Nanotechnology Perceptions
ISSN 1660-6795
www.nano-ntp.com

Input-Output Analysis In Economic Research: Historical Perspectives And Present-Day Relevance

Dr. V. Siva Elango

Associate Professor of Economics Department of Economics and Research Centre Aditanar College of Arts and Science Tiruchendur, Thoothukudi District. (Affiliated with Manonmaniam Sundaranar University, Tirunelveli, Tamilnadu)

Input-output analysis is a method used to understand how changes in one sector of the economy affect others. Developed by economist Wassily Leontief, this analysis maps the connections between industries, showing how the output from one sector becomes the input for another. This approach helps policymakers see the ripple effects of spending or investments across the economy. It breaks down impacts into three types: direct effects (like initial spending on materials and labor), indirect effects (when suppliers hire more workers), and induced effects (extra spending by newly hired workers). Input-output analysis is essential in economic planning, helping governments make informed decisions, manage resources, and ensure sustainable growth. It also highlights dependencies within supply chains, supporting balanced development.

Keywords: input-output analysis, economic impact, Leontief, economic planning.

Introduction

Input–output analysis is a well-established technique in quantitative economic research, belonging to the family of impact assessment methods. Its primary goal is to map the direct and indirect consequences of an initial impulse across all economic sectors in an economic system. Essentially, it depicts the system-wide effects of an exogenous change within a relevant economic framework.

Input–output models are based on the principle that any output requires a corresponding input. This input may consist of raw materials and services from other industries, labor from households, or amenities provided by the government. The output includes a sectoral variety of products and services. A conventional input–output table operates on a double-entry bookkeeping principle: the totals of the columns equal the totals of the rows. Input–output tables can apply to the global economic system, the national economy, or regional systems.

Regional input–output tables allow examination of interdependencies and linkages between industries, households, and the government within and between regions. This method has found applications worldwide and is foundational in policy impact analysis.

Review of Literature

One example of input–output modeling is a 1998 Indian study by Sen estimating the impact of foreign students on the local economy of India. Since universities and their host cities often invest heavily in their image, it is useful to understand the economic effects of expenditures to attract international students. In this study, the impact on the local economy was found to be significant, as one rupee of investment generated 1.8 rupees of household income and created numerous jobs.

Another example is examining the impact of a particular industry, such as forestry, on other industries. The forestry sector depends on inputs from other industries and household labor and delivers products to multiple sectors. Therefore, input–output analysis is a useful tool. Using an input–output table, analysts can estimate the impact of a growing or shrinking forestry sector. McGregor and McNicoll conducted such an analysis in the United Kingdom, assuming a reduction of the forestry sector's output to zero in a simulation. Unsurprisingly, the forestry industry was the most affected, but households and sectors like banking, finance, insurance, energy, and water also experienced significant negative effects.

Input–output analysis has become a dominant method in applied economic research, valued for its consistency at a system-wide level and its ability to estimate all direct and indirect effects of an initial stimulus. This value has been widely recognized throughout the history of input–output modeling.

Historical Background

The input–output theory was developed by Wassily Leontief in the late 1920s. Born in 1906 in Saint Petersburg, Leontief created the first input–output table of the U.S. economy in 1932. Initially, input–output analysis received little attention due to its perceived mathematical complexity and data requirements. However, during World War II, its value became apparent, particularly in identifying bottlenecks in military production chains, such as determining the need for additional workers.

Initially used on a national level, input–output tables were later expanded to regional and international scales. In 1973, Leontief was awarded the Nobel Prize in Economics for his pioneering work on input–output transaction tables, which remain a standard tool for economists today.

Economic Impact on Input-Output Analysis

Input–output (I-O) models estimate three main types of economic impact: direct, indirect, and induced. These terms refer to the first, second, and third levels of economic effects that spread through the economy when a change is made in spending or investment in a particular area.

