A New Method for Interindustry Linkage Analysis Based on Demand-Driven and Multisector Input-Output Model and Its Application in China’s Manufacturing and Producer Services

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Interindustry linkage analysis is an important interdisciplinary research field of technical economic and complex systems, and the results can be used as critical bases for making strategies and policies of economic development. This study reviews the previous methods for measuring interindustry linkages and their disadvantages and puts forward a new method for interindustry linkage analysis in a complex economic system on the basis of demand-driven and multisector input-output model. Firstly, it makes a further decomposition of the Leontief inverse matrix in the economic sense and decomposes the gross output of one industrial sector or its sub-industries into three components. Then, it analyzes the structural features of output and measures the interindustry linkages between two industrial sectors with three indices: interindustry linkage effect, interindustry linkage contribution, and interindustry linkage coefficient. Compared with the previous measurements, the method in this study has three obvious advantages: it integrates the sectoral internal effect and external linkage effect at the same time; it can not only measure the interindustry linkage effects between two given industrial sectors but also clearly describe the composition ratio of the direct and indirect interindustry linkage effects; and it adopts, respectively, the absolute flow value, relative flow value, and unit relative value to measure the linkages comprehensively. Finally, this study takes China’s input and output in 2017 as an application case to analyze the structural features of output of its manufacturing and producer services and measure the interindustry linkages between them.

1. Introduction

National economy is a large and complex system, and the industries in it interact with and impact each other. Interindustry linkage is a kind of technical and economic link existing extensively among the industries and the concept was first introduced by Hirschman in 1958 based on the theory of unbalanced development [1]. Since the 1950s, with the acceleration of industrialization in developing countries, interindustry linkages have gained extensive attention from academia circle, industrial field, and policy-makers and are used to measure the relative importance of industries in order to identify the key industries which are central for economic development and can drive economic high-speed growth. Therefore, an applicable and reasonable method to measure the interindustry linkages is helpful to recognize the relationship between or among industries, promote the level of balanced development of the entire economic system, and even optimize the industrial structure of the national economy. Over the years, the previous scholars have conducted many research studies on the analysis of interindustry linkages from different perspectives. In general, the traditional econometric analysis and input-output analysis are two main and common kinds of methods which can be used to well describe the interrelatedness of industries.

The former is a relatively indirect method which generally first puts forward hypotheses and then usually adopts the econometric model such as the panel data regression.
model or the vector autoregressive (VAR) model to search the supporting empirical evidences based on the macro-statistics data of the economy system; e.g., Banga and Goldar use regression analysis model to research the contribution of services to manufacturing output growth and productivity on the basis of Indian panel data [2]; Francois and Woerz use regression analysis model to research the interaction between production services and manufacturing on the basis of the panel data on goods and services trade of Organization for Economic Co-operation and Development (OECD) during 1994–2004 [3]; Ke et al. conduct a panel data analysis of Chinese cities and construct a simultaneous equation model of co-agglomeration of producer services and manufacturing that highlights the synergy effects of the two sectors located in the same cities or neighboring cities [4]; Kong and Liang use VAR model to analyze the interaction between producer services and manufacturing in Shaanxi Province, China [5].

The latter is a relatively direct method which is first introduced by Leontief in 1936 [6], and it quantitatively analyzes or computes the interindustry linkages or relationships through the input-output data and a series of linear equations; e.g., Guerrieri and Meliciani study empirically the interindustry linkages between producer service and three major industries on the basis of the input-output data of Denmark, the UK, Germany, France, Japan, and the US [7]; through measuring the backward and forward linkages of one certain industry, Chiu and Lin investigate the role and influence of the maritime sector on the national economy of Taiwan [8]; Mattioli and Lamonica evaluate the information and communications technology (ICT) role in the world economy [9]; Khanal et al. study the significance of economic linkages between the tourism sector and the rest of the economy in Lao People’s Democratic Republic (Lao PDR) [10]; Guerra and Sancho measure the role of energy and non-energy efficiency gains in an interconnected and multisector economy with the hypothetical extraction method [11], which is a powerful input-output analysis tool and will be discussed later; Sajid et al. conduct a serial of researches on carbon linkages via hypothetical extraction method or its modification [12, 13]; Wang et al. employ the hypothetical extraction method to map flows of embodied air pollutant emission from economic sectors in China [14] and even conduct an analysis on interregional and sectoral linkages of air pollutant emissions in Beijing-Tianjin-Hebei region of China [15]; Ali et al. use the Asian Development Bank input-output database to analyze and compare the performance of the construction sector in some south Asian countries [16].

Comparing the two kinds of methods mentioned above, although the latter is insufficient in terms of data immediacy and availability due to the fact that input-output data usually are only issued by the official statistics department every few years, it can provide a more convective and micro-view perspective to describe the interrelatedness of industries, and overcome the disadvantages of the former that it is difficult to obtain high quality economic statistics data and reflect promptly when the economic structure changes greatly. What is more, due to an apparent intimate tie between the interdependencies studied in input-output analysis and the causal relations expressed in Hirschman’s interindustry linkages, Hirschman’s interindustry linkages have been embraced by input-output economists [17].

Therefore, on the foundation of the theory of input-output analysis, this study designs a new method for interindustry linkage analysis based on demand-driven and multisector input-output model and applies it in the scenario of China’s Manufacturing and Producer Services. Since its obvious advantages, compared with the previous measurements of interindustry linkages specifically discussed later, the authors hold that it is a helpful tool for analyzing the interrelatedness between two industrial sectors and identifying the key weak links.

Section 2 reviews the theory of input-output and interindustry linkages and summarizes the features and disadvantages of different attempts to measure the interindustry linkages. In Section 3, demand-driven and multisector input-output model is carried out, in which the output and Leontief inverse matrix are structurally decomposed in economic sense; it also presents the ways to analyze the output structural features of an industrial sector and its sub-industries and measure the interindustry linkages between two different industrial sectors; in particular, this study takes China as an example to emphatically analyze the interindustry linkages between its manufacturing and producer services in a framework of multisector economic system. Section 4 presents the results of the application in China, and then the specific discussion and policy implication are presented in Section 5. The paper ends up with a discussion of the value of this method in analyzing the interindustry linkages in multisector economic system.

2. Theoretical Background

According to the view of Hirschman [1], any nonprimary activity which does not only produce for final demand exerts two distinct effects by means of its demand for and supply of intermediate inputs, respectively, so the interindustry linkage has two different types. The demand stimulates other sectors to satisfy its intermediate requirements, which is named backward linkage; the supply also stimulates sectors because its output is also taken as an input in new activities, which is named forward linkage. Chenery and Watanable’s work firstly attracts the scholars’ attention [18], which is conducted on the basis of the input coefficient matrix and considered to be the earliest measurement of Hirschman’s interindustry linkages. However, the analysis based on the input coefficient matrix only considers the first round of consumption in the entire economic system, ignoring the interrelatedness of indirect transfer; namely, the measurement is incomplete. Rasmussen’s dispersion indices on the basis of Leontief inverse matrix (also called total requirements matrix) is another attempt to measure interindustry linkages [19], and it has been widely used because it can be credited with including indirect effects and distinguishing between backward linkage and forward linkage, despite the fact that Rasmussen’s original research is before Hirschman introduced the concept of interindustry linkages. Based on
the pioneering work of Hirschman, Chenery and Watanable, and Rasmussen, the theoretical and applied researches on the measurement of interindustry linkages have been conducted widely, and the later scholars have put forward various schemes to refine the measurement of interindustry linkages.

