sustainability

Article

Analysis of Changes in Inter-Industrial Linkages and Economic Effects of Coal Industry in China Using Input–Output Model

Zian Chen and Sunhee Suk *

Graduate School of Fisheries and Environmental Sciences, Nagasaki University, 1-14 Bunkyo-machi, Nagasaki 852-8521, Japan; bb53423805@ms.nagasaki-u.ac.jp
* Correspondence: suksunhee@nagasaki-u.ac.jp; Tel.: +81-95-819-2866

Abstract: This research quantifies the inter-industrial linkages (forward linkages and backward linkages) and economic effects (production-inducing effects and supply-shortage effects) and their changes through the input–output analysis of China's coal industry in different time periods (2005, 2010, 2015, 2020). The results show that, from an overall point of view, the linkages (backward and forward) between the coal industry and other industries, as well as the economic effects of the coal sector, have tended to weaken in recent years, and both of these indicators for the coal sector in 2020 are weaker than the levels in 2005. However, individual sectors differ from the overall trend: the non-metal mineral products sector has shown an upward trend in recent years in the degree of total demand for coal sector products and the degree of influence by supply shortages in the coal sector, while these two indicators for the construction sector have been on an upward trend since 2005; the electricity, heat production, and supply sector has shown an upward trend in recent years in the degree of influence by supply shortages in the coal sector. Based on the analytical results of this study, some policy insights are provided for China's low-carbon transition.

Keywords: coal industry; input–output analysis; inter-industrial linkages; economic effects; low-carbon transition

check for updates

Citation: Chen, Z.; Suk, S. Analysis of Changes in Inter-Industrial Linkages and Economic Effects of Coal Industry in China Using Input–Output Model. *Sustainability* **2023**, *15*, 15158. https://doi.org/10.3390/su152015158

Academic Editor: Cristina Raluca Gh. Popescu

Received: 12 September 2023
Revised: 18 October 2023
Accepted: 21 October 2023
Published: 23 October 2023

1. Introduction

China is the world's largest coal producer and consumer, accounting for over half of global coal production and consumption in 2020 [1]. Due to China's energy landscape of rich coal endowment but limited oil and natural gas, coal has long been the chief form of energy used, occupying a dominant position in energy production and consumption. From a macroeconomic perspective, the coal sector in China plays an essential role in providing the necessary energy and other resources to support economic development [2].

However, while the coal sector has strongly supported China's economic development, it has also caused serious environmental problems in China, one of which is the large amount of greenhouse gas emissions. Specifically, China is the largest emitter of coal mine methane in the world, accounting for around half of global coal mine methane emissions [3]. In 2021, the use of coal in China caused 7.96 billion metric tons of CO_2 emissions, accounting for about 70% of China's total emissions that year [4]. In September 2020, Chinese President Xi Jinping announced that China will "aim to peak CO_2 emissions by 2030 and achieve carbon neutrality by 2060" [5], implying that China will take more aggressive measures to accelerate the low-carbon transition of its energy system and industrial sectors and promote the optimization and upgrading of industrial structures to achieve a low-carbon economy.

Moving away from dependence on coal is one of the key aspects of China's low-carbon transition. However, coal not only dominates China's energy system, but the coal industry also interacts and is closely linked with other industries in the national economy through complex input–output relationships. It is therefore important to understand the relationship between the coal industry and other industries and to estimate the economic effects of the coal industry when making strategic decisions related to the low-carbon transition in various industrial sectors.

Figure 1 shows annual coal production/consumption and its proportion in China's total energy production/consumption from 2005 to 2020. As mentioned above, coal dominates China's energy system, with its production and consumption showing a steady upward trend each year between 2005 and 2012. The period 2002–2012 is also commonly referred to as the "golden decade" of China's coal industry, during which rising market demand and coal prices attracted a large amount of social capital. However, it also led to over-production and yield over-concentration [6].

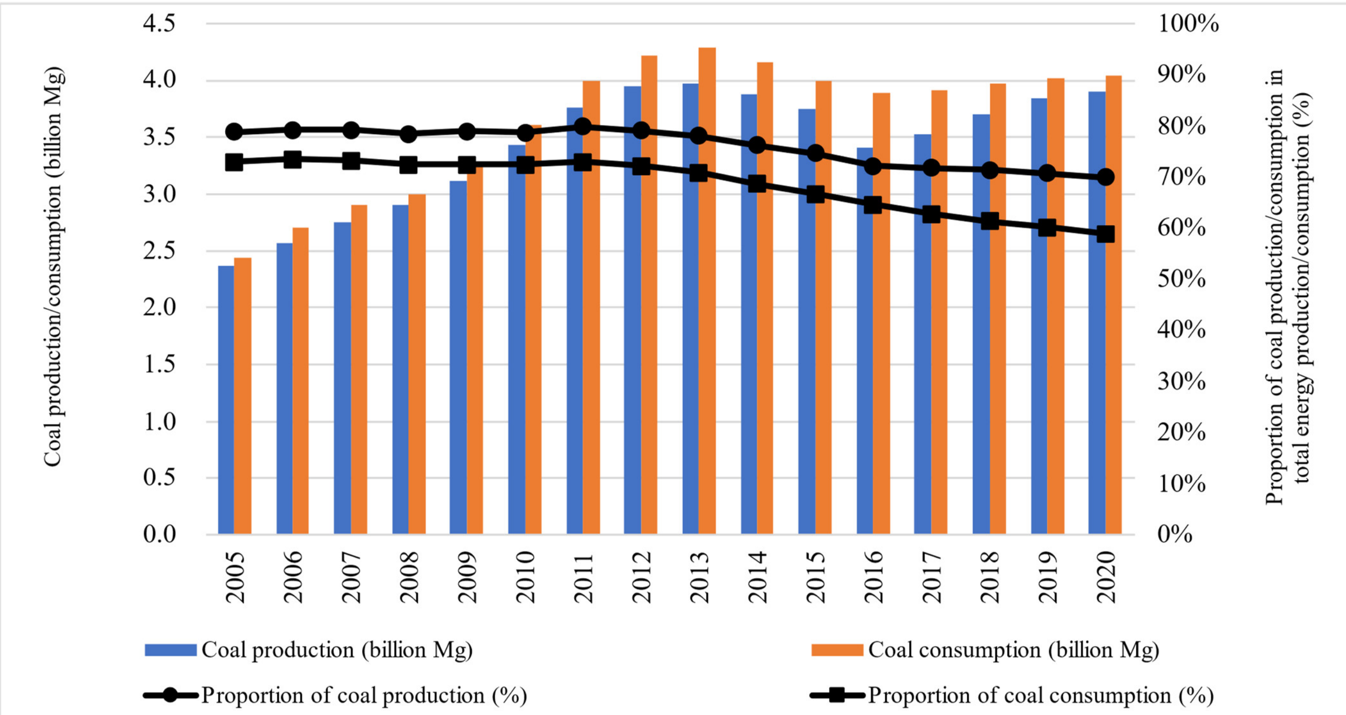

Figure 1. Coal production/consumption and its proportion in total energy production/consumption of China in 2005–2020. (Data source: [7], the conversion of short ton to the International System of Units (Mg) is based on the following unit conversion relationships: 1 Mg = 1 metric ton = 1.10231 short ton).