1. **Direct Impact**: This is the immediate effect, like the initial spending on materials and labor. For example, building a bridge requires spending on cement, steel, equipment, and labor.
2. **Indirect Impact**: This occurs when suppliers respond to the increased demand. For example, suppliers of cement and steel may need to hire more workers to meet the demand for materials for the bridge project.

3. **Induced Impact**: This results from the additional spending by workers in these industries. For instance, the newly hired workers might spend more on goods and services in their communities, creating further economic activity.

Leontief (1986) explains how industries are connected through the movement of goods and services, final demand, and main inputs. Table -1 shows a typical input-output table, which tracks the flow of products and services between industries in an economy over time. In this table, each row shows what an industry produces (output), and each column shows what it needs from other industries (input).

For example, if industry - 1 provides goods to industry -2, that output from industry -1 becomes the input for industry 2. We can label:

a) x_{ij} as the amount of product from industry i to industry j
b) V_j as the main input needed by industry j
c) X_i as the total output from industry i
It's assumed that each industry makes only one type of product.

Table – 1 : Application of Input – Output Transaction

	Intermediate consumption			Net final demand	Total output
	Industry 1	Industry 2	Industry 3		
Industry 1	x_{11}	x_{12}	x_{13}	Y_1	X_1
Industry 2	x_{21}	x_{22}	x_{23}	Y_2	X_2
Industry 3	x_{31}	x_{32}	x_{33}	Y_{31}	X_3
Value Added	V_1	V_2	V_3	-	-
Total Input	X_1	X_2	X_3	-	-

In this system, final demand comes from outside the model, so things like labor need to be paid for. Leontief uses a special production formula where inputs needed to make a product have fixed amounts.The formula looks like this:

$$x_{ij} = a_{ij} X_j \qquad for\ i,j, = 1,2, \dots \dots \dots \dots \dots \dots \dots \dots \dots n$$

where each input amount is fixed. The matrix B (made up of b_{ij} values) is called the "interindustry coefficients" matrix.

According to Nations (1999), this fixed setup works because production methods usually don't change much over a short period. If production methods do change, new data can replace old data in the table. Rao and Rao (1998) explain that the goal of this open model is to create a plan that meets all demands, both inside and outside the economy. This input-output model can also be shown in a table like Table 2.

Table – 2 : Application of Input – Output Coefficient

	Industry 1	Industry 2	Industry 3	Net final demand
Industry 1	b_{11}	b_{12}	b_{13}	Y_1
Industry 2	b_{21}	b_{22}	b_{23}	Y_2
Industry 3	b_{31}	b_{32}	b_{33}	Y_{31}
Value Added	V_1	V_2	V_3	-

In this table-2, each entry in the j^{th} column shows the amount of each type of input needed to make one unit of output in industry 'j'. Meanwhile, each entry in the i^{th} row shows the output from industry 'i' needed to produce one unit of each type of output. When final demand Y is included, we have the basic input-output model, represented in matrix form as:

$$BX + Y = X \quad or \quad (I - B)X = Y \text{.............................. (1)}$$

For this equation to work, the inverse of (I − A) must not only exist but also be non-negative. Since the total output X and final demand Y are both non-negative, it also makes sense that the inverse of (I − B) should be non-negative. We will look at findings by Rao and Rao (1998), Seneta (2006), and Kemeny and Snell (1976) related to this. According to Rao and Rao (1998), if the matrix (I − B) is nonsingular and non-negative, then a non-negative solution exists, given by:

$$X = (I - B)^{-1}Y \text{...(2)}$$

Here, $(I - B)^{-1}$ is called the Leontief inverse, or multiplier matrix. Furthermore, Rao and Rao (1998) provide this result for finding a non-negative solution to the basic input-output model. Let A be a non-negative matrix. Then $(I - B)^{-1}$ exists and is non-negative if and only if there exists a non-negative vector x such that $x > Ax$. (This condition, $x > Ax$, means there is a production schedule x where each industry produces more than it uses.) From this result, we have a condition for a non-negative Leontief inverse. If the sum of entries in each column 'j' of matrix B (interindustry coefficients) is less than one, it means that each industry is profitable:

$$\sum_{t=1}^{n} b_{ij} < 1 \quad for \quad j = 1, \dots\dots\dots\dots\dots\dots\dots.., n.$$