Jones questions the use of Rasmussen’s index of sensitivity of dispersion as a measurement of forward linkage, then puts forward a new method to measure the forward linkage on the basis of Ghosh inverse matrix instead of Leontief inverse matrix, and elaborates its value in detail [20]. Cuello et al. refine Rasmussen’s measurement through introducing a serial of parameters which are used in weighting the coefficients in Leontief inverse matrix, in order to take the relative importance of different industries into consideration [21]. Referring to the research of Cuello et al., Drejer even introduces knowledge as a weight in terms of knowledge intensive industries [17]. Hazari and Laumas discuss whether the weighting of different industries should be considered in the measurement of interindustry linkages, although their viewpoints are not the same; Hazari holds that weighting or not weighting depends on the purpose of analysis [22], while Laumas is more inclined to adopt the measurement in the weighted form [23].

Since Rasmussen’s dispersion indices and the modified methods evaluate the two types of linkages separately, hypothetical extraction method is proposed as a new and more practical method [24, 25]. In this method, the importance of a sector, also called its total linkage, is measured by comparing numerically the output levels of economy before and after the hypothetical extraction, in which the row and column input–output data of this sector are deleted. (Instead of physically deleting them, they can simply be replaced by zeros.) Cella modifies the method, and the measure of total linkage in his research not only excludes feedback processes which are purely internal to the selected industry, but also is decomposable into additive components measuring backward and forward linkages, respectively [26]. Duarte et al. further modify Cella’s method and decompose the total linkage into four components, internal effect, mixed effect, net backward linkage, and net forward linkage, when studying the behavior of the productive sectors of the Spanish economy as direct and indirect consumers of water [27]. Different from the studies that have mostly calculated both backward and forward linkages using only demand-driven Leontief inverse matrix, Sajid et al. estimate the linkages from both demand and supply with Leontief inverse matrix and Ghosh inverse matrix, when studying the intersectoral carbon linkages of Turkey [28].

The measure methods on the foundation of the research of Chenery and Watanable and Rasmussen are all based on classical input-output analysis model. When using these classical measurements of interindustry linkages, scholars firstly may face two difficult problems: which coefficient matrix should be chosen; whether and how the researchers weight the different industries according to their scales and importance. Furthermore, Leontief inverse matrix or Ghosh inverse matrix based on the row balance or column balance in the input-output tables can only represent the overall interrelatedness, which contains not only direct and indirect interrelatedness but also internal effect and external linkage. Finally, the classical measurements only describe the interrelatedness between a given industry and the entire economic system, rather than that between two given industries. As for the hypothetical extraction method, though many scholars have been improving and modifying it in order to better and more accurately measure the importance of the sector, it still has some drawbacks. First of all, its underlying hypothetical deviates somewhat from the economic reality. In the scenario of hypothetical extraction, the row and the column referring to the selected industry in input coefficient matrix are replaced by zeros, while the rest remain the same. In fact, as mentioned, the industries in the economic system interact with and impact each other. The interrelatedness among the rest of the industries may change even dramatically when an industry is removed. So the difference between the output levels before and after the hypothetical extraction probably should not be equated with the real impact of the interindustry linkages. What is more, hypothetical extraction method provides a very practical and simple measure for interindustry linkages between a given industry and the entire economy system; however, the measure for interindustry linkages between two given industries is still inexplicit. In addition, with mounting evidence favoring simultaneous application of both Ghosh supply and Leontief demand for forward and backward linkages, the researches on hypothetical extraction method which only adopts Leontief inverse matrix may provide erroneous evidence or biased suggestions.

With the continuous progress of the input-output theoretical model, now the researchers have many new choices to analyze the interindustry linkages, e.g., the dynamic input-output model aiming to overcome the static analysis disadvantages of the classical input-output model [29, 30], the input-output optimization model that combines optimization theory and input-output theory [31, 32], and the spatial input-output model aiming to analyze the interregional input-output relationships [33, 34]. Now the inter-country input-output tables which are regularly published in the world mainly include the Word Input-output Table (WIoT), OECD Inter-Country Input-Output (ICIO) Table, and the Asian International Input-Output Table (AIIOOT). Miller first adopted the input-output theory to study the economic impacts between different regions and constructed a two-region input-output model to measure the interregional feedback effect, but it does not involve the concept and measurement of interindustry spillover effect [35]. Later scholars, e.g., Round, Sonis, and Dietzenbacher, distinguish the interindustry spillover effect and interindustry feedback effect between different regions, study the relationship between them and their multiplier effect, and conduct the empirical researches [36–38].

According to the research of Round, the output as well as Leontief inverse matrix can be multiplicatively decomposed into three components: the separate effects of multipliers
wholly within a group of accounts, the effect of an exogenous injection which feeds back upon itself but via other parts of the system, and the effect an increase in income in one group of accounts has upon another. In many kinds of analysis involving multipliers, it is convenient to formulate them so that their sum rather than their sequential multiplication yields the total multipliers. The output as well as Leontief inverse matrix also can be additively decomposed, which is equivalent to Round’s multiplicative decomposition. On the foundation of Miller and Round’s two-region input-output analysis, this study regards different industrial sectors in the entire economic system as different regions in the spatial scope and constructs a demand-driven and multisector input-output model, focusing on the output structural analysis and the measurement of interindustrial linkages between two given industrial sectors in a multisector economic system.

In demand-driven and multisector input-output model, the gross output can be decomposed into three components, intraindustry multiplier effect, interindustry spillover effect, and interindustry feedback effect. Intr industry multiplier effect is a kind of sectoral internal effect, and an industrial sector’s intraindustry multiplier effect refers to the output induced by the increase of its final demand in an input-output system which only contains this industrial sector, and it indicates the viability of this industrial sector. Intraindustry spillover effect is a kind of external linkage effect, and an industrial sector’s spillover effect refers to the rest of the industrial sectors’ output induced by the increase of its final demand, which indicates the impacting capacity of this industrial sector. In this study, the conception of interindustry incoming spillover effect is introduced in order to analyze the output structure easily, which is precisely opposite to that of intraindustry spillover effect. An industrial sector’s interindustry incoming spillover effect refers to the output induced by the increase of the rest of the industrial sectors’ final demand. Interindustry feedback effect is also a kind of external linkage effect, and an industrial sector’s interindustry feedback effect refers to the output induced by the increase of its final demand after the multiplier effect, namely, the transfer of the technology, products, or services from this industrial sector to the other industrial sectors and then back to itself. So, the gross output of an industrial sector or its subindustry is the total sum of its intraindustry multiplier effect, interindustry incoming spillover effect, and interindustry feedback effect.