With the start of the 12th Five-Year Plan period (2011–2015), China has suffered a slump in economic growth and a noticeable degradation of ecological and environmental issues [2]. At the same time, its energy strategy has changed dramatically. Specifically, the "Air Pollution Prevention and Control Action Plan" was released by the State Council in 2013, with the aim of limiting direct coal consumption to 65% of primary energy until 2017 by using a combination of substitute energy sources (coal to gas and coal to electricity), renewable energy, and energy efficiency measures [8]. After that, the "Action Plan for Clean and Efficient Use of Coal (2015–2020)" was issued by the National Energy Administration (NEA) in 2015, with the main tasks including improving the quality of coal products and improving the efficiency of comprehensive use of coal resources [9]. The production and consumption of coal continued to decline between 2013 and 2016, and its proportion in the energy system also began to decline from 2011. In 2016, the National Development and Reform Commission (NDRC) and the NEA released the "13th Five-Year Plan for the Development of the Coal Industry" (2016–2020), which called for strict control of new production capacity, elimination of excess outdated capacity, limitations on consumption, and optimization of the coal production structure [10]. While the share of coal in the energy system continued to decline, coal production and consumption began to rebound, with an upward trend between 2016 and 2020.

The announcement of China's carbon peak and carbon neutrality goals in 2020 opened the way for a transition to a low-carbon economy, with the coal industry once again facing significant challenges. In other words, China needs to gradually reduce its dependence on coal while ensuring economic development. In 2021, the State Council issued the "Action Plan for carbon dioxide peaking before 2030", which includes key actions to promote coal consumption substitution, transformation, and upgrading and accelerate coal reduction efforts [11].

In summary, since the beginning of the 12th Five-Year Plan period, a series of related policies have led to a continuous decrease in the proportion of coal production/consumption in total energy production/consumption. However, the production and consumption of coal have rebounded in recent years and shown a trend of continual increase. In addition, the role of the coal industry as part of the overall chain of industry is constantly changing along with the changes in economic development and the enactment of related policies, which makes it necessary to track changes in the relationship between the coal industry and other industries as well as the economic effects throughout different periods of the coal industry. Providing an overview of changes in trends related to industry can inform the formation of corresponding policy measures aimed at promoting the development of a low-carbon economy.

Some scholars have already conducted a comprehensive analysis of China's coal industry. Wang [12] discussed the imbalanced development of the coal and electricity industries in China, highlighting their heavy reliance on each other but also noting that excessive government intervention has made it difficult for them to form stable and cost-saving relationships. Liu [13] carried out an empirical analysis of the coal industry's coordinated development path based on an investigation and study of several coal cities in China. Through the analysis, the author suggested that the coal industry needs to pay high taxes and fees, fulfill its dutiful social responsibility, and implement a reasonable tax and fee system to realize the coordinated development strategy for the coal industry. Zhang et al. [14] offered new perspectives by concentrating on residual coal exploitation and its impact on both sustainable coal industry development and sustainable coal supply in China. They argued that residual coal exploitation will have a positive impact on both coal supply and the sustainable development of the coal industry in China but that factors such as economic development and environmental concerns can impede coal industry development. Zhang et al. [15] measured and evaluated the Chinese coal industry's capacity utilization (CU) over the past decades to scientifically evaluate its resource allocation. The study found that there is a significant decoupling between economic growth and coal capacity utilization, indicating that China's supply-side reform has been effective in optimizing its energy mix. The study also suggests that capacity elimination in China's coal sector may not cause a macroeconomic slump provided it is done gradually and with proper planning. Wang et al. [16] provided a review and prospects for clean utilization technology in China's coal industry. The study concluded that the development and implementation of intelligent and ecological coal mining technologies and clean utilization technologies are crucial for improving the efficiency, safety, and sustainability of China's coal industry while reducing its ecological and environmental impacts. Zhao et al. [17] provided a quantitative analysis of the future development of China's coal industry, with a focus on the composite index, evaluation system, industrial transition, and carbon emission reduction. The key findings of this study suggest that, to comprehensively develop China's coal industry, priority should be placed on energy security, safe and efficient mining, minimal environmental impact, and market competitiveness to satisfy national energy demands and ecological protection and industry sustainability goals. Zhang et al. [18] explored if the capacity reduction policy has enhanced the efficiency and environmental development of the coal industry. Even though the coal capacity reduction policy has reached a certain level of success, it is still necessary to establish and further develop the long-term policy of eliminating backward production capacity and preventing the resumption of reduced production capacity in the context of carbon neutralization. Zhong et al. [19] identified key factors that affect the transformation of the Chinese coal sector and analyzed the relationships and impacts on the industry's development. The authors suggest that policymakers should focus on developing supportive policies and promoting technological innovation to facilitate a high-quality transformation of China's coal industry. Zhang and Ponomarenko [20] analyzed the development changes in China's coal industry in the post-epidemic era and suggested future sustainable development directions for China's coal industry, including reducing carbon emissions and phasing out dependence on coal for economic development. Zhang et al. [21] discussed the quantification and multivariate decomposition of total factor productivity (TFP) growth in China's coal sector. The study concluded that China needs to strengthen the role of TFP growth in promoting the development of the coal industry, abandon the conventional methods of increasing output by increasing the input of production factors, and promote the energy production and consumption revolution to optimize the development system of the coal industry.

The above studies analyzed China's coal industry from different perspectives and provided valuable policy insights for the sustainable development of China's coal industry. However, few studies have discussed the inter-linkages between the coal industry and other industries or the economic effects of the coal industry. Most extant studies regarding the economic impact of a particular sector have used input–output analysis (I-O analysis), a classic approach to macroeconomic analysis that tracks the interdependencies between different sectors in an economy. This type of analysis method provides a breakdown of each sector in terms of its impact on the economy, and thus, it is recognized as a useful tool for identifying the impact of a particular sector within an economy and has widely been used in recent years to analyze the economic impact and role of specific sectors in different countries, such as the maritime and transportation industry in Korea [22,23], the air transport and fisheries industry in China [24,25], the marine industry in Ireland [26], and the seafood industry in Norway [27]. For studies of energy-related sectors, Han et al. used I-O analysis to examine the role of the four electricity sectors (hydroelectric, fossil fuels, nuclear, and non-utility) in the Korean economy for the period 1985–1998 [28]. Tang et al. employed an I-O approach to assess the economic impacts of China's petroleum industry in 1987–2007 [29]. Chun et al. adopted I-O analysis combined with the scenario-based exogenous specification method to evaluate the impact of investment in the hydrogen sector on the Korean economy for the period from 2020 to 2040 [30]. Lee et al. assessed and compared the role of the natural gas supply sector in the economies of Japan and South Korea by conducting an I-O analysis of these two countries [31]. In addition, some studies have focused on the mining industry, which included analysis of the coal mining industry. For example, Stilwell et al. analyzed the impact on the South African economy of gold, coal, and other mining activities between 1971 and 1993 by using I-O techniques [32]. San Cristóbal and Biezma used the I-O method to summarize the linkages of the mining and quarrying industry in the 10 European Union countries and identified several subsectors that could be considered as key sectors [33]. Kim et al. divided the Korean mining sector into four subsectors (coal, crude oil and natural gas, metal ores, and non-metallic mineral mining) and quantified the economic effects of the mining sector and the four subsectors in 2015 through the I-O analysis [34]. Regarding studies covering input–output analysis of the Chinese coal industry, Lei et al. [35] conducted a quantitative analysis of the economic and social impacts of different mineral developments in China from diverse perspectives by adopting the basic hypotheses of I-O economics, industrial linkage model, and income distribution antithesis. The results indicated that the coal mining and washing industry has provided a powerful push to increase China's fixed asset investment and GDP, created a large number of jobs, and also acted positively to promote China's technological investment. However, negative impacts on the environment and income inequality were also noted. Li et al. [2] used a method of combining I-O analysis and an APL model to empirically analyze China's coal industry chain and its evolutionary trends at the macroscopic level.

