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 nearly three quarters of a century.

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 1985 textbook (Miller and Blair, 1985).

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). A fairly complete 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).

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 very 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.

Input–output has been also 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. The columns describe the composition of inputs required by a particular industry to produce its output. These interindustry exchanges of goods constitute the shaded portion of the table depicted in Figure 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)

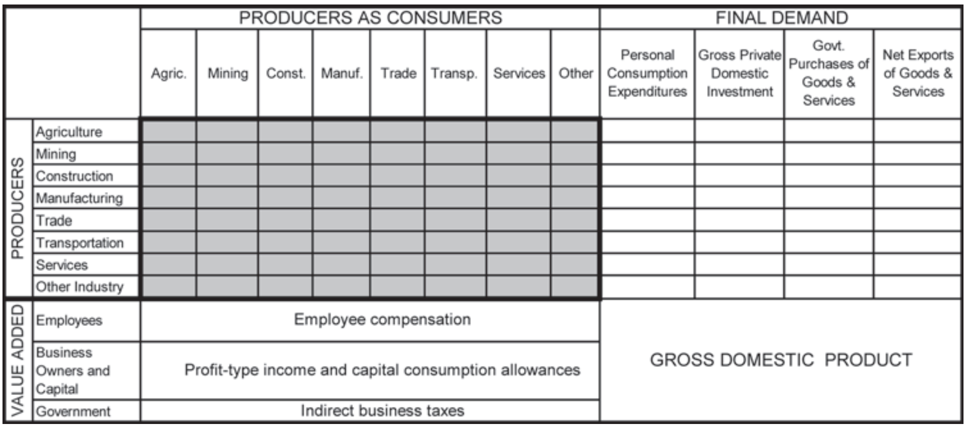

Figure 1.1 Input–Output Transactions Table

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 a 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 14 chapters, beginning with the theory and assumptions of the basic input–output framework, then exploring many of the extensions developed over the last half century. 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 7–13 cover many issues associated with the application of input–output analysis to practical problems. The concluding chapter, Chapter 14, sketches a number 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 to this chapter 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. Next the balanced regional model is presented, which is mathematically identical to the IRIO framework, but is designed conceptually to capture the distinction between industrial production for regional versus national markets as opposed to delivery to specific regions as in the IRIO framework. In the final section a number of applied studies are cited in order to illustrate the extraordinary range of geographic scale reflected in real-world studies – from sub-city neighborhoods to so-called "world" models. Appendices to this chapter provide additional development of mathematical tools helpful for conceptualizing and implementing regional models.
- 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 result 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.

The appendices 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 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 a variety of special circumstances encountered with commodity-by-industry models, such as nonsquare commodity–industry systems 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 nonsquare commodity-by-industry systems are provided in an appendix on this text's website (www.cambridge.org/millerandblair).
- Chapter 6 examines a number of 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 a number of mathematical formulations of household and income multipliers.
- Chapter 7 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 biproportional scaling (or RAS) technique and some "hybrid model" variants.

- Chapter 8 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, which presume a regional estimate of input–output data can be derived using some information about a target region. The RAS technique developed in Chapter 7 is applied to developing regional input–output tables using a base national table or a table for another region and some available data for the target region. These are illustrated using data from a three-region model for China. 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 and Leontief's World Model.
- Chapter 9 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. Early approaches to energy input–output analysis are reviewed and compared with contemporary approaches and the strengths and limitations of alternative approaches are examined. Special methodological considerations such as adjusting for energy conversion efficiencies are developed and a number of illustrative applications are presented, 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 introduced (more general approaches to structural decomposition analysis using input–output models are covered in Chapter 13). The appendix to this chapter develops more formally the strengths and limitations of alternative energy input–output formulations.
- Chapter 10 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 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 multiobjective programming are introduced. The chapter also explores augmenting a basic Leontief input–output model with pollution generation and elimination sectors. Finally, expansion of the input–output framework to include ecologic sectors to more comprehensively trace

economic–ecosystem relationships is presented along with a variety of illustrative applications.