3. Materials and Methods

3.1. Demand-Driven and Multisector Input-Output Model.

Suppose that the entire economic system contains \( n \) (\( n \geq 2 \)) industrial sectors and each industrial sector contains one or more subindustries. Denote the industrial sector as Ind with superscript, such as \( \text{Ind}^p \) (\( p \in \{1, 2, \ldots, n\} \)) and the subindustry in it with subscript, such as \( \text{Ind}^p_u \) (\( u \in \{1, 2, \ldots, m_p\} \)), where \( m_p \) is the number of subindustries in \( \text{Ind}^p \). \( X \) represents the gross output of the entire economic system, \( X^p \) represents the gross output of \( \text{Ind}^p \), and \( X^p_u \) represents the gross output of \( \text{Ind}^p_u \). Similarly, \( Y \) represents the final demand of the entire economic system, \( Y^p \) represents the final demand of \( \text{Ind}^p \), and \( Y^p_u \) represents the final demand of \( \text{Ind}^p_u \). It is worth mentioning that the final demand in this study also contains the part of net exports if the system is an open economy. Both of \( X \) and \( Y \) are column vectors consisting of the industrial sectors’ gross output or final demand, and both of \( X^p \) and \( Y^p \) are also column vectors consisting of the subindustries’ gross output or final demand, e.g., \( X = [X^1, X^2, \ldots, X^n]^T \), \( Y = [Y^1, Y^2, \ldots, Y^n]^T \), \( X^p = [X^p_1, X^p_2, \ldots, X^p_m]^T \), \( Y^p = [Y^p_1, Y^p_2, \ldots, Y^p_m]^T \). According to the classical demand-driven input-output theory, the quantitative relationship between the gross output and final demand can be expressed as follows:

\[
AX + Y = X. \tag{1}
\]

In a multisector input-output scenario, equation (1) can be written specifically as follows:

\[
\begin{bmatrix}
A_{11} & A_{12} & \cdots & A_{1n} \\
A_{21} & A_{22} & \cdots & A_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
A_{n1} & A_{n2} & \cdots & A_{nn}
\end{bmatrix}
\begin{bmatrix}
x^1 \\
x^2 \\
\vdots \\
x^n
\end{bmatrix}
+ 
\begin{bmatrix}
y^1 \\
y^2 \\
\vdots \\
y^n
\end{bmatrix}
= 
\begin{bmatrix}
x^1 \\
x^2 \\
\vdots \\
x^n
\end{bmatrix}
\tag{2}
\]

where \( A \) is the input coefficient matrix of the entire economic system, \( A^q \) is a submatrix in \( A \), and \( A^q_{uv} \) consists of the element \( a_{uv}^q \) which represents the direct consumption of \( \text{Ind}^q_u \) per unit of output of \( \text{Ind}^q_v \) (\( q \in \{1, 2, \ldots, n\} \); \( v \in \{1, 2, \ldots, m_q\} \)). After serials of mathematical derivation, equation (2) can be transformed as follows:

\[
X = \begin{bmatrix} X^1 \\ X^2 \\ \vdots \\ X^n \end{bmatrix} = (I - A)^{-1}Y = BY = \begin{bmatrix} Y^1 \\ Y^2 \\ \vdots \\ Y^n \end{bmatrix}, \tag{3}
\]

where \( B \) is the Leontief inverse matrix of the entire economic system and \( B^q \) is its submatrix. \( B \) is the so-called multiplier in the demand-driven input-output model, which represents the multiplicative relationship between the gross output and final demand.

Referring to the research on interregional input-output model, the gross output or the Leontief inverse matrix \( B \) of the entire economic system can be decomposed into three components, intraregional multiplier effect, interregional spillover effect, and interregional feedback effect. When regarding the industrial sectors as regions, the gross output or the Leontief inverse matrix \( B \) of the entire economic system can be also similarly decomposed into three components, intraregional multiplier effect, interindustry spillover effect, and interindustry feedback effect. For the sake of specific distinction, this study names the components in the gross output as intraregional multiplier effect, interindustry spillover effect, and interindustry feedback effect, and the components in the Leontief inverse matrix \( B \) as...
intraindustry multiplier effect coefficient matrix, interindustry spillover effect coefficient matrix, and interindustry feedback effect coefficient matrix, labeled as $M$, $S$, and $F$.

Leontief inverse matrix $B$ has two different kinds of decompositions, multiplicative decomposition and additive decomposition, in which three components are labeled as $M_m$, $S_m$, $F_m$ and $M_m$, $S_m$, $F_m$, respectively. The decompositions are presented as follows:

$$B = F_m S_m M_m = \begin{bmatrix} F^{11} & 0 & \cdots & 0 \\ 0 & F^{22} & \cdots & 0 \\ \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & \cdots & F^{nn} \end{bmatrix} \begin{bmatrix} I & S^{11} & \cdots & S^{1n} \\ S^{21} & I & \cdots & S^{2n} \\ \cdots & \cdots & \cdots & \cdots \\ S^{n1} & S^{n2} & \cdots & I \end{bmatrix} \begin{bmatrix} M^{11} & 0 & \cdots & 0 \\ 0 & M^{22} & \cdots & 0 \\ \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & \cdots & M^{nn} \end{bmatrix}$$

(4)

$$B = M_a + S_a + F_a = \begin{bmatrix} M^{11} & 0 & \cdots & 0 \\ 0 & M^{22} & \cdots & 0 \\ \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & \cdots & M^{nn} \end{bmatrix} + \begin{bmatrix} (F^{11} - I)M^{11} & 0 & \cdots & 0 \\ 0 & (F^{22} - I)M^{22} & \cdots & 0 \\ \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & \cdots & (F^{nn} - I)M^{nn} \end{bmatrix}$$

(5)

where $M^{pp}$, $S^{pq}$, and $F^{pp}$ are defined in equations (6)–(8):

$$M^{pp} = (I - A^{pp})^{-1},$$

(6)

$$F^{pp} = B^{pp} (I - A^{pp}),$$

(7)

$$S^{pq} = (B^{pp} - B^{pp} A^{pp})^{-1} B^{pq} (I - A^{qq}), \quad (p \neq q).$$

(8)

Since the additive decomposition is easier to understand in economic sense and more intuitive for output analysis, this study just adopts it instead of the multiplicative decomposition; namely, $M$, $S$, and $F$ in the following content are represented by $M_a$, $S_a$, $F_a$ in equation (5), shown as follows:

$$M = \begin{bmatrix} M^{11} \\ 0 & M^{22} & \cdots & 0 \\ \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & \cdots & M^{nn} \end{bmatrix},$$

$$S = \begin{bmatrix} S^{11} & \cdots & S^{1n} \\ \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots \\ S^{n1} & S^{n2} & \cdots \end{bmatrix} \begin{bmatrix} F^{11} S^{12} M^{22} & \cdots & F^{11} S^{1n} M^{nn} \\ F^{22} S^{21} M^{11} & \cdots & F^{22} S^{2n} M^{mn} \\ \cdots & \cdots & \cdots \\ F^{nn} S^{n1} M^{11} & \cdots \end{bmatrix}$$

(9)

Interindustry spillover effect coefficient matrix $S$ can be further decomposed into two parts which, respectively, represent the impacts on the output in the first round and the rest of the rounds. In this study, the two parts are named as direct interindustry spillover effect coefficient matrix $S_d$ and indirect interindustry spillover effect coefficient matrix $S_i$, presented as follows:

$$S = S_d + S_i = \begin{bmatrix} 0 & S^{12} M^{22} & \cdots & S^{1n} M^{nn} \\ S^{21} M^{11} & 0 & \cdots & S^{2n} M^{mn} \\ \cdots & \cdots & \cdots & \cdots \\ S^{n1} M^{11} & S^{n2} M^{22} & \cdots & 0 \end{bmatrix} + \begin{bmatrix} (F^{11} - I)S^{12} M^{22} & \cdots & (F^{11} - I)S^{1n} M^{nn} \\ (F^{22} - I)S^{21} M^{11} & \cdots & (F^{22} - I)S^{2n} M^{mn} \\ \cdots & \cdots & \cdots \\ (F^{nn} - I)S^{n1} M^{11} & (F^{nn} - I)S^{n2} M^{22} & \cdots & 0 \end{bmatrix}$$

(10)

So, the Leontief inverse matrix $B$ of the entire economic system in multisector input-output model can be decomposed as follows:

$$B = \begin{bmatrix} F^{11} M^{11} & F^{11} S^{12} M^{22} & \cdots & F^{11} S^{1n} M^{nn} \\ F^{22} S^{21} M^{11} & F^{22} M^{22} & \cdots & F^{22} S^{2n} M^{mn} \\ \cdots & \cdots & \cdots & \cdots \\ F^{nn} S^{n1} M^{11} & F^{nn} S^{n2} M^{22} & \cdots & F^{nn} M^{nn} \end{bmatrix} = M + S + F.$$

(11)

On the basis of this kind of decomposition, the relationship of gross output and final demand shown in equation (3) can be rewritten as follows:
or its subindustries. I/he proportion of containing it and that in the actual economy containing final demand of this industrial sector in an economy only refers to the difference between output induced by the final demand of other in-

output totally induced by the final demand of other industries (Ind\(i\)), namely, the scale of the unit flow value from one given industrial sector to the other industrial sector or its subindustries; interindustry feedback effect of industrial sector Ind\(i\) and its subindustry Ind\(i_j\) in algebraic expression are presented in Table 1.