The authors identified that coal production and the supply of electric power, steam, and hot water constitute one of the four most important industrial chains in China, and industries related to the coal industry include chemicals, metal smelting and pressing, general-purpose electrical equipment manufacturing, power supply, and construction. The authors also emphasized the urgency to change the national structure of the coal industry in order to alleviate environmental pressures.

The above elaborated on previous studies related to the coal industry and an effective method to reveal the economic impact and role of specific sectors in an economy, i.e., I-O analysis and its related studies. However, among these studies, there is not only a lack of studies that consider the background of China's transition to a low-carbon economy but also a lack of studies that comprehensively consider the inter-industrial linkages and economic effects of China's coal industry. To address this gap, this study applies the I-O method, with the aim of providing policy insights for China's transition to a low-carbon economy by analyzing the inter-industrial linkages and economic effects of China's coal industry in different time periods, as well as their changes. Specifically, this study uses I-O tables (for China) for 2005, 2010, 2015, and 2020 and contributes through (1) the calculation of the total input coefficient and power of dispersion index of the coal industry, to comprehensively analyze the backward linkages of China's coal industry; (2) the calculation of the total output coefficient and sensitivity of dispersion index of China's coal industry, to provide a comprehensive analysis of the forward linkage of China's coal industry; (3) the calculation of the production-inducing and the supply-shortage effect of China's coal industry, to quantify its economic effects; (4) analyzing the changing characteristics of these indicators; and (5) providing, based on the calculation results, some policy insights for exploring pathways toward low-carbon economic transformation in China. The remainder of this paper is organized as follows: Section 2 provides the data sources and methodology, Section 3 presents the results of the I-O analysis, and Section 4 presents the conclusions and policy insights.

2. Methodology and Data

2.1. Method: I-O Analysis

2.1.1. General Framework of the I-O Model

The input–output model (I-O model) is an analytical framework developed by Wassily Leontief in the late 1930s [36]. It is aimed at creating a comprehensive framework that captures the interdependencies and interrelationships between different industries and sectors in an economy. The I-O model is based on an I-O table that shows the flow of goods and services between sectors, as well as a set of linear balance equations that describe these flows, as follows [37]:

$$X_i = \sum_{j=1}^{n} x_{ij} + Y_i = \sum_{j=1}^{n} a_{ij} X_j + Y_i \quad (i = 1, 2, \ldots, n) \tag{1}$$

$$X_j = \sum_{i=1}^{n} x_{ij} + V_j = \sum_{i=1}^{n} r_{ij} X_i + V_j \quad (j = 1, 2, \ldots, n) \tag{2}$$

where X_i is the total output of sector i; a_{ij} is the direct input coefficient which divides x_{ij}, the inter-industry input of producing sector j from supply sector i by X_j, the total input of sector j; r_{ij} is the direct output coefficient which divides x_{ij} by X_i, the total output of sector i; Y_i is the final demand of sector i, and V_j is the value added by sector j. Equations (1) and (2) represent the demand-driven model and the supply-driven model, respectively.

Based on the I-O framework, the inter-industrial linkages between China's coal industry and other industries are quantified. Typically, the inter-industrial linkages between the coal industry and other industries can be mainly divided into backward linkages from an input perspective and forward linkages from an output perspective. The former is the connection between the coal industry and its upstream industries, where the coal industry purchases products from other industries as a purchaser. The latter is the connection between the coal industry and its downstream industries, where the coal industry sells its products to other industries as a supplier. In this study, the backward linkages are measured by calculating the total input coefficient and the power of dispersion index. The forward linkages are measured by calculating the total output coefficient and the sensitivity of dispersion index. Treating the coal industry exogenously, this study further examines its economic effects, including production-inducing and supply-shortage effects.

2.1.2. Backward Linkages

- Total Input Coefficient

The total input coefficient measures the quantity of direct and indirect input from other sectors to produce one unit of output of the coal sector. It can be applied to measure the total dependence of the coal sector on its upstream sectors. Its coefficient matrix can be represented by B using the following formula:

$$B = (I - A)^{-1} - I \tag{3}$$

where A represents the direct input coefficient matrix whose elements are direct input coefficient a_{ij}. I is the $n \times n$ identity matrix, and $(I - A)^{-1}$ denotes the Leontief inverse matrix.

- Power of dispersion index

The power of dispersion index was developed by Rasmussen in 1956 and has been widely applied to evaluate backward linkages [38]. This index represents the extent of the change in overall output if final demand in a given sector were to increase by one unit. It is expressed as

$$p_j = \frac{\frac{\sum_{i=1}^{n} L_{ij}}{n}}{\frac{\sum_{j=1}^{n}\sum_{i=1}^{n} L_{ij}}{n^2}} \tag{4}$$

where p_j denotes the power of dispersion index, and n is the number of industries. $\sum_{i=1}^{n} L_{ij}/n$ is the average of the j column's elements in the Leontief inverse matrix $L = (I - A)^{-1}$. $\sum_{j=1}^{n}\sum_{i=1}^{n} L_{ij}/n^2$ is the average of all elements in the Leontief inverse matrix. If $p_j > 1$, this means that the economy as a whole will experience above-average output growth due to a unit increase in demand for the products of sector j.

2.1.3. Forward Linkages

- Total output coefficient

The total output coefficient represents the amount of the coal sector's one-unit output that is completely consumed by each sector. It can be used to analyze the degree of total demand for the coal industry by its downstream sectors. Its coefficient matrix can be represented by W and is given by the following formula:

$$W = (I - R)^{-1} - I \tag{5}$$

where R represents the direct output coefficient matrix whose elements are direct output coefficient r_{ij}, and $(I - R)^{-1}$ denotes the Ghosh inverse matrix.