Or, in matrix form:

$$B'1_n < 1_n \text{...(3)}$$

where 1_n is an $n \times 1$ vector of ones. Based on Lemma (1) and (3), $(I - B)^{-1}$ exists and is non-negative. Since:

$$(I - B') - 1 = (I - B) - 1', \text{.................................(4)}$$

the Leontief inverse is also non-negative. This leads to the following result: Suppose an economy has n industries, each producing one product. If all industries are profitable, then for any non-negative final demand Y, there is a unique non-negative solution to the input-output model (1), with total output X given by:

$$X = (I - B)^{-1}Y$$

Kemeny and Snell (1976) define an industry as profitless if the sum of entries in its column equals 1, meaning it just breaks even—its total output equals its required input. Thus, each industry in this study is either profitable or break-even, with no unprofitable industries (industries with a loss during the period).

Although the condition in Corollary 1 is easy to check, it is not strictly necessary, as shown in the example that follows: In an economy of two industries A and B, the data in crores of rupees is given below:

Table – 3 : Input – Output Transaction Table

-		Buying Sector		Final Demand	Total Output
-	-	A	B		
Selling Sector	A	18	8	10	36
	B	9	24	15	48

Determine the total output, if the final demand, if the final demand changes to 30 for industry A and 40 for industry B.

$(I\text{-}B)^{-1}$ D = X

$$\left(\begin{bmatrix}1 & 0\\ 0 & 1\end{bmatrix} - \begin{bmatrix}b_{11} & b_{12}\\ b_{21} & b_{22}\end{bmatrix}\right) \times \begin{bmatrix}d_1\\ d_2\end{bmatrix} = \begin{bmatrix}x_1\\ x_2\end{bmatrix}$$

$$b_{11} = \frac{rupee\ value\ of\ the\ output\ of\ industry\ A\ consumbed\ by\ industry\ A}{rupee\ value\ of\ the\ total\ output\ of\ industry\ A}$$

$$b_{11} = \frac{18}{36}$$

$$b_{11} = \frac{1}{2}$$

$$b_{12} = \frac{rupee\ value\ of\ the\ output\ of\ industry\ A\ consumbed\ by\ industry\ B}{rupee\ value\ of\ the\ total\ output\ of\ industry\ B}$$

$$b_{12} = \frac{8}{48}$$

$$b_{\ 12} = \frac{1}{6}$$

$$b_{21} = \frac{rupee\ value\ of\ the\ output\ of\ industry\ B\ consumbed\ by\ industry\ A}{rupee\ value\ of\ the\ total\ output\ of\ industry\ A}$$

$$b_{21} = \frac{9}{36}$$

$$b_{21} = \frac{1}{4}$$

$$b_{22} = \frac{rupee\ value\ of\ the\ output\ of\ industry\ B\ consumbed\ by\ industry\ B}{rupee\ value\ of\ the\ total\ output\ of\ industry\ B}$$

$$b_{22} = \frac{24}{48}$$

$$b_{22} = \frac{1}{2}$$

$$[I - B] = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} - \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix}$$

$$[I - B] = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} - \begin{bmatrix} \frac{1}{2} & \frac{1}{6} \\ \frac{1}{4} & \frac{1}{2} \end{bmatrix} = \begin{bmatrix} \frac{1}{2} & -\frac{1}{6} \\ -\frac{1}{4} & \frac{1}{2} \end{bmatrix}$$

Determinant of $|I - B| = \frac{1}{2} - \frac{1}{24} = \frac{6-1}{24} = \frac{1}{24}$ # 0.

The Hawkins-Simon conditions are essential in input-output analysis, ensuring the viability and sustainability of an economic system. They assess whether an economy can meet all output demands with the available resources. Proposed by David Hawkins and Herbert Simon, these conditions are applied to input-output tables (square matrices) that capture input and output relationships across industries.