3.2. Interindustry Linkage Analysis. Denote \(M\), \(S\), and \(F\) as the intraindustry multiplier effect, interindustry incoming spillover effect, and interindustry feedback effect of Z in demand-driven and multi-sector input-output model are presented in Table 2. Denote \(S\) (Ind\(i\), Z) and \(F\) (Ind\(i\), Z) as the interindustry incoming spillover effect from Ind\(i\) to Z (q \(\neq\) p), and this study adopts \(S\) (Ind\(i\), Z) to measure the interindustry linkage effect from Ind\(i\) to Z. As mentioned above, \(S\) (Ind\(i\), Z) can be further decomposed into two parts, which, respectively, represent the direct and indirect interindustry linkage effect from Ind\(i\) to Z and are presented as follows:

\[
S(\text{Ind}^i, \text{Ind}^j) = eF_{pp}S_{pq}M_{qq}Y_q = eS_{pq}M_{qq}Y_q + e(F_{pp} - I)S_{pq}M_{qq}Y_q,
\]

This study adopts the proportion of \(S\) (Ind\(i\), Z) in the gross output of Z to measure the contribution of the interindustry linkage effect, named as interindustry linkage contribution and labeled as LinkC (Ind\(i\), Z), and adopts the ratio of \(S\) (Ind\(i\), Z) and the final demand of Ind\(i\) to measure the efficiency of the interindustry linkage effect, named as interindustry linkage coefficient and labeled as LinkE (Ind\(i\), Z). LinkC (Ind\(i\), Z) and LinkE (Ind\(i\), Z) can be written as follows:

\[
\text{LinkC} (\text{Ind}^i, \text{Ind}^j) = \frac{S(\text{Ind}^i, \text{Ind}^j)}{X^p},
\]

\[
\text{LinkC} (\text{Ind}^i, \text{Ind}^j) = \frac{S(\text{Ind}^i, \text{Ind}^j)}{X^p},
\]

\[
\text{LinkE} (\text{Ind}^i, \text{Ind}^j) = \frac{S(\text{Ind}^i, \text{Ind}^j)}{eY_q},
\]

Interindustry linkage effect indicates the scale of the absolute flow value from one given industrial sector to the other industrial sector or its subindustries; interindustry linkage contribution indicates the contribution of the interindustry linkage effect on the gross output, namely, the scale of the relative flow value from one given industrial sector to the other industrial sector or its subindustries; interindustry linkage coefficient indicates the efficiency of the interindustry linkage effect, namely, the scale of the unit flow value from one given industrial sector to the other industrial sector or its subindustries. The higher value of them refers to the greater absolute flow value, contribution, or efficiency.

3.3. Input-Output Data in China 2017. In this subsection, this study takes the input-output data in China 2017 as example and adopts the method mentioned above to analyze the structural features of output and measure the
interindustry linkages between two industrial sectors. Since China’s authority and the industry policy-makers have almost regarded manufacturing and producer services as the most critical industrial sectors for industrial transformation and upgrading and have successively introduced a series of industrial policies to promote the integration level of the two industrial sectors, this application case mainly focuses on the interindustry linkages between them.

Firstly, the entire economic system of China is divided into three industrial sectors: manufacturing, producer services, and the rest of the industries, and each of them has some subindustries. In China Input-Output Table in Year 2017, manufacturing has many subindustries. Since the scale of some subindustries of manufacturing is too small, manufacturing is only further divided into three components, low-tech manufacturing, mid-tech manufacturing, and high-tech manufacturing in this study according to the Industrial Classification for National Economic Activities (ICNEA) issued in 2017. The six subindustries of producer services are wholesale service, logistic service, information service, finance service, business service, and technology service. The three subindustries of the rest of the industries are the primary industry, the second industry excluding manufacturing labeled as the rest second industry in brief, and the tertiary industry excluding producer services labeled as the rest of the tertiary industry in brief. The classification of the entire economic system is specifically presented in Appendix A, and the rearranged China Input-Output Table in Year 2017 is shown in Appendix B.

Table 1: Decomposition components of gross output in demand-driven and multisector input-output model.

| Industrial sector or subindustry | Gross output | Intr.industry multiplier effect | Interindustry incoming spillover effect | Interindustry incoming spillover effect from Ind\(p\) | Interindustry feedback effect |
|---------------------------------|-------------|---------------------------------|----------------------------------------|-----------------------------------------------|-------------------------------|
| \(\text{Ind}_p\)               | \(\Xi^p\)   | \(e_{pM}Y_p\)                   | \(e_{\sum_q \beta^{pq}S_{pq}M^{qF}Y_q}, (p \neq q)\) | \(e_{\sum_q \beta^{pq}S_{pq}M^{qF}Y_q}, (p \neq q)\) | \((F_{pp} - 1)M^{pF}Y_p\) |
| \(\text{Ind}_u\)               | \(\Xi^u\)   | \(e_{uM}Y_u\)                   | \(e_{\sum_q \beta^{pq}S_{pq}M^{qF}Y_q}, (p \neq q)\) | \(e_{\sum_q \beta^{pq}S_{pq}M^{qF}Y_q}, (p \neq q)\) | \((F_{pp} - 1)M^{pF}Y_p\) |

Table 2: The sectoral internal effect and external linkage effect in demand-driven and multisector input-output model.

| Industrial sector or subindustry | Sectoral internal effect | External linkage effect |
|---------------------------------|-------------------------|-------------------------|
| \(\text{Ind}_p\)               | \(e_{pM}Y_p\)           | \(\Xi^p - e_{pM}Y_p\)  |
| \(\text{Ind}_u\)               | \(e_{uM}Y_u\)           | \(\Xi^u - e_{uM}Y_u\)  |

4. Results

On the basis of the method mentioned in Section 3.1, the decomposition components of gross output of manufacturing, producer services, and their subindustries in China 2017 are presented in Table 3.

Further, combining the data in Table 3 and the method mentioned in Section 3.2, the output structural features of the two industrial sectors and their subindustries, namely, the proportions of sectoral internal effect and external linkage effect, are presented in Table 4; the interindustry linkages from manufacturing to producer services are presented in Table 5, and those from producer services to manufacturing are presented in Table 6.

Through data observation and comparison in Tables 4–6, this study finds the following results on manufacturing and producer services.

As for manufacturing in China 2017, (1) its viability, namely, intr.industry multiplier effect or sectoral internal effect, contributes 48.96% of the gross output of itself, and the external linkage effect, namely, the total sum of interindustry spillover effect and interindustry feedback effect, contributes 51.04% of the gross output of itself, in which the interindustry linkage effect from the rest of the industrial sector accounts for 35.51%, shown in Table 4; (2) the interindustry linkage effect, direct interindustry linkage effect, and indirect interindustry linkage effect from producer services to manufacturing are 7.16, 6.04, and 1.12 Trillion Yuan, respectively, shown in Table 6; (3) the interindustry linkage contribution and coefficient from producer services to manufacturing are 7.09% and 0.5129, respectively, shown in Table 6.

