrates the basic concepts of structural decomposition analysis (SDA) within an input–output framework. The concept of decomposition of multipliers, introduced in Chapter 6, is revisited later in Chapter 11 applied to Social Accounting Matrices (SAMs) as a way to analyze economic structure. The application of SDA to MRIO is developed to introduce a spatial context. The chapter explores many applications and summaries of their results. Appendices (some of which appear in the supplementary online resources for this text, <http://www.cambridge.org/millrandblair>) to this chapter develop extended presentations of additional decomposition results as well as an overview of early applied studies and some further mathematical results.
- Chapter 9 introduces approaches designed to deal with the major challenge in input–output analysis that the kinds of information-gathering surveys needed to collect input–output data for an economy can be expensive and very time consuming, resulting in tables of input–output coefficients that are outdated before they are

produced. These techniques, known as partial survey and nonsurvey approaches to input–output table construction, are central to modern applications of input–output analysis. The chapter begins by reviewing the basic factors contributing to the stability of input–output data over time, such as changing technology, prices, and the scale and scope of business enterprises. Several techniques for updating input–output data are developed, and the economic implications of each described. The bulk of the chapter is concerned with the widely utilized biproportional scaling (or RAS) technique and some related “hybrid model” variants.

- Chapter 10 surveys a range of partial survey and nonsurvey estimation approaches for creating input–output tables at the regional level. Variants of the commonly used class of estimating procedures using location quotients are reviewed; these presume a regional estimate of input–output data can be derived using some information about a target region. The RAS technique developed in Chapter 9 is applied using a base national table or a table for another region and some available data for the target region. Techniques for partial survey estimation of commodity flows between regions are also presented, along with discussions of several real-world multinational applications, including the China–Japan Transnational Interregional Model, Leontief’s World Model, and models from the Global MRIO Lab.
- Chapter 11 expands the input–output framework to a broader class of economic analysis tools known as social accounting matrices (SAM) and other so-called extended input–output models to capture activities of income distribution in the economy in a more comprehensive and integrated way, including especially employment and social welfare features of an economy. The basic concepts of SAMs are explored and derived from the SNA introduced in Chapters 4 and 5, and the relationships between SAMs and input–output accounts are presented. The concept of SAM multipliers as well as the decomposition of SAM multipliers into components with specific economic interpretations are introduced and illustrated. Finally, techniques for balancing SAM accounts for internal accounting consistency are discussed, and several illustrative applications of the use of SAMs are presented.
- Chapter 12 explores the extension of the input–output framework to more detailed analysis of energy consumption associated with industrial production, including some of the complications that can arise when measuring input–output transactions in physical units of production rather than in monetary terms of the value of production. The chapter reviews early efforts to develop energy input–output analysis, compares them with contemporary approaches, and examines the strengths and limitations of the alternatives commonly used today. Special methodological considerations such as adjusting for energy conversion efficiencies are developed along with several illustrative applications, including estimation of the energy costs of goods and services, impacts of new energy technologies, and energy taxes. Finally, the role of structural change of an input–output economy associated with changing patterns of energy use is illustrated, building on the more general approaches to structural decomposition analysis using input–output models developed in Chapter 8. An appendix to this chapter, included in the supplementary online