In essence, these conditions ensure that if ‘B’ is the technical matrix, then the system is viable if:

- ✓ the diagonal elements $[I - B]$ of are positive, and
- ✓ the determinant of $|I - B|$ is also positive. Here is a summary:

- ❖ **Non-Negativity of Outputs**: Production levels must be non-negative, ensuring each industry meets at least the total demand, with no negative outputs.
- ❖ **Productivity Condition**: Each industry’s output should exceed its input consumption, ensuring that the sum of inputs is less than or equal to the total output. This guarantees a net positive production for each sector, making the economy sustainable.

- **Invertibility of the Matrix**: The input-output matrix must be invertible so that outputs can depend on final demand. This requires that the matrix of technical coefficients has a non-zero determinant, maintaining economic balance.
- **Positive Determinant Condition**: The leading principal minors of the technical matrix must be positive, indicating that each industry can adjust output without unsustainable demand from others.

If these conditions are met, the system is "productive" and can sustain itself without deficits. Inverse of $[I-B]$ are

Minor of $[I-B]$ = $\begin{bmatrix} \frac{1}{2} & -\frac{1}{4} \\ -\frac{1}{6} & \frac{1}{2} \end{bmatrix}$

Cofactor of $[I-B]$ = $\begin{bmatrix} \frac{1}{2} & \frac{1}{4} \\ \frac{1}{6} & \frac{1}{2} \end{bmatrix}$

Adjoint of $[I-B]$ = $\begin{bmatrix} \frac{1}{2} & \frac{1}{6} \\ \frac{1}{4} & \frac{1}{2} \end{bmatrix}$

Inverse of $[I-B]^{-1} = \frac{1}{|I-B|}$ (Adjoint of $[I-B]$)

$$[I-B]^{-1} = \frac{1}{\frac{5}{24}} \begin{bmatrix} \frac{1}{2} & \frac{1}{6} \\ \frac{1}{4} & \frac{1}{2} \end{bmatrix} = \frac{24}{5} \times \begin{bmatrix} \frac{1}{2} & \frac{1}{6} \\ \frac{1}{4} & \frac{1}{2} \end{bmatrix} = \begin{bmatrix} \frac{24}{10} & \frac{24}{30} \\ \frac{24}{20} & \frac{24}{10} \end{bmatrix}$$

Verification of $(I-B)^{-1} D = X$

$$\begin{bmatrix} \frac{24}{10} & \frac{24}{30} \\ \frac{24}{20} & \frac{24}{10} \end{bmatrix} \times \begin{bmatrix} 10 \\ 15 \end{bmatrix} = \begin{bmatrix} 36 \\ 48 \end{bmatrix}$$

$$\begin{bmatrix} \frac{24}{10} \times 10 & \frac{24}{30} \times 15 \\ \frac{24}{20} \times 10 & \frac{24}{10} \times 15 \end{bmatrix} = \begin{bmatrix} 36 \\ 48 \end{bmatrix}$$

$$\begin{bmatrix} \frac{1080}{30} \\ \frac{960}{20} \end{bmatrix} = \begin{bmatrix} 36 \\ 48 \end{bmatrix}; \qquad \begin{bmatrix} 36 \\ 48 \end{bmatrix} = \begin{bmatrix} 36 \\ 48 \end{bmatrix}$$

This verifies the given data. If the final demand changes to 30 crore rupees for industry A and 40 crore rupees for Industry B, the new demand vector is $D_{New} = \begin{bmatrix} 30 \\ 40 \end{bmatrix}$