As for producer services in China 2017, (1) its viability contributes 38.06% of the gross output of itself, and the external linkages contribute 61.94% of the gross output of itself, in which the interindustry linkage effect from the rest of the industrial sector accounts for 35.79%, shown in Table 4; (2) the interindustry linkage effect, direct interindustry linkage effect, and indirect interindustry linkage effect from manufacturing to producer services are 11.09, 10.12, and 0.97 Trillion Yuan, respectively, shown in Table 5; (3) the interindustry linkage contribution and coefficient from manufacturing to producer services are 22.53% and 0.4625, respectively, shown in Table 5.
### Table 3: Decomposition components of gross output of manufacturing, producer services, and their subindustries.

| Industrial sector or subindustry | Gross output | Intraindustry multiplier effect | Interindustry incoming spillover effect | Interindustry incoming spillover effect from manufacturing | Interindustry incoming spillover effect from producer services | Interindustry incoming spillover effect from the rest of the industries | Interindustry feedback effect |
|----------------------------------|--------------|---------------------------------|----------------------------------------|---------------------------------------------------------|------------------------------------------------------------|---------------------------------------------------------------|-----------------------------|
| Manufacturing                     | 100.89       | 49.40                           | 42.99                                  | —                                                       | 7.16                                                       | 35.83                                                          | 8.51                        |
| Low-tech manufacturing            | 26.70        | 16.91                           | 8.00                                   | —                                                       | 1.50                                                       | 6.50                                                           | 1.79                        |
| Mid-tech manufacturing            | 26.19        | 6.65                            | 16.58                                  | —                                                       | 2.01                                                       | 14.58                                                          | 2.95                        |
| High-tech manufacturing           | 48.00        | 25.83                           | 18.40                                  | —                                                       | 3.65                                                       | 14.75                                                          | 3.76                        |
| Producer services                 | 49.22        | 18.73                           | 28.70                                  | 11.09                                                   | —                                                         | 17.61                                                          | 1.78                        |
| Wholesale service                 | 11.59        | 4.23                            | 6.91                                   | 3.30                                                   | —                                                         | 3.60                                                           | 0.45                        |
| Logistic service                  | 10.26        | 3.33                            | 6.50                                   | 2.79                                                   | —                                                         | 3.71                                                           | 0.42                        |
| Information service               | 5.65         | 3.68                            | 1.85                                   | 0.56                                                   | —                                                         | 1.29                                                           | 0.11                        |
| Finance service                   | 9.43         | 3.13                            | 5.94                                   | 1.85                                                   | —                                                         | 4.09                                                           | 0.36                        |
| Business service                  | 7.18         | 1.94                            | 4.92                                   | 1.95                                                   | —                                                         | 2.98                                                           | 0.32                        |
| Technology service                | 5.10         | 2.41                            | 2.58                                   | 0.64                                                   | —                                                         | 1.94                                                           | 0.11                        |

The unit of the data expressed is Trillion Yuan.

### Table 4: Output structural features of manufacturing, producer services, and their subindustries.

| Industrial sector or subindustry | Gross output | Proportion of sectoral internal effect | Proportion of external linkage effect | Interindustry linkage contribution from the rest of the industries |
|----------------------------------|--------------|--------------------------------------|--------------------------------------|---------------------------------------------------------------|
| Manufacturing                     | 100.00       | 48.96                                | 51.04                                | 35.51                                                         |
| Low-tech manufacturing            | 100.00       | 63.35                                | 36.65                                | 24.35                                                         |
| Mid-tech manufacturing            | 100.00       | 25.41                                | 74.59                                | 55.65                                                         |
| High-tech manufacturing           | 100.00       | 53.82                                | 46.18                                | 30.73                                                         |
| Producer services                 | 100.00       | 38.06                                | 61.94                                | 35.79                                                         |
| Wholesale service                 | 100.00       | 36.53                                | 63.47                                | 31.09                                                         |
| Logistic service                  | 100.00       | 32.49                                | 67.51                                | 36.21                                                         |
| Information service               | 100.00       | 65.15                                | 34.85                                | 22.90                                                         |
| Finance service                   | 100.00       | 33.21                                | 66.79                                | 43.36                                                         |
| Business service                  | 100.00       | 26.98                                | 73.02                                | 41.46                                                         |
| Technology service                | 100.00       | 47.30                                | 52.70                                | 37.92                                                         |

The unit of all the data expressed is %.

### Table 5: Interindustry linkages from manufacturing to producer services and its subindustries.

| Industrial sector or subindustry | Interindustry linkage effect (Trillion Yuan) | Direct interindustry linkage effect (Trillion Yuan) | Indirect interindustry linkage effect (Trillion Yuan) | Interindustry linkage contribution (%) | Interindustry linkage coefficient |
|----------------------------------|---------------------------------------------|-----------------------------------------------|-----------------------------------------------|----------------------------------------|----------------------------------|
| Producer services                | 11.09                                       | 10.12                                         | 0.97                                          | 22.53                                  | 0.4625                           |
| Wholesale service                | 3.30                                        | 3.06                                          | 0.24                                          | 28.50                                  | 0.1378                           |
| Logistic service                 | 2.79                                        | 2.56                                          | 0.23                                          | 27.19                                  | 0.1165                           |
| Information service              | 0.56                                        | 0.50                                          | 0.06                                          | 9.91                                   | 0.0234                           |
| Finance service                  | 1.85                                        | 1.65                                          | 0.20                                          | 19.59                                  | 0.0771                           |
| Business service                 | 1.95                                        | 1.77                                          | 0.17                                          | 27.11                                  | 0.0812                           |
| Technology service               | 0.64                                        | 0.58                                          | 0.06                                          | 12.60                                  | 0.0268                           |
Similarly, the results of the subindustries of manufacturing or producer services can also be summarized according to Tables 4–6, which are not presented for brevity.

Compared with the previous measurements of interindustry linkages based on Leontief inverse matrix or similar coefficient matrix, this study further decomposes Leontief inverse matrix into three components based on demand-driven and multisector input-output model, in which the different industrial sectors in the entire economic system are regarded as different regions in the spatial scope. The method in this study has three obvious advantages.

Firstly, the method takes multiplier effect as sectoral internal effect and takes the total sum of spillover effect and feedback effect as external linkage effect. When analyzing the structural features of the gross output, it integrates the sectoral internal effect and external linkage effect at the same time, which can make it easy to understand the driving mechanism of industrial development.

Secondly, the classical measurements of interindustry linkages based on Leontief inverse matrix or similar coefficient matrix generally only reflect the overall interrelatedness, namely, the interindustry linkages between the given industry and the entire economic system, while the method in this study can not only measure the interindustry linkage effects between two given industrial sectors, but also clearly describe the composition ratio of the direct and indirect interindustry linkage effects through the further decomposition of spillover effect.

Thirdly, the method adopts, respectively, the absolute flow value, relative flow value, and unit relative value of the input-output relationship as the measurement of interindustry linkage effect, interindustry linkage contribution, and interindustry linkage coefficient, which can comprehensively reflect and evaluate the degree of industry linkages.