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- resources for this text (<http://www.cambridge.org/millerandblair>), develops the strengths and limitations of alternative energy input–output formulations in more detail.
- Chapter 13 reviews the extensions of the input–output framework to incorporate activities of environmental pollution and elimination associated with economic activities as well as the linkages of input–output to models of ecosystems. The chapter begins with the augmented Leontief model for incorporating pollution generation and elimination, from which many subsequent approaches have been developed. The chapter then describes the now widespread application of input–output analysis to environmental lifecycle assessment and establishing a “pollution footprint” for industrial activity. The special case of analyzing the relationship between global climate change and industrial activity with a carbon footprint is then explored along with using input–output to attribute pollution generation to the demands driving consumption compared with the more traditional attribution of pollution generation to the sectors of industrial production necessary to meet that demand. The chapter continues with a “generalized” input–output framework which assumes that pollution generation (as well as other measurable factors associated with industrial production, such as energy or material consumption measured in physical units or employment measured in person-years) simply vary in direct proportion to the level of industrial production. Applications are presented of the generalized input–output formulation to measuring impacts of specified changes to industrial activity and to planning problems where the objective is to seek an optimal mix of industrial production subject to input–output relationships between industrial sectors and to constraints on factors associated with industrial production, such as pollution, energy use, and employment. In exploring the application of the generalized input–output framework to planning problems, basic concepts of linear and multi objective programming are introduced. Finally, expansion of the input–output framework to include ecologic sectors as a means to trace more comprehensively economic–ecosystem relationships is presented along with a variety of illustrative applications.
 - Chapter 14 describes so-called mixed input–output models that are driven by a mix of output and final demand specifications rather than driven either solely by specification by final demand or total output. This chapter also introduces dynamic input–output models that more explicitly capture the role of capital investment and utilization in the production process.
 - Chapter 15 briefly describes some additional extensions to input–output analysis for which space does not permit a detailed treatment in this text, including measuring total factor productivity, modeling economic impacts of disasters, the inoperability input–output model, accounting for alternative technologies, and linkages to economic or computable general equilibrium models.
 - Appendix A is an introductory review of matrix algebra concepts and methods used throughout this text, including matrix operations such as addition, multiplication, transposition, inversion, and partitioning.
 - Appendix B summarizes a highly aggregated series of the US input–output tables referenced and used in exercise problems in a number of chapters or in the exercise problems and solutions associated with each chapter. The data, exercise problems,

and solutions, and a number of other data sets referenced throughout this text are included in supplementary appendices included on the Internet website associated with this book (<http://www.cambridge.org/millerandblair>) and summarized in Section 1.4.

- Appendix C provides an historical account of the early development of input–output analysis, including a “pre-history” of the concepts that led to Leontief’s work as well as the many methodological developments and applications since.

1.4 Internet Website and Text Locations of Real Datasets

A website associated with this text, <http://www.cambridge.org/millerandblair>, includes supplementary appendices in three general areas: (1) additional text (appendices) in selected areas that were not possible to include in the printed text for a variety of reasons, (2) exercise problems and solutions aligned with chapters of this text along with a computational workbook providing expanded discussion of the problems and solutions, and (3) downloadable datasets of many of the examples and problems printed in the text, as well as a library of supplementary real but highly aggregated datasets referenced throughout this text for various regions and nations as well as illustrative interregional input–output (IRIO) and multiregional input–output (MRIO) data and social accounting matrices (SAM). As noted, additional details about these supplemental resources are included in Appendix B.

References

- Baumol, William. 2000. “Leontief’s Great Leap Forward,” *Economic Systems Research*, **12**, 141–152.
- Leontief, Wassily. 1936. “Quantitative Input–Output Relations in the Economic System of the United States,” *Review of Economics and Statistics*, **18**, 105–125.
1941. *The Structure of American Economy 1919–1939*. New York: Oxford University Press.
- Miller, Ronald E. and Peter D. Blair. 1985. *Input–Output Analysis: Foundations and Extensions*. Englewood Cliffs, NJ: Prentice-Hall.
2009. *Input–Output Analysis: Foundations and Extensions* (Second Edition). Cambridge: Cambridge University Press.
- Polenske, Karen R. 1999. “Wassily W. Leontief, 1905–1999,” *Economic Systems Research*, **11**, 341–348.
2004. “Leontief’s ‘Magnificent Machine’ and Other Contributions to Applied Economics,” in Erik Dietzenbacher and Michael L. Lahr (eds.), *Wassily Leontief and Input–Output Economics*. New York: Cambridge University Press, pp. 9–29.
- Polenske, Karen R. and Jiří V. Skolka (eds.). 1976. *Advances in Input–Output Analysis. Proceedings of the Sixth International Conference on Input–Output Techniques*. Vienna, April 22–26, 1974. Cambridge, MA: Ballinger.
- Rose, Adam and William Miernyk. 1989. “Input–Output Analysis: The First Fifty Years,” *Economic Systems Research*, **1**, 229–271.
- Stone, Richard. 1984. “Where Are We Now? A Short Account of Input–Output Studies and Their Present Trends,” in *United Nations Industrial Development Organization (UNIDO), Proceedings of the Seventh International Conference on Input–Output Techniques*. New York: United Nations, pp. 439–459. [Reprinted in Ira Sohn (ed.). 1986. *Readings in Input–Output Analysis*. New York: Oxford University Press, pp. 13–31.]