1. Introduction*

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The core of input–output analysis is a matrix of input–output coefficients,

$$A = \begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{pmatrix},$$

where the first column represents the input requirements per unit of the first output, and so on for the other columns. The inventor, Wassily Leontief, considered the first column of input–output coefficients the recipe for making the first output. The matrix stacks the recipes of the different outputs next to each other, like pages in a cookbook. Input–output analysis is an important tool for a number of fields. In national accounting it orders the statistics of the different sectors of the economy, including industries, households, government, investment and trade in a systematic manner, avoiding pitfalls such as the double counting of intermediate inputs. Input–output analysis laid the foundation of the United Nations System of National Accounts. In economics it traces the indirect effects of economic measures, such as investments and price interventions, on all those sectors of the economy. Final consumptions are expressed in resource contents and prices are expressed in resource costs. The hallmark of economics, general equilibrium analysis, is made operational. In environmental analysis, impacts of final consumptions are traced across the world and, related, the cost of environmental protection is determined and expressed in price increases.

The field of input–output analysis is fragmented. Statisticians collect and organize the input and output data and construct input–output coefficients. Economists analyze the input–output coefficients and their changes to measure and explain important economic concepts such as productivity, efficiency and comparative advantage. Applied economists and environmental analysts build models around input–output matrices for scenario and impact analyses. This *Handbook*, however, encompasses all these dimensions. It is important that statisticians, theorists and practitioners look over the fences between their gardens. The reasons are that there are many issues in collecting statistics, constructing input–output coefficients, and their use in modeling, and that these issues can be resolved only by looking over the fence.

Let me explain. A matrix of input–output coefficients suggests that the economy can be partitioned into n industries and that each industry produces a single output. Then, indeed, a_{ij} is the amount of i required per unit of j. However, industries produce multiple, overlapping commodities and both categories have their own classifications. So what is a unit of j? Is it a commodity or is it industry produce? The answer is that it can be either. Commodity input coefficients and industry coefficients coexist. They are different and a question is, which one is relevant? Well, that depends on the policy issue one is interested in. By looking over the fence one gets a clue.

There is no one-size-fits-all input–output matrix and sometimes the very concept of such a matrix is better dropped. Statisticians collect and organize inputs and outputs. Coefficients are constructed. Economists and applied scientists use them as a modeling tool to answer policy questions. In this book the steps are described in detail and occasionally it is explained that a shortcut can be made from the input and output flow data to the modeling of economic issues. Input–output matrices are intermediate constructs, not necessities.

Many scientific tools have been in the air and discovered simultaneously or nearly simultaneously by different scientists, independently or dependently. Not so input–output analysis. This field was invented and implemented single-handedly by Wassily Leontief. He had the insight at a young age back in the USSR, but developed it later in the USA. He was involved with the construction of a series of input–output tables and used them for analysis. Douglas S. Meade describes this history vividly in Chapter 2, "Early Days of the Input–Output Table." This chapter sets the tone for the *Handbook*, placing the IO table center stage. It shows the evolution from interindustry tables to separate input and output tables with explicit accounting of products. This approach makes the *Handbook* an indispensable tool for builders and analysts of input–output tables alike.

Chapter 3 by Joerg Beutel explains in great detail the modern compilation of input and output tables and shows how they are embedded in the System of National Accounts, which has emerged as the worldwide standard. The system evolves and the author of Chapter 3 is a, if not *the*, key figure in this development. The chapter consolidates many technical reports, making the material accessible.

The modern distinction between products and industries makes the construction of input–output coefficients a non-trivial affair. Another statistician who stands in the middle of these developments – José M. Rueda-Cantuche – takes up this topic. Chapter 4 presents all the issues that plague the construction of input–output coefficients – what they are, which methods are available, what are the pros and cons – and provides a framework to address them, providing guidance for the reader.

An important distinction, emerging throughout the *Handbook*, is between direct and total coefficients. Input–output matrix A presents the direct coefficients, the inputs required to produce one unit of an output, and those for all the output. The production of an output vector y requires an input vector Ay, which, however, must also be produced. By the same reasoning it requires an input vector $AAx = A^2y$. And so on. The total output necessary to sustain output vector y is, therefore, $y + Ay + A^2y + \ldots$. Not only the desired output y itself must be produced, but also the direct requirement Ay and the indirect requirements $A^2y + A^3y + \ldots$. The total requirements are By, where $B = I + A + A^2 + \ldots$. B is the matrix of total coefficients, can be seen to be equal to $(I - A)^{-1}$, and, therefore, is called the "Leontief inverse." The Leontief inverse is the main tool of input–output analysis. One may argue that direct coefficients, A, are merely a tool to determine total coefficients, B, and that, therefore, total coefficients may better be estimated directly from the System of National Accounts, as discussed in Chapter 4.

The concept of indirect requirements has made a revival in environmental analysis. We are all concerned about CO_2 emissions, not only from our acts of consumption, such as car driving, but also from indirect requirements. Since many goods we use have imported components, there is a spatial pattern of the direct and indirect requirements and their associated emissions. This pattern is called a footprint. Chapter 5 by Richard Wood presents footprint analysis. Footprint analysis is a spatial disaggregation of the Leontief inverse. In the old days it was called multiregional input–output analysis (MRIO). Nowadays MRIO has a bigger sway over environmental analysis than over trade analysis, the historic concern, because the implicit assumption of MRIO that the regional distribution of inputs is given makes sense in environmental accounting, but not in international trade analysis.