### 5. Discussion and Policy Implication

In accordance with the above results, four viewpoints in agreement with the cognitive patterns have been tested again by the empirical evidence from China. Firstly, compared with the indirect interindustry linkage effects, the direct interindustry linkage effects between manufacturing and producer services are overwhelmingly dominant, accounting for about 80%–90% of the total interindustry linkage effects (see Tables 5 and 6). Secondly, the viability of manufacturing is overall significantly stronger than that of producer services; namely, the proportion of sectoral internal effect on the gross output of manufacturing is significantly greater than that of producer services (see Table 4). Thirdly, among the interindustry linkages from producer services to the subindustries of manufacturing, the interindustry linkages to mid-tech or high-tech manufacturing are significantly stronger than those to low-tech manufacturing (see Table 6). Fourthly, the output of manufacturing induced by per unit final demand of producer services is larger than that of producer services induced by per unit final demand of manufacturing; namely, the interindustry linkage coefficient from producer services to manufacturing is higher than that from manufacturing to producer services (see Tables 5 and 6).

What is more, some unique local features of manufacturing and producer services in China can be also drawn as follows, and in this study we think they are helpful for the policymakers and economists to better evaluate the development status of two critical industrial sectors in China.

1. Whether it is the manufacturing or producer services, the total sum of interindustry spillover effect and interindustry feedback effect is higher than intraindustry multiplier effect (see Table 4), indicating that the external linkage effect is the main driving force for the output of these two industrial sectors, and the viability of them is secondary. In addition, compared with the intraindustry multiplier effect, the interindustry feedback has a certain scale, which means that the estimation error will be obvious when a single-sector model is used instead of multisector model. This is different from some researches on multiregional input-output model [40, 41], in which the interregional feedback effect is usually neglected for the very small scale compared with the intraregional multiplier effect. One reasonable explanation is that the interdependence of different industrial sectors is much stronger than that of different regions, for goods’ or services’ transfer barriers of the former are significantly less than that of the latter.

2. The interindustry linkage effects and contributions between manufacturing and producer services in China are not strong overall, compared with those from the rest of the industries to manufacturing or producer service (see Tables 4–6). In 2017, the interindustry linkage effect and proportion from
producer services to manufacturing are 7.16 trillion Yuan and 7.09%, and both of them are far smaller than those from the rest of the industries to manufacturing, which are 35.83 trillion Yuan and 35.51%. In spite of the fact that the interindustry linkage proportion from manufacturing to producer services is higher than that from producer services to manufacturing and the interindustry linkage effect from manufacturing to producer services is also higher than that from producer services to manufacturing, they are still smaller than those from the rest of the industries to producer services. The empirical results show that the impact of the rest of the industries in China on manufacturing or producer services is very significant, accounting for the major or overwhelming major of the external linkage effect. If analyzing the interindustry linkages between manufacturing and producer services only with the two-sector model and ignoring the role of the rest of the industries, it will greatly weaken the applicability of the conclusions.

(3) Interindustry linkages from manufacturing to wholesale service and logistic service are relatively strong, while those from manufacturing to information service and technology service are relatively weak. Among the interindustry linkages from manufacturing to the subindustries of producer services, the linkage to wholesale service is the highest, followed by logistic service, business service, financial service, and technology service, and the lowest is to information service (see Table 5). Since the labor productivities of information service and technology service are usually higher than those of wholesale service and logistic service, the empirical results show that in China the pull force from manufacturing is more significant in the field of low-level producer services instead of high-level services and the evolution of interindustry linkages between manufacturing and producer services is still in the primary stage.

After the analysis and evaluation of the output structural features and interindustry linkages in Chinese three-sector economic system, in the perspective of improving the current weak links, this study puts forward the following three policy suggestions aiming to promote the integration level of manufacturing and producer services in China.

First of all, the policy-makers in China should pay great attention to the fact that the interindustry linkages between manufacturing and producer services are not strong overall and the interindustry linkage effect from producer services to manufacturing is weaker than that from manufacturing to
Table 8: The rearranged China input-output table in year 2017.

| Input/output                | Low-tech manufacturing | Mid-tech manufacturing | High-tech manufacturing | Wholesale service | Logistic service | Information service | Finance service | Business service | Technology service | The primary industry | The rest of the second industry | The rest of the tertiary industry | Final demand | Gross output |
|-----------------------------|------------------------|------------------------|-------------------------|-------------------|------------------|--------------------|----------------|------------------|-------------------|---------------------|-------------------------------|-------------------------------|--------------|--------------|
| Low-tech manufacturing      | 8570.65                | 431.49                 | 1121.97                 | 115.54            | 139.46           | 197.62             | 336.74         | 807.92           | 130.31            | 968.79              | 757.57                        | 2350.60                      | 10769.80     | 26698.46     |
| Mid-tech manufacturing      | 679.78                 | 8395.67                | 5840.35                 | 35.64             | 839.76           | 13.75              | 30.39          | 417.47           | 261.79            | 71.56               | 8428.48                       | 229.44                        | 947.66        | 26191.75     |
| High-tech manufacturing     | 1855.21                | 1614.27                | 22273.82                | 182.76            | 1040.60          | 442.85             | 59.08          | 642.04           | 895.56            | 1026.88             | 3240.54                       | 2466.20                       | 12258.21     | 47998.02     |
| Wholesale service           | 1549.47                | 767.84                 | 2333.58                 | 73.63             | 251.15           | 81.05              | 60.57          | 240.88           | 117.57            | 236.66              | 1225.90                       | 719.93                        | 3931.11       | 11589.36     |
| Logistic service            | 908.80                 | 784.20                 | 1430.63                 | 723.60            | 1104.33          | 85.64              | 165.63         | 450.98           | 232.75            | 250.33              | 936.06                        | 816.30                        | 2366.07       | 10255.33     |
| Information service         | 63.27                  | 36.37                  | 291.76                  | 69.37             | 176.57           | 925.69             | 306.41         | 68.59            | 61.44             | 15.91               | 329.36                        | 460.22                       | 2847.83       | 5652.80      |
| Finance service             | 220.97                 | 571.45                 | 671.38                  | 477.29            | 1105.40          | 1169.5             | 791.20         | 488.66           | 140.81            | 145.11              | 1352.42                       | 1290.09                       | 2062.31       | 9434.05      |
| Business service            | 515.64                 | 264.19                 | 922.68                  | 1088.66           | 209.57           | 372.34             | 841.23         | 724.08           | 206.59            | 26.88               | 520.43                        | 831.95                        | 656.30        | 7180.55      |
| Technology service          | 55.36                  | 76.54                  | 347.53                  | 84.05             | 24.52            | 17.64              | 11.04          | 0.84             | 573.84            | 78.43               | 1718.69                       | 27.16                         | 2088.97       | 5104.60      |
| The primary industry        | 5736.01                | 25.29                  | 515.11                  | 0.12              | 1.01             | 3.65               | 0.91           | 51.53            | 29.18             | 1468.38             | 192.74                        | 482.74                       | 2505.72       | 11012.40     |
| The rest of the second      | 446.59                 | 6089.86                | 1548.79                 | 123.18            | 274.74           | 68.64              | 84.86          | 34.83            | 52.19             | 114.09              | 5029.42                       | 551.91                        | 20227.97     | 34647.09     |
| industry                    |                        |                        |                        |                   |                   |                   |               |                  |                  |                    |                               |                               |              |              |
| The rest of the tertiary    | 256.72                 | 253.01                 | 550.12                  | 909.20            | 442.44           | 374.07             | 1342.65        | 900.91           | 356.54            | 64.15               | 516.78                        | 2382.75                       | 21659.60     | 30008.94     |
| industry                    |                        |                        |                        |                   |                   |                   |               |                  |                  |                    |                               |                               |              |              |
| Value added                 | 5839.97                | 6881.57                | 10150.31                | 7706.30           | 4645.76          | 2952.91            | 5403.32        | 2351.83          | 2046.02           | 6545.24             | 10398.69                       | 17399.65                      |                   |              |
| Gross input                 | 26698.46               | 26191.75               | 47998.02                | 11589.36          | 10255.33         | 5652.80            | 9434.05        | 7180.55          | 5104.60           | 11012.40            | 34647.09                       | 30008.94                      |                   |              |

1The original input-output table in 2017 has totally 149 industries, and it can be downloaded through http://data.stats.gov.cn/files/html/quickSearch/trcc/trcc01.html; the final demand in this table contains the part of net exports. The unit of the data expressed is Billion Yuan.
producer services. It means that the producer services are a more obvious weak link compared with manufacturing, so it is necessary to further strengthen the supporting of producer services for manufacturing and take measures such as promoting the industrial clustering degree or improving the serviceability of producer services.