$(I-B)^{-1} D_{New} = X_{New}$

$$\begin{bmatrix} \frac{24}{10} & \frac{24}{30} \\ \frac{24}{20} & \frac{24}{10} \end{bmatrix} \times \begin{bmatrix} 30 \\ 40 \end{bmatrix} = \begin{bmatrix} x_{1new} \\ x_{2new} \end{bmatrix}$$

$$\begin{bmatrix} \frac{24}{10} \times 30 & \frac{24}{30} \times 40 \\ \frac{24}{20} \times 30 & \frac{24}{10} \times 40 \end{bmatrix} = \begin{bmatrix} x_{1new} \\ x_{2new} \end{bmatrix}$$

$$\begin{bmatrix} \frac{3120}{30} \\ \frac{2640}{20} \end{bmatrix} = \begin{bmatrix} x_{1new} \\ x_{2new} \end{bmatrix}$$

$$\begin{bmatrix} x_{1new} \\ x_{2new} \end{bmatrix} = \begin{bmatrix} 104 \\ 132 \end{bmatrix}$$

When final demand increases to 30 crores for Industry A and 40 crores for Industry B, the new output vector is computed as $(I-B)^{-1} D_{New} = X_{New}$; $D_{New} = \begin{bmatrix} 30 \\ 40 \end{bmatrix}$, indicating total outputs of 104 crores for Industry A and 132 crores for Industry B. This demonstrates how input-output analysis can predict output requirements under changing demand conditions, ensuring economic sustainability.

The Importance of Using Input-Output Analysis in Economic Research

These findings show that input-output analysis is a crucial tool in both theory and practice in economics. It helps us understand and manage the complex relationships within an economy.

- **Economic Interdependencies**: Input-output analysis reveals the interdependent relationships between industries within an economy, showing how one industry's output becomes the input for others. This understanding aids policymakers in assessing the interconnectedness of various sectors, as demonstrated by Leontief's foundational work in economic systems.
- **Regional and National Impact Analysis**: By mapping economic activity across regions or nations, input-output tables help economists assess localized impacts of policies or investments. This approach supports regional economic planning by highlighting which sectors are most influenced by changes in demand, allowing targeted strategies to strengthen regional economies.
- **Evaluating Economic Stimulus Effects**: Input-output models measure direct, indirect, and induced economic impacts resulting from spending in a specific sector. This tri-level analysis, as illustrated in the examples of infrastructure investments, assists governments in forecasting the ripple effects of spending decisions across the economy, influencing employment and household income.
- **Supporting Policy and Investment Decisions**: Governments and businesses use input-output analysis to determine the effectiveness of economic policies and investments. For example, a country might assess how subsidies in the forestry

sector could influence both local and national economies by examining the impact across connected industries.

- **Enhancing Resource Allocation Efficiency**: By tracing the flow of resources, input-output analysis identifies areas where resources may be underutilized or over-concentrated. This efficiency check, guided by the Leontief matrix, allows decision-makers to optimize resources across sectors, improving productivity and economic balance.
- **Monitoring Supply Chain Dependencies**: Input-output tables provide a detailed look into supply chain dynamics, enabling businesses to identify critical supply dependencies. This insight is essential for sectors like manufacturing, where understanding material inputs helps mitigate risks associated with supply chain disruptions.
- **Measuring International Trade Impact**: Input-output analysis facilitates the understanding of how international trade affects domestic industries by mapping imports and exports within the economy. This insight assists in crafting trade policies that aim to maximize domestic economic benefits while managing dependencies on foreign inputs.
- **Predicting Responses to Technological Change**: Technological advancements often alter industry structures. Input-output analysis can be used to simulate how these changes, like automation, impact industries and job markets by adjusting input and output coefficients, helping economists and policymakers plan for technology-induced shifts.
- **Ensuring Economic Viability and Sustainability**: By applying the Hawkins-Simon conditions, input-output analysis ensures that economies meet their production demands sustainably. This method confirms that outputs exceed inputs, affirming each sector's productivity and supporting the economy's ability to sustain itself without deficits.

Conclusion

While the Leontieff approach hasn't been widely used in input-output model analysis, it offers a natural way to explain the relationships between industries in an economy, and further research in this area is needed. Although the average cycle length provides useful insight into how industries interact, it doesn't clearly identify specific groups or clusters of similar industries.

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