- Sensitivity of dispersion index

Rasmussen also provides another index that describes the extent to which the system of industries is dependent on a particular industry—the sensitivity of dispersion index [38]. It measures the extent of the increase in the production of a particular industry, driven by a unit increase in the final demand for all industries in the system. It is described as

$$s_i = \frac{\frac{\sum_{j=1}^{n} L_{ij}}{n}}{\frac{\sum_{i=1}^{n}\sum_{j=1}^{n} L_{ij}}{n^2}} \quad (6)$$

where s_i denotes the sensitivity of dispersion index, and n is the number of industries. $\sum_{i=1}^{n} L_{ij}/n$ is the average of the i row's elements in the Leontief inverse matrix $L = (I - A)^{-1}$. $\sum_{j=1}^{n}\sum_{i=1}^{n} L_{ij}/n^2$ is the average of all elements in the Leontief inverse matrix. If $s_i > 1$, it means that the unit growth in demand in all sectors will lead to above-average growth in sector i.

2.1.4. Economic Effects

- Production-inducing effect

Equation (1) can be converted into a matrix form as $X = (I - A)^{-1}Y$, where X is the total output matrix, and Y is the final demand matrix. But this standardized demand model cannot properly assess the effects of new productive activities in a particular industry on the rest of the economy because changes in final demand can be caused by forces outside the model, such as changes in the patterns of consumption by consumers or changes in government purchases. Hence, the coal sector should therefore be treated exogenously and put in the final demand group [23,25]. To treat the coal sector as exogenous, the subscript "e" is added to the new matrices, and the subscript "m" is added to the vectors related to the coal sector, so that $X_e = (I - A_e)^{-1}(Y_e + A_m X_m)$. Assuming $\Delta Y_e = 0$, Equation (7) then yields

$$\Delta X_e = (I - A_e)^{-1} A_m \Delta X_m \quad (7)$$

where ΔX_e is the production-inducing multiplier, which shows changes in the output of sectors other than sector m. $(I - A_e)^{-1}$ represents the Leontief inverse matrix after deleting the m-related row and column. A_m denotes a column vector that is left after eliminating the mth element from the sector m-related column vector of A. ΔX_m denotes the change in the output of sector m.

This study utilizes Equation (7) to assess the impact of a change in the supply investment of the coal sector on the output of all other sectors in China, that is, the production-inducing effect.

- Supply-shortage effect

The traditional I-O model, assuming fixed input coefficients and perfectly elastic input supply, focuses on analyzing the effects of final demand, or backward linkage, and the output orientation of activities [23,25]. However, it may not be suitable for addressing the impacts of primary supply or forward linkage and input-oriented activities. Equation (2) can be converted into a matrix form as $X' = V'(I - R)^{-1}$. A prime (′) refers to the transpose of the given matrix, and V is the value-added matrix. As in the case of the production-inducing effect, treating the coal sector exogenously and all other sectors are assumed to remain unchanged:

$$\Delta X'_e = R_m \Delta X_m (I - R_e)^{-1} \quad (8)$$

where $\Delta X'_e$ is the supply-shortage multiplier, which shows the output changes of other sectors other than the sector m. $(I - R_e)^{-1}$ represents the Ghosh inverse matrix after deleting the m-related row and column. R_m denotes a row vector that remains after removing the mth element from the mth row vector of R. ΔX_m is the change in the output of sector m.

This study uses Equation (8) to assess the impact of a unit supply shortage in the coal sector on the output of other sectors, that is, the supply-shortage effect.

2.2. Data

To track the changes in the inter-industrial linkages and economic effects of China's coal industry in different time periods and to reflect its latest features, this study uses China's latest 2020 I-O table, published by the National Bureau of Statistics, to conduct the I-O analysis [39]. On this basis, for the inter-temporal comparisons, this study further selects three additional China's I-O tables (2015, 2010, and 2005) with a time interval of five years for I-O analysis. This set of time-series input–output tables facilitates the analysis of the changes in the inter-industrial linkages and economic effects of the coal industry in different time periods while reflecting its latest features.

Considering that the statistical sectors in these four I-O tables are in some way different (42 sectors in 2005, 2010, and 2015; 153 sectors in 2020), this study adjusted these four input–output tables to 38 sectoral input–output tables with the same sectors, based on The Standard of Industrial Classification GB/T 4754-2017 [40]. Table 1 shows the sector names and industrial classifications of the 38 sectors.

According to the above Standard, the term "coal industry" used in this study refers to the production activities of mining, washing, and grading of various kinds of coal, that is, the coal mining and dressing in Table 1.

Table 1. Sector name and classification in I-O tables.

Code	Sector Name	Category
1	Agriculture, forestry, animal husbandry, and fishery	Primary industry
2	Coal mining and dressing	Secondary industry
3	Petroleum and natural gas extraction	Secondary industry
4	Metal mining and dressing	Secondary industry
5	Non-metal mineral mining and dressing	Secondary industry
6	Food products and tobacco processing	Secondary industry
7	Textile	Secondary industry
8	Leather, furs, down, and related products	Secondary industry
9	Timber processing and furniture manufacturing	Secondary industry
10	Paper, cultural, educational and sports goods manufacturing	Secondary industry
11	Petroleum processing, coking, and nuclear fuel processing	Secondary industry
12	Chemical products	Secondary industry
13	Non-metal mineral products	Secondary industry
14	Metal smelting and rolling processing	Secondary industry
15	Metal products	Secondary industry
16	General and special equipment manufacturing	Secondary industry
17	Transportation equipment manufacturing	Secondary industry
18	Electrical, mechanical, and equipment manufacturing	Secondary industry
19	Communications equipment, computers, and other electronic equipment manufacturing	Secondary industry
20	Instrumentation and metal products machinery and equipment repair services	Secondary industry
21	Other manufacturing and waste scrap	Secondary industry
22	Electricity, heat production and supply	Secondary industry
23	Gas production and supply	Secondary industry
24	Water production and supply	Secondary industry
25	Construction	Secondary industry
26	Transportation, storage and postal	Tertiary industry
27	Information transmission, software and information technology services	Tertiary industry
28	Wholesale and retail trade	Tertiary industry
29	Accommodation and catering	Tertiary industry
30	Finance	Tertiary industry
31	Real estate	Tertiary industry
32	Leasing and business services	Tertiary industry

Table 1. *Cont.*

Code	Sector Name	Category
33	Research and technology services	Tertiary industry
34	Water, Environment and Public Facilities Management	Tertiary industry
35	Residential Services, and Other Services	Tertiary industry
36	Education	Tertiary industry
37	Culture, sports, and entertainment	Tertiary industry
38	Health, social-related work, public management	Tertiary industry

3. Results and Discussion

3.1. Backward Linkages

3.1.1. Total Input Coefficient

Figures for the coal sector's total input coefficient of different sectors in 2005, 2010, 2015, and 2020 were calculated. Table 2 lists the top 10 sectors in each year.

Table 2. Total input coefficients for China's coal industry in each year.