Secondly, in view of the fact that low-tech manufacturing is the key weak link among the subindustries of manufacturing, it is necessary to accelerate the transformation of traditional low-tech manufacturing through the universal application and integration of producer services, in response to the trends of industrialization upgrading in China.

Finally, in view of the fact that information service is the key weak link among the subindustries of producer service, it is necessary to speed up the pace of manufacturing servitization, especially manufacturing digitization, and promote the widespread application of information technology in the field of manufacturing.

6. Conclusions

This study puts forward a new method for interindustry linkage analysis in a complex economic system on the basis of demand-driven and multisector input-output model, in which the output as well as Leontief inverse matrix is decomposed into three components and interindustry linkage effect, interindustry linkage contribution, and interindustry linkage coefficient are adopted as the measuring indices. Compared with the previous measurements of interindustry linkages based on Leontief inverse matrix or similar coefficient matrix, the method in this study has some obvious advantages. As a whole, this method is a refinement of Hirschman’s backward linkage, which is critical in the perspective of output structure in demand side.

Based on the method and input-output data, this study also conducts an empirical study on the interindustry linkages between China’s manufacturing and producer services, and the results show that the external linkage effect is the main driving force for the output of these two industrial sectors, and the viability of them is secondary; the interindustry linkage effects and contributions between manufacturing and producer services in China are not strong overall, compared with those from the rest of the industries to manufacturing or producer service; interindustry linkages from manufacturing to wholesale service and logistic service are relatively strong, while those from manufacturing to information service and technology service are relatively weak. The authors hold that the method in this study is helpful for policy-makers and relevant stakeholders to better understand the interrelatedness between two industrial sectors in a complex economic system and identify the key weak links which guide them to promote balanced development of economy.

Finally, it is worth mentioning that this study only discusses Hirschman’s backward linkage on the basis of Leontief inverse matrix, mainly due to the fact that the output structure on the demand side generally is paid more attention. Further research may focus on the forward linkage on the basis of Ghosh inverse matrix and explore the structural features of output on the supply side, or some other important economic factors, such as value added, employment, and resource utilization.

Appendix

A. The Classification of the Entire Economic System of China

The classification of the entire economic system of China is shown in Table 7

B. The Rearranged China Input-Output Table in Year 2017 (Unit: Billion Yuan)

The rearranged China input-output table in year 2017 is shown in Table 8

C. Some Critical Vectors and Matrices of the Application Case in China 2017

\[
X = \begin{bmatrix}
X^1 \\
X^2 \\
X^3
\end{bmatrix} = \begin{bmatrix}
26.70 \\
26.19 \\
48.00 \\
11.59 \\
10.26 \\
5.65 \\
9.43 \\
7.18 \\
5.10 \\
11.01 \\
34.65 \\
30.01
\end{bmatrix}, \quad (C.1)
\]

\[
Y = \begin{bmatrix}
Y^1 \\
Y^2 \\
Y^3
\end{bmatrix} = \begin{bmatrix}
10.77 \\
0.95 \\
12.26 \\
3.93 \\
2.37 \\
2.85 \\
2.06 \\
0.66 \\
2.09 \\
2.51 \\
20.23 \\
21.66
\end{bmatrix}, \quad (C.2)
\]
Note: the unit of the elements in $X$ and $Y$ is Trillion Yuan.

\[
A = \begin{bmatrix}
A_{11} & A_{12} & A_{13} \\
A_{21} & A_{22} & A_{23} \\
A_{31} & A_{32} & A_{33}
\end{bmatrix}
\]
\[
= \begin{bmatrix}
0.32 & 0.02 & 0.01 & 0.01 & 0.03 & 0.04 & 0.11 & 0.03 & 0.09 & 0.02 & 0.08 \\
0.03 & 0.32 & 0.12 & 0.00 & 0.08 & 0.00 & 0.00 & 0.06 & 0.05 & 0.01 & 0.24 \\
0.07 & 0.06 & 0.46 & 0.02 & 0.10 & 0.08 & 0.01 & 0.09 & 0.18 & 0.09 & 0.08 \\
0.06 & 0.03 & 0.05 & 0.01 & 0.02 & 0.01 & 0.01 & 0.03 & 0.02 & 0.02 & 0.04 \\
0.03 & 0.03 & 0.03 & 0.06 & 0.11 & 0.02 & 0.02 & 0.06 & 0.05 & 0.02 & 0.03 \\
0.00 & 0.00 & 0.01 & 0.01 & 0.02 & 0.16 & 0.03 & 0.01 & 0.01 & 0.00 & 0.01 \\
0.01 & 0.02 & 0.01 & 0.04 & 0.11 & 0.02 & 0.08 & 0.07 & 0.03 & 0.01 & 0.04 \\
0.02 & 0.01 & 0.02 & 0.09 & 0.02 & 0.07 & 0.09 & 0.10 & 0.04 & 0.00 & 0.02 \\
0.00 & 0.00 & 0.01 & 0.01 & 0.00 & 0.00 & 0.00 & 0.00 & 0.11 & 0.01 & 0.05 \\
0.21 & 0.00 & 0.01 & 0.00 & 0.00 & 0.00 & 0.00 & 0.01 & 0.13 & 0.01 & 0.02 \\
0.02 & 0.23 & 0.03 & 0.01 & 0.03 & 0.01 & 0.00 & 0.01 & 0.01 & 0.15 & 0.02 \\
0.01 & 0.01 & 0.01 & 0.08 & 0.04 & 0.07 & 0.14 & 0.13 & 0.07 & 0.01 & 0.01 \\
\end{bmatrix}
\]

\[
B = \begin{bmatrix}
1.57 & 0.11 & 0.13 & 0.07 & 0.09 & 0.12 & 0.12 & 0.26 & 0.12 & 0.19 & 0.11 \\
0.19 & 1.75 & 0.48 & 0.07 & 0.26 & 0.10 & 0.07 & 0.23 & 0.25 & 0.10 & 0.59 \\
0.37 & 0.37 & 2.06 & 0.13 & 0.33 & 0.28 & 0.13 & 0.36 & 0.51 & 0.29 & 0.41 \\
0.14 & 0.10 & 0.14 & 1.03 & 0.07 & 0.05 & 0.04 & 0.09 & 0.08 & 0.06 & 0.10 \\
0.11 & 0.11 & 0.12 & 0.10 & 1.17 & 0.06 & 0.06 & 0.13 & 0.11 & 0.06 & 0.10 \\
0.02 & 0.02 & 0.03 & 0.02 & 0.04 & 1.21 & 0.05 & 0.03 & 0.03 & 0.01 & 0.03 \\
0.06 & 0.10 & 0.09 & 0.08 & 0.17 & 0.06 & 1.13 & 0.14 & 0.09 & 0.04 & 0.11 \\
0.07 & 0.07 & 0.09 & 0.13 & 0.07 & 0.12 & 0.12 & 1.17 & 0.10 & 0.03 & 0.07 \\
0.02 & 0.04 & 0.03 & 0.01 & 0.02 & 0.01 & 0.01 & 1.14 & 0.02 & 0.08 & 0.01 \\
0.40 & 0.04 & 0.06 & 0.02 & 0.03 & 0.04 & 0.04 & 0.08 & 0.05 & 1.20 & 0.05 \\
0.11 & 0.50 & 0.22 & 0.05 & 0.13 & 0.07 & 0.05 & 0.10 & 0.11 & 0.06 & 1.36 \\
0.07 & 0.08 & 0.08 & 0.13 & 0.11 & 0.13 & 0.21 & 0.21 & 0.14 & 0.04 & 0.08 \\
\end{bmatrix}
\]