- 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 a number of illustrative applications of the use of SAMs are presented.
- Chapter 12 presents the so-called supply side input–output model, with which the name Ghosh is most often associated. 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 13 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 and in Chapter 10 as applied to SAMs is revisited as a way to analyze economic structure. The application of SDA to MRIO is developed to introduce a spatial context, many applications are cited and summaries of their results are presented. Next, mixed endogenous–exogenous models are explored. These models expand upon the standard input–output model by allowing for exogenous specification of both (some) final demands and (some) outputs. This chapter also introduces dynamic input–output models that more explicitly capture the role of capital investment and utilization in the production process. Appendices develop extended presentations of additional decomposition and mixed-model results.
- Chapter 14 briefly describes some additional extensions to input–output analysis for which space does not permit a detailed treatment, including linkages to econometric models, computable general equilibrium models, and measuring economic productivity.
- Appendix A is an introductory review of matrix algebra concepts and methods used throughout this text.
- Appendix B presents a highly aggregated series of the US input–output tables referenced and used in end-of-chapter problems in a number of chapters or in supplementary problems included on the Internet website associated with this book (www.cambridge.org/millerandblair).

Table 1.1 Illustrative Real Input–Output Data Locations

Data	Location
US Domestic Direct Requirements Matrix, 2003	Table 2.7
US Domestic Total Requirements Matrix, 2003	Table 2.8
Chinese Interregional and Intraregional Transactions, 2000	Table 3.7
Direct Input Coefficients for the Chinese Multiregional Economy, 2000	Table 3.8
Leontief Inverse Matrix for the Chinese Multiregional Economy, 2000	Table 3.9
Four-Region, Three-Sector IRIO Model for the USA and Asia	Prob. 3.9
Three-Region, Five-Sector IRIO Model for Japan, 1965	Table A4.1.1
Three-Region, Five-Sector MRIO Model for the USA, 1963	Table A4.1.3
Components of US Total Commodity Final Demand, 2003	Table 5.11
Seven-Sector US Input–Output Tables for 1997, 2003, and 2005	Prob. 7.1
Seven-Sector Direct Input Coefficients Outputs for Washington State, 1997	Prob. 8.10
Input–Output Transactions for the US Economy in Hybrid Units, 1967	Table 9.5
Technical Coefficients for the US Economy in Hybrid Units, 1967	Table 9.6
Leontief Inverse for the US Economy in Hybrid Units, 1967	Table 9.7
Nine-Sector Hybrid Units US Technical Coefficients, 1963 and 1980	Prob. 9.10
Macro SAM for Sri Lanka, 1970	Prob. 11.5
Macro SAM for the US Economy, 1988	Prob. 11.8
SAM with Expanded Interindustry Detail for the USA, 1988	Table 11.22
Selected US Input–Output Tables, 1919–2006	Appendix B

- 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, www.cambridge.org/millerandblair, includes supplementary information 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) solutions to end-of-chapter problems as well as supplementary problems, case studies, and suggested input–output analysis experiments and study projects and (3) downloadable datasets of many of the examples and problems printed in the text as well as a library of supplementary real-world datasets and references to additional data that have come to our attention.

Throughout this text, in various illustrative examples and problems, we employ real but highly aggregated input–output related data for various regions and nations as well as illustrative interregional input–output (IRIO) and multiregional input–output (MRIO) data and social accounting matrices (SAM). For convenience, Table 1.1 shows a listing of these sets of data and their locations in this text.

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2 Foundations of Input–Output Analysis

2.1 Introduction

In this chapter we begin to explore the fundamental structure of the input–output model, the assumptions behind it, and also some of the simplest kinds of problems to which it is applied. Later chapters will examine the special features that are associated with regional models and some of the extensions that are necessary for particular kinds of problems – for example, in energy or environmental studies or as part of a broader system of social accounts.

The mathematical structure of an input–output system consists of a set of n linear equations with n unknowns; therefore, matrix representations can readily be used. In this chapter we will start with more detailed algebraic statements of the fundamental relationships and then go on to use matrix notation and manipulations more and more frequently. Appendix A contains a review of matrix algebra definitions and operations that are essential for input–output models. While solutions to the input–output equation system, via an inverse matrix, are straightforward mathematically, we will discover that there are interesting economic interpretations to some of the algebraic results.

2.2 Notation and Fundamental Relationships

An input–output model is constructed from observed data for a particular economic area – a nation, a region (however defined), a state, etc. In the beginning, we will assume (for reasons that will become clear in the next chapter) that the economic area is a country. The economic activity in the area must be able to be separated into a number of segments or producing sectors. These may be industries in the usual sense (e.g., steel) or they may be much smaller categories (e.g., steel nails and spikes) or much larger ones (e.g., manufacturing). The necessary data are the flows of products from each of the sectors (as a producer/seller) to each of the sectors (as a purchaser/buyer); these *interindustry* flows, or transactions (or intersectoral flows – the terms *industry* and *sector* are often used interchangeably in input–output analysis) are measured for a