Rank	2005		2010		2015		2020	
	Sector	Value	Sector	Value	Sector	Value	Sector	Value
1	S14	0.207	S2	0.258	S2	0.256	S2	0.202
2	S22	0.189	S14	0.172	S14	0.175	S30	0.097
3	S26	0.123	S16	0.130	S30	0.170	S14	0.090
4	S16	0.108	S12	0.124	S12	0.169	S22	0.089
5	S13	0.098	S22	0.123	S22	0.160	S32	0.078
6	S2	0.097	S26	0.104	S16	0.139	S26	0.067
7	S12	0.094	S11	0.067	S32	0.1107	S28	0.066
8	S11	0.085	S30	0.055	S26	0.1106	S12	0.065
9	S28	0.074	S18	0.050	S28	0.084	S16	0.061
10	S18	0.069	S15	0.0498	S15	0.070	S15	0.052
Total		1.788		1.663		2.186		1.239

As Table 2 shows, the sum of the coal sector's total input coefficient of different sectors declined slightly from 2005 to 2010, rebounded between 2010 and 2015, and began to decline after 2015, indicating that the total (direct and indirect) dependence of China's coal sector on its upstream sectors fluctuated over these four years but showed a significant downward trend in recent years, and the total dependence of the coal sector on its upstream sectors is weaker in 2020 than the level in 2005. For different industrial categories (Figure 2), the production activities of the coal sector are most dependent on the products or services of the secondary industry. In the secondary industry, the coal sector's total input coefficient of itself (S2), Metal smelting and rolling processing (S14), Electricity, heat production and supply (S22), and Chemical products (S12) is relatively larger, indicating that the coal sector has a relatively large direct and indirect consumption of products or services from these sectors. Although the coal sector is relatively dependent on the products of the above sectors for its production activities, the direct and indirect consumption of these sectors' products by the coal industry exhibits a decreasing trend in recent years. For the tertiary industry, the coal sector shows a relatively large direct and indirect consumption of Transportation, storage and postal (S26), Finance (S30), and Leasing and business service (S32). However, the coal industry's direct and indirect consumption of these sectors also exhibits a downward trend in recent years.

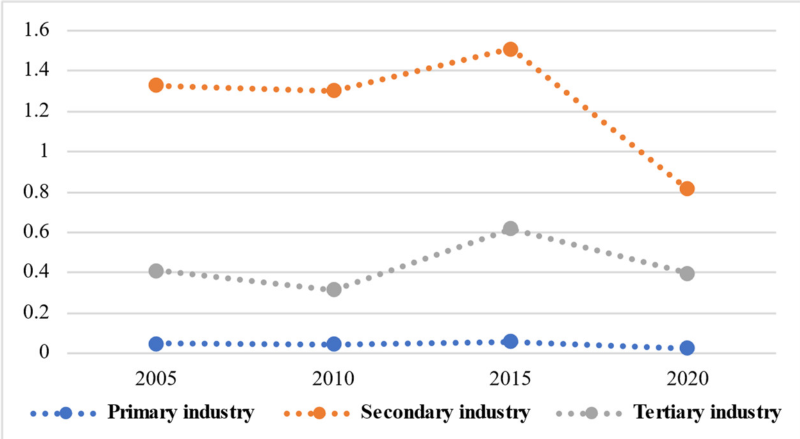

Figure 2. Coal sector's total input coefficients by industrial category in China.

It is worth noting that comparing the result of the coal sector's total input coefficient with coal production from 2005–2020 reveals certain changes in the coal industry itself. Specifically, coal production in 2020 is higher than in 2015, while the total dependence of the coal sector on its upstream sectors in 2020 is lower than the level in 2015. This may reflect the fact that the coal industry has adapted to changing demands in recent years through technological innovation and increased production efficiency, which implies that it requires fewer upstream resources and services for the same or higher unit of coal production. Technological advancements and efficiency improvements can help reduce resource waste and decrease dependence on upstream sectors. A similar difference is also observed between 2005 and 2010, but it should be noted that although the total dependence of the coal industry's production activities on its upstream industries decreased in 2010 compared to 2005, the total dependence of the coal industry on itself, the coal products, increased significantly during this period and became the most dependent product of the coal industry's production activities. So, the difference in this period can be explained by the fact that the total dependence of the coal industry's production activities on the upstream industry gradually shifted to the dependence on its own products, which kept production rising during this period.

3.1.2. Power of Dispersion Index

Figures for the power of dispersion index for 38 sectors in China for 2005, 2010, 2015, and 2020 are shown in Table 3.

From the results of the four years studied, the power of dispersion index of the coal industry was less than 1 except for 2015, when it roughly equaled 1. This indicates that the coal industry's pull effect on other industries is generally lower than the social average level, having a relatively weak capacity for pulling in other sectors. In terms of the degree of variation, the coal sector's power of dispersion index and its rankings fluctuated throughout this period. Compared to 2005, in 2020, the coal industry's power of dispersion index ranking dropped from 21st to 30th. Furthermore, its ranking and value have significantly decreased in recent years, implying that the pull effect of the coal sector on other sectors has been on a weakening trend in recent years.

Combining the results of the total input coefficient with the power of dispersion index, the backward linkage between the coal sector and its upstream sectors fluctuates continuously in the four years under study but tends to weaken in recent years, and the backward linkage between the coal sector and its upstream sectors is weaker in 2020 than the level in 2005.

Table 3. Power of dispersion index for 38 sectors.

Rank	2005		2010		2015		2020	
	Sector	Value	Sector	Value	Sector	Value	Sector	Value
1	S19	1.384	S19	1.386	S14	1.319	S19	1.496
2	S20	1.248	S18	1.329	S19	1.299	S18	1.334
3	S17	1.246	S17	1.305	S18	1.293	S17	1.305
4	S18	1.237	S20	1.297	S15	1.270	S20	1.280
5	S15	1.212	S15	1.272	S16	1.245	S8	1.271
6	S16	1.195	S16	1.251	S17	1.239	S16	1.253
7	S14	1.187	S14	1.220	S12	1.207	S7	1.230
8	S12	1.146	S8	1.209	S13	1.188	S9	1.196
9	S7	1.141	S12	1.207	S10	1.183	S15	1.192
10	S8	1.136	S10	1.197	S20	1.178	S10	1.169
11	S32	1.132	S9	1.188	S25	1.177	S12	1.166
12	S10	1.128	S13	1.156	S21	1.174	S25	1.162
13	S25	1.128	S7	1.152	S22	1.141	S14	1.128
14	S13	1.123	S25	1.147	S9	1.133	S22	1.070
15	S9	1.113	S22	1.095	S7	1.132	S13	1.069
16	S5	1.057	S5	1.047	S4	1.097	S33	1.033
17	S23	1.033	S4	1.032	S8	1.095	S32	1.031
18	S33	1.015	S23	1.001	S5	1.058	S6	1.019
19	S4	1.006	S32	1.000	S23	1.046	S23	1.007
20	S22	0.996	S6	1.000	S11	1.038	S11	1.003
21	S2	0.957	S11	0.996	S32	1.033	S29	0.977
22	S11	0.955	S34	0.951	S2	1.019	S26	0.975
23	S6	0.947	S26	0.922	S33	0.977	S34	0.952
24	S27	0.933	S29	0.910	S6	0.955	S5	0.905
25	S34	0.915	S24	0.904	S24	0.941	S27	0.894
26	S38	0.912	S21	0.899	S26	0.908	S24	0.869
27	S37	0.904	S33	0.885	S34	0.839	S38	0.859
28	S24	0.900	S2	0.873	S29	0.837	S37	0.853
29	S21	0.898	S37	0.835	S27	0.825	S35	0.845
30	S26	0.894	S35	0.833	S3	0.811	S2	0.845
31	S35	0.880	S38	0.829	S38	0.792	S4	0.818
32	S29	0.871	S27	0.817	S35	0.776	S3	0.740
33	S28	0.816	S3	0.772	S37	0.775	S1	0.727
34	S36	0.729	S1	0.713	S1	0.700	S21	0.725
35	S1	0.711	S30	0.629	S28	0.638	S28	0.702
36	S30	0.699	S28	0.597	S30	0.602	S36	0.650
37	S3	0.680	S36	0.581	S31	0.545	S30	0.647
38	S31	0.537	S31	0.561	S36	0.513	S31	0.603