\[
M = \begin{bmatrix}
1.48 & 0.04 & 0.07 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0.09 & 1.51 & 0.35 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0.20 & 0.18 & 1.92 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1.01 & 0.03 & 0.02 & 0.01 & 0.04 & 0.03 & 0 & 0 \\
0 & 0 & 0 & 0.08 & 1.13 & 0.03 & 0.03 & 0.08 & 0.07 & 0 & 0 \\
0 & 0 & 0 & 0.01 & 0.03 & 1.20 & 0.05 & 0.02 & 0.02 & 0 & 0 \\
0 & 0 & 0 & 0.06 & 0.14 & 0.04 & 1.11 & 0.10 & 0.05 & 0 & 0 \\
0 & 0 & 0 & 0.12 & 0.04 & 0.09 & 0.12 & 1.13 & 0.06 & 0 & 0 \\
0 & 0 & 0 & 0.01 & 0.00 & 0.00 & 0.00 & 1.13 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1.15 & 0.01 & 0.02 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.01 & 1.17 & 0.02 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.01 & 0.02 & 1.09
\end{bmatrix}
\]
\[
S = \begin{bmatrix}
0 & 0 & 0 & 0.07 & 0.09 & 0.12 & 0.12 & 0.26 & 0.12 & 0.19 & 0.11 & 0.17 \\
0 & 0 & 0 & 0.07 & 0.26 & 0.10 & 0.07 & 0.23 & 0.25 & 0.10 & 0.59 & 0.11 \\
0 & 0 & 0 & 0.13 & 0.33 & 0.28 & 0.13 & 0.36 & 0.51 & 0.29 & 0.41 & 0.27 \\
0.14 & 0.10 & 0.14 & 0 & 0 & 0 & 0 & 0 & 0.06 & 0.10 & 0.06 \\
0.11 & 0.11 & 0.12 & 0 & 0 & 0 & 0 & 0 & 0.06 & 0.10 & 0.07 \\
0.02 & 0.02 & 0.03 & 0 & 0 & 0 & 0 & 0 & 0.01 & 0.03 & 0.03 \\
0.06 & 0.10 & 0.09 & 0 & 0 & 0 & 0 & 0 & 0.04 & 0.11 & 0.08 \\
0.07 & 0.07 & 0.09 & 0 & 0 & 0 & 0 & 0 & 0.03 & 0.07 & 0.07 \\
0.02 & 0.04 & 0.03 & 0 & 0 & 0 & 0 & 0 & 0.02 & 0.08 & 0.01 \\
0.40 & 0.04 & 0.06 & 0.02 & 0.03 & 0.04 & 0.04 & 0.08 & 0.05 & 0 & 0 & 0 \\
0.11 & 0.50 & 0.22 & 0.05 & 0.13 & 0.07 & 0.05 & 0.10 & 0.11 & 0 & 0 & 0 \\
0.07 & 0.08 & 0.08 & 0.13 & 0.11 & 0.13 & 0.21 & 0.21 & 0.14 & 0 & 0 & 0
\end{bmatrix}
\]
\hspace{1cm} (C.6)

\[
S_d = \begin{bmatrix}
0 & 0 & 0 & 0.06 & 0.07 & 0.11 & 0.11 & 0.24 & 0.09 & 0.17 & 0.08 & 0.16 \\
0 & 0 & 0 & 0.06 & 0.21 & 0.08 & 0.05 & 0.18 & 0.19 & 0.07 & 0.50 & 0.08 \\
0 & 0 & 0 & 0.11 & 0.29 & 0.25 & 0.31 & 0.30 & 0.46 & 0.25 & 0.32 & 0.23 \\
0.13 & 0.09 & 0.13 & 0 & 0 & 0 & 0 & 0 & 0 & 0.06 & 0.09 & 0.06 \\
0.10 & 0.10 & 0.11 & 0 & 0 & 0 & 0 & 0 & 0 & 0.06 & 0.09 & 0.06 \\
0.02 & 0.02 & 0.03 & 0 & 0 & 0 & 0 & 0 & 0 & 0.01 & 0.03 & 0.03 \\
0.06 & 0.09 & 0.08 & 0 & 0 & 0 & 0 & 0 & 0 & 0.04 & 0.10 & 0.08 \\
0.07 & 0.06 & 0.08 & 0 & 0 & 0 & 0 & 0 & 0 & 0.03 & 0.06 & 0.06 \\
0.02 & 0.04 & 0.03 & 0 & 0 & 0 & 0 & 0 & 0 & 0.02 & 0.08 & 0.01 \\
0.38 & 0.02 & 0.05 & 0.02 & 0.02 & 0.03 & 0.03 & 0.07 & 0.04 & 0 & 0 & 0 \\
0.08 & 0.43 & 0.19 & 0.04 & 0.11 & 0.05 & 0.03 & 0.08 & 0.09 & 0 & 0 & 0 \\
0.05 & 0.05 & 0.07 & 0.12 & 0.10 & 0.12 & 0.20 & 0.20 & 0.13 & 0 & 0 & 0
\end{bmatrix}
\hspace{1cm} (C.7)

\[
S_r = \begin{bmatrix}
0 & 0 & 0 & 0.01 & 0.02 & 0.01 & 0.01 & 0.03 & 0.02 & 0.02 & 0.03 & 0.02 \\
0 & 0 & 0 & 0.02 & 0.05 & 0.03 & 0.02 & 0.05 & 0.05 & 0.03 & 0.09 & 0.03 \\
0 & 0 & 0 & 0.02 & 0.05 & 0.03 & 0.02 & 0.06 & 0.06 & 0.04 & 0.08 & 0.04 \\
0.01 & 0.01 & 0.01 & 0 & 0 & 0 & 0 & 0 & 0.00 & 0.01 & 0.01 \\
0.01 & 0.01 & 0.01 & 0 & 0 & 0 & 0 & 0 & 0.00 & 0.01 & 0.01 \\
0.00 & 0.00 & 0.00 & 0 & 0 & 0 & 0 & 0 & 0.00 & 0.00 & 0.00 \\
0.01 & 0.01 & 0.01 & 0 & 0 & 0 & 0 & 0 & 0.00 & 0.01 & 0.01 \\
0.01 & 0.01 & 0.01 & 0 & 0 & 0 & 0 & 0 & 0.00 & 0.01 & 0.01 \\
0.00 & 0.00 & 0.00 & 0 & 0 & 0 & 0 & 0 & 0.00 & 0.00 & 0.00 \\
0.02 & 0.02 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0 & 0 & 0 \\
0.03 & 0.07 & 0.03 & 0.01 & 0.02 & 0.01 & 0.02 & 0.02 & 0.02 & 0 & 0 & 0 \\
0.02 & 0.03 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0.01 & 0 & 0 & 0
\end{bmatrix}
\hspace{1cm} (C.8)
Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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