Chapter 6 by Thijs ten Raa analyzes the close connections between direct requirements, multiplier effects, total requirements, factor contents, and productivity. Roughly speaking an input–output coefficient is input per output, whereas productivity is output per input. This suggests that productivity growth, the driver of economic progress, is a matter of reducing input–output coefficients. This intuition is roughly right, but there are many interesting observations to be made. For one, productivity may also grow by more efficient allocation of resources between industries. This field is full of formulas, many hotly debated yet very useful, and Chapter 6 puts some order in the house.

Historically, input–output analysis focuses on the direct and indirect material and factor requirements of production, but modern advanced economies are not about material goods but about services. Services are difficult to measure, slippery. Yet input–output analysis has a handle on services and this is exposited in Chapter 7 by Giovanni Russo and Laura Chies. One of the modern economic trends, outsourcing, is analyzed in this chapter; it serves as a good introduction to international trade.

The classical example of the theory of international trade is that of trade in cloth and wine between England and Portugal. Even if Portugal has an advantage in producing both commodities, it makes sense to import cloth. This Ricardian principle of comparative advantage is well understood, but not really enough to understand modern patterns of trade. Cloth and wine were simple commodities in those days – the countries where they were made could be identified. Not so with modern products. A laptop is a cosmopolitan product with parts from all over the world. An even more difficult, yet important question is where the value of the laptop is earned. To answer this question international trade theorists now turn to input–output analysis. Chapter 8 by Bart Los is the place to be.

Next to international economics, input–output analysis feeds environmental economics, the topic of Chapter 9 by Kim Swales and Karen Turner. It dwells on footprints, presents energy economics, and the so-called rebound effect. Energy savings translate into more purchasing power – think of extra vacation trips – which counters the conservation program. Indirect effects, not only in production, but also in consumption are critical. Obviously this foreshadows the next topic.

Chapter 10 by Kurt Kratena embeds input–output relationships in a full-fledged general equilibrium model of the economy. International trade and environmental policy negotiations are backed up by computable general equilibrium models to assess the effects of alternative measures and these models have an input–output core to model production. This is a main application of the input–output apparatus and connects it with mainstream economic modeling.

The two central concepts of economic theory are equilibrium and efficiency. Equilibrium is analyzed in Chapter 10 and Victoria Shestalova analyzes efficiency in Chapter 11. In the idyllic neoclassical world of complete markets and perfect competition the two are connected. According to the First Welfare Theorem, an equilibrium is efficient, and according to the Second Welfare Theorem any efficient allocation can be brought about as a competitive equilibrium if the resources are reshuffled between people (a big if). In reality, however, inefficiencies abound and input–output analysis can be used to measure them. For example, markets for clean air are incomplete and input–output can be used to calculate so-called shadow prices.

Chapters 12 and 13 round up the *Handbook*, treating two difficult but important topics, namely uncertainty and dynamics. The main input–

output model is deterministic, but obviously we are better to have some clue of the sensitivity of model results with respect to variations in the data and/or scenario specifications. Even the model itself may be random, if only because input–output coefficients tend to be at the level of industries or commodity groups, while the data are micro at the level of firms and commodities. The micro-variation translates into estimates of coefficients, multipliers and model results, along with their spreads. Chapter 12 by Umed Temursho provides a comprehensive review of uncertainty treatment.

The basic idea of dynamic input–output analysis, the subject of Chapter 13 by Yasuhide Okuyama, is that commodities are dated. As the Leontief inverse determines the requirements of final demand, the dynamic inverse determines the path of requirements of a final demand path. It is not reasonable to maintain the implicit assumption of input–output coefficients, namely that inputs are complements, in a world where commodities may only differ by time of delivery, $t = 1, \dots, T$. Instead of working with a huge input–output matrix of dimension $nT \times nT$, dynamic input–output analysis complements the $n \times n$-dimensional A matrix with a capital matrix of the same dimension. Every industry must have an n-dimensional capital stock per unit of output. If output grows, the capital stock must grow in proportion. The addition to the stock of capital is investment and is separated out (endogenized) from the final consumption vector. While this basic idea is in perfect agreement with economic growth theory, the dynamic input–output model has challenging issues.

It is customary in input–output analysis to denote gross output (including intermediate demand) by vector x and net output (excluding intermediate demand) by vector y. However, since the field has become fragmented, the notation is no longer uniform and some choice has to be made. Net output is closely related but not the same as final demand, at least not in multiregional models, and this is one reason why in some studies final demand is denoted by vector f, or, when disaggregated into various users (such as households and government) by matrix F, as in equilibrium analysis. In footprint analysis, however, F stands for the matrix of non-produced inputs: factors including environmental impacts. In productivity analysis F represents something different, namely a production function. I have decided to respect these different customs. Each chapter defines its own symbols. Another example worth mentioning is the so-called make, supply or output table, V, which shows the products supplied by the firms or industries. The inventor of this concept, Richard Stone, defined it for reasons of national accounting as a matrix of the industries-by-products dimension. Indeed, this is very handy in the construction of input–output coefficients (Chapter 4), but beyond that it has become common to define

V as a matrix of the opposite dimension, products by industries, and I respect that. I do not always go with the flow. The main field journal, *Economic Systems Research*, uses bold roman print for vectors and matrices, replacing A by $\mathbf{A}$ and x by $\mathbf{x}$. This *Handbook*, however, sticks to the notation of the old literature, which still prevails in the general economic literature and, moreover, seems more pleasing to the eye.

NOTE

* Professor Wassily Leontief – to whom the author was research assistant at New York University – shaped the field and he dedicates the *Handbook* to his memory. He also wishes to remember the lesson of his initial German, later Dutch, mother Eva Sachs: "Lern – the only things that cannot be taken from you are in your head."