3.2. Forward Linkages

3.2.1. Total Output Coefficient

Figures for the coal sector's total output coefficient of different sectors in 2005, 2010, 2015, and 2020 were calculated. Table 4 lists the top 10 sectors in each year.

Table 4. Total output coefficients for China's coal industry in each year.

Rank	2005		2010		2015		2020	
	Sector	Value	Sector	Value	Sector	Value	Sector	Value
1	S22	0.681	S22	0.751	S22	0.716	S22	0.713
2	S14	0.383	S14	0.571	S14	0.551	S25	0.501
3	S12	0.308	S12	0.448	S12	0.512	S12	0.373
4	S13	0.306	S25	0.442	S25	0.471	S14	0.371
5	S25	0.290	S13	0.357	S13	0.263	S13	0.322
6	S16	0.208	S16	0.274	S2	0.256	S2	0.202
7	S19	0.182	S2	0.258	S11	0.197	S11	0.157
8	S18	0.131	S17	0.1995	S16	0.183	S16	0.130
9	S17	0.130	S11	0.1994	S18	0.162	S19	0.127
10	S11	0.127	S18	0.195	S17	0.145	S18	0.120
Total		4.261		5.130		4.691		4.186

The coal sector's total output coefficient of other industries increased from 2005 to 2010 and gradually decreased from 2010. This means that the degree of total (direct and indirect) demand of the downstream sectors for the products of the coal sector exhibits a downward trend since 2010, and the degree of total demand of the downstream sectors for the products of the coal sector is weaker in 2020 than the level in 2005. For different industry categories (Figure 3), the secondary industry has a strong degree of total demand for coal industry products. As shown in Table 4, sectors that are significant consumers (including direct consumption and indirect consumption) of the coal sector are all from the secondary industry, mainly including Electricity, heat production and supply (S22), Metal smelting and rolling processing (S14), Chemical products (S12), Non-metal mineral products (S13), and Construction (S25). Although the overall trend shows a decline in the degree of total demand for coal sector products by sectors in the secondary industry since 2010, individual sectors such as Non-metal mineral products (S13) and Construction (S25) exhibited an upward trend in the degree of total demand for coal sector products in recent years and since 2005, respectively.

Similarly, comparing the total output coefficient of the coal industry with coal consumption from 2005 to 2020 reveals that the consumption of coal in 2020 is higher than in 2010 and 2015, while the degree of total demand for the coal industry by downstream industries in 2020 is lower than in 2010 and 2015. This might be attributed to the fact that with the development of clean energy and technological innovation, the degree of total demand for coal from downstream industries as a whole has been on a decreasing trend in recent years. However, coal may be consumed directly in other areas rather than through production processes in downstream sectors. For example, individuals and households (especially in rural areas) use coal for heating or cooking. This may be one factor that is contributing to the rise in coal consumption.

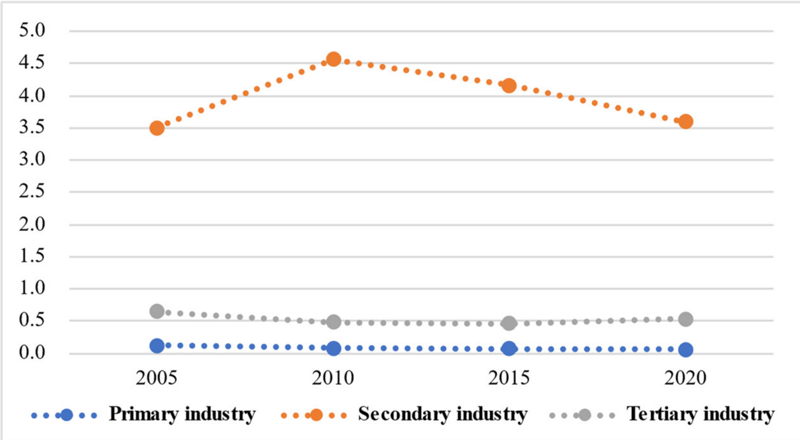

Figure 3. Coal sector's total output coefficients by industrial category in China.

3.2.2. Sensitivity of Dispersion Index

Figures for the sensitivity of dispersion index for 38 sectors in China for 2005, 2010, 2015, and 2020 are shown in Table 5.

Table 5. Sensitivity of dispersion index for 38 sectors.

Rank	2005		2010		2015		2020	
	Sector	Value	Sector	Value	Sector	Value	Sector	Value
1	S14	2.586	S11	2.357	S12	3.104	S12	2.565
2	S12	2.300	S12	2.086	S14	2.197	S14	1.924
3	S22	1.831	S14	1.752	S22	1.895	S28	1.742
4	S26	1.771	S13	1.720	S1	1.842	S1	1.720
5	S1	1.646	S1	1.533	S30	1.727	S19	1.694
6	S13	1.599	S21	1.471	S6	1.584	S22	1.657
7	S19	1.525	S2	1.383	S26	1.580	S26	1.639
8	S11	1.482	S16	1.342	S19	1.579	S30	1.573
9	S3	1.424	S22	1.313	S28	1.440	S32	1.550
10	S28	1.412	S15	1.283	S32	1.308	S6	1.293
11	S16	1.396	S18	1.261	S16	1.285	S3	1.093
12	S2	1.195	S10	1.251	S11	1.195	S16	1.091
13	S10	1.126	S3	1.210	S7	1.114	S7	1.036
14	S18	1.117	S6	1.197	S18	1.008	S11	0.985
15	S17	1.059	S17	1.079	S2	0.980	S18	0.981
16	S7	1.010	S26	1.044	S10	0.954	S31	0.971
17	S32	0.940	S19	1.033	S17	0.947	S2	0.964
18	S6	0.934	S25	0.969	S3	0.942	S17	0.942
19	S30	0.900	S29	0.962	S15	0.892	S10	0.936
20	S15	0.890	S5	0.894	S13	0.802	S27	0.898
21	S27	0.801	S9	0.881	S4	0.787	S15	0.897
22	S29	0.768	S28	0.876	S29	0.683	S4	0.816
23	S4	0.763	S7	0.857	S33	0.660	S13	0.789

Table 5. *Cont.*

Rank	2005		2010		2015		2020	
	Sector	**Value**	**Sector**	**Value**	**Sector**	**Value**	**Sector**	**Value**
24	S9	0.649	S30	0.848	S31	0.657	S29	0.714
25	S21	0.646	S27	0.773	S9	0.652	S9	0.679
26	S25	0.568	S4	0.737	S27	0.595	S5	0.650
27	S35	0.567	S32	0.717	S5	0.594	S33	0.649
28	S20	0.544	S31	0.677	S8	0.561	S21	0.638
29	S8	0.532	S20	0.666	S20	0.549	S8	0.631
30	S33	0.526	S8	0.661	S35	0.524	S20	0.606
31	S5	0.514	S33	0.507	S21	0.518	S35	0.566
32	S31	0.471	S34	0.465	S25	0.455	S23	0.494
33	S37	0.452	S35	0.440	S23	0.444	S37	0.474
34	S38	0.446	S37	0.402	S37	0.424	S34	0.457
35	S24	0.423	S24	0.388	S38	0.403	S25	0.447
36	S36	0.402	S36	0.388	S34	0.403	S24	0.423
37	S34	0.399	S23	0.387	S24	0.366	S38	0.414
38	S23	0.391	S38	0.190	S36	0.352	S36	0.402

From the results of the four years under study, the promoting effect of the coal sector on the development of the national economy exhibited a downward trend since 2010. Compared to 2010, in 2020, the coal sector's sensitivity of dispersion index ranking dropped from 7th to 17th. From 2015, the sensitivity of dispersion index of the coal sector dipped below 1, which indicates that the promoting effect of the coal sector on the development of the national economy has dropped below the social average level in recent years.

Combining the results of the total output coefficient with the sensitivity of dispersion index, from an overall point of view, the forward linkage between the coal sector and its downstream sectors has shown a weakening trend since 2010, and the forward linkage between the coal sector and its downstream sectors is weaker in 2020 than the level in 2005.

3.3. Economic Effects

3.3.1. Production-Inducing Effect

Figures for the production-inducing multiplier of China's coal sector of different sectors in 2005, 2010, 2015, and 2020 were calculated. Table 6 lists the top 10 sectors in each year.

As Table 6 shows, the coal sector's production-inducing multiplier decreased from 2005 to 2010, rebounded from 2010 to 2015, and began to decline after 2015. The coal sector's production-inducing effect on other sectors exhibits a downward trend in recent years, and the coal sector's production-inducing effect is weaker in 2020 than the level in 2005. When there was a CNY 1 change in the supply investment of the coal industry in 2005, 2010, 2015, and 2020, the value of output in the other sectors increased by CNY 1.5, CNY 1.1, CNY 1.5, and CNY 0.9, respectively. From the perspective of the industrial category (Figure 4), the coal sector had a large production-inducing effect on sectors from the secondary industry, such as Metal smelting and rolling processing (S14), Electricity, heat production and supply (S22), General and special equipment manufacturing (S16), and Chemical products (S12). However, the coal sector's production-inducing effect on these sectors exhibits a downward trend in recent years. Furthermore, the coal sector also has a high production-inducing effect on some sectors of the tertiary industry, such as Transportation, storage and postal (S26), Information transmission, software and information technology services (S27), Finance

(S30), and Leasing and business services (S32), but also exhibits a downward trend in recent years.

Table 6. Coal sector's production-inducing multipliers by sector in China.

Rank	2005		2010		2015		2020	
	Sector	**Value**	**Sector**	**Value**	**Sector**	**Value**	**Sector**	**Value**
1	S14	0.184	S14	0.137	S14	0.140	S30	0.081
2	S22	0.173	S16	0.104	S30	0.136	S14	0.075
3	S26	0.112	S12	0.099	S12	0.135	S22	0.074
4	S16	0.099	S22	0.098	S22	0.128	S32	0.065
5	S13	0.089	S26	0.083	S16	0.110	S26	0.055
6	S12	0.085	S11	0.053	S32	0.088	S28	0.055
7	S11	0.077	S30	0.044	S26	0.088	S12	0.054
8	S28	0.068	S18	0.040	S28	0.067	S16	0.050
9	S18	0.063	S15	0.040	S15	0.055	S15	0.044
10	S3	0.054	S1	0.036	S19	0.052	S9	0.024
Total		1.542		1.117		1.536		0.862

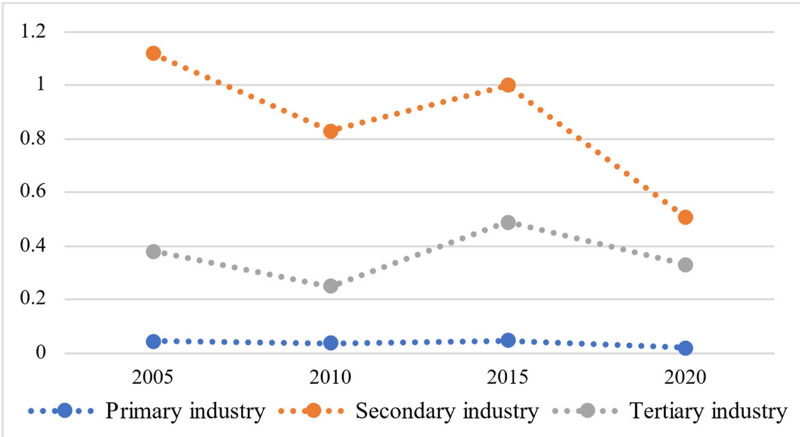

Figure 4. Coal sector's production-inducing multipliers by industrial category in China.

3.3.2. Supply-Shortage Effect

Figures for the supply-shortage multiplier of China's coal sector of different sectors in 2005, 2010, 2015, and 2020 were calculated. Table 7 lists the top 10 sectors in each year.

The coal sector's supply-shortage multiplier increased slightly from 2005 to 2010 and began to decline after 2010. The coal sector's supply-shortage effect on other sectors exhibits a downward trend in recent years and is weaker in 2020 than the level in 2005. When the product supply of the coal industry reduced in 2005, 2010, 2015, and 2020 by CNY 1, the supply-shortage effect on other sectors was CNY 3.8, CNY 3.9, CNY 3.5, and CNY 3.3, respectively. The coal sector thus had a high supply-shortage effect on the secondary industry. In these four years, the top 10 sectors in relation to the supply-shortage effect of the coal sector were all sectors from the secondary industry, such as Electricity, heat production and supply (S22), Metal smelting and rolling processing (S14), Chemical products (S12), Non-metal mineral products (S13), and Construction (S25). Although the supply-shortage effect of the coal industry on the secondary industry exhibits an overall downward trend in recent years (Figure 5), some sectors show an upward trend, such as Electricity, heat production and supply (S22), Non-metal mineral products (S13), and

Construction (S25). Of these, the supply-shortage effect on Construction (S25) has been on an upward trend since 2005.

Combining the results of the production-inducing effect and the supply-shortage effect, it is clear that overall, the economic effects of the Chinese coal industry exhibit a weakening trend in recent years and are weaker in 2020 than the level in 2005.

Table 7. Coal sector's supply-shortage multipliers by sector in China.

Rank	2005		2010		2015		2020	
	Sector	Value	Sector	Value	Sector	Value	Sector	Value
1	S22	0.620	S22	0.597	S22	0.570	S22	0.593
2	S14	0.349	S14	0.454	S14	0.439	S25	0.416
3	S12	0.281	S12	0.356	S12	0.408	S12	0.310
4	S13	0.279	S25	0.351	S25	0.375	S14	0.309
5	S25	0.265	S13	0.284	S13	0.210	S13	0.267
6	S16	0.190	S16	0.218	S11	0.157	S11	0.131
7	S19	0.166	S17	0.159	S16	0.146	S16	0.108
8	S18	0.119	S11	0.159	S18	0.129	S19	0.105
9	S17	0.119	S18	0.155	S17	0.116	S18	0.100
10	S11	0.116	S19	0.135	S15	0.107	S17	0.089
Total		3.796		3.873		3.530		3.313

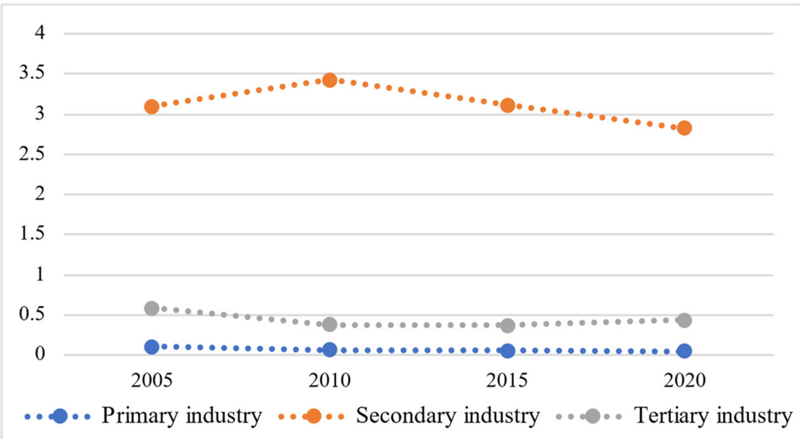

Figure 5. Coal sector's supply-shortage multipliers by industrial category in China.

4. Conclusions and Policy Insights

In this study, the I-O approach is applied to measure the inter-industrial linkages and the economic effects of China's coal industry, as well as their changes in different time periods, with the aim of providing valuable policy insights for China's transition to a low-carbon economy. The results show that, from an overall point of view, the linkages (backward and forward) between the coal industry and other industries, as well as the economic effects of the coal industry, have tended to weaken in recent years, and both of these indicators for the coal sector in 2020 are weaker than the levels in 2005. However, individual sectors differ from the overall trend: the non-metal mineral products sector has shown an upward trend in recent years in the degree of total demand for coal sector products and the degree of influence by supply shortages in the coal sector, while these two indicators for the construction sector have been on an upward trend since 2005; the electricity, heat production, and supply sector has shown an upward trend in recent years in the degree of influence by supply shortages in the coal sector.

A comparison of coal production/consumption for 2005–2020 with the results of the total input/output coefficient reveals certain changes in the coal industry. That is, the coal industry's technological advances and efficiency improvements in recent years have allowed it to require fewer upstream resources and services to achieve the same or higher unit of coal production. In addition, the consumption of coal by areas beyond the production process in the downstream sectors, for example, the use of coal for cooking or heating by individuals and households (especially in rural areas), may be the main reason for the rebound in coal consumption in recent years.

From the above conclusions, some important insights can be derived for governments formulating low-carbon transition policies, as follows. (1) Since the non-metal mineral product industry has been on an increasing trend in recent years in the degree of total demand for coal industry products and the degree of impact due to supply shortage in the coal industry, while these two indicators for the construction industry have been on an upward trend since 2005, the government should provide the relevant policy support and incentives to improve the energy efficiency in these two industries and to promote a shift in the demand for coal toward clean energy. (2) The government should focus on coal consumption in areas other than production activities in the downstream sectors, such as coal use by individuals and households for cooking or heating in rural areas. The government should provide subsidies or incentives to promote the use of clean energy equipment and energy-efficient equipment by individuals and households in rural areas. (3) Although in recent years, with the development of clean energy, the degree of total demand for coal in the electric power and heat production and supply industry has tended to weaken, it has been most influenced by the shortage of coal supply, and this effect has been on the rise in recent years. This shows that coal is still the main source of energy for the power, heat production, and supply industry, and it is difficult to achieve decoupling from coal dependence in the short term. The development of clean energy should be further encouraged, along with the establishment of a comprehensive coal supply and reserve management system, to ensure that the power and heat production and supply industry can respond in a timely manner when coal supplies are restricted, in order to implement steady and orderly transition measures.

This paper examined China's coal industry's inter-industrial linkages and economic effects through the I-O analysis in different years. The results provided a reference for future low-carbon transition policies. However, there is a limitation in this paper: the data in the input–output tables used in this paper were all calculated based on the producer prices of the current year. This means that the price factors may affect the accuracy of the analysis results. In order to eliminate the influence of the price factors and to make the I-O tables for different years more suitable for cross-year analysis, it is necessary to deflate the data in the input–output tables by applying appropriate price indices. Ideally, each component of an input–output table would have a price index corresponding to it. However, due to the limited availability of data in this respect at present, the accuracy of the analysis may also be affected if an inappropriate price index is used for deflating. Therefore, this paper maintained the use of current price input–output tables for the analysis. Future studies should consider the most appropriate approach to appropriately remove external disturbances such as inflation to better ensure the accuracy of the analysis.

Author Contributions: Conceptualization, Z.C.; methodology, Z.C.; software, Z.C.; validation, Z.C.; formal analysis, Z.C.; investigation, Z.C.; resources, Z.C.; data curation, Z.C.; writing—original draft preparation, Z.C.; writing—review and editing, Z.C.; visualization, Z.C.; supervision, S.S.; project administration, S.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Nagasaki University "Doctoral Program for World-leading Innovative and Smart Education" for Global Health, KENKYU SHIDO KEIHI ("the Research Grant").

Data Availability Statement: The data used are all public data that can be downloaded from the websites mentioned in the paper.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. British Petroleum. *BP Statistical Review of World Energy 2021*; British Petroleum Press: London, UK, 2021.
2. Li, Y.; Zhang, B.; Wang, B.; Wang, Z. Evolutionary Trend of the Coal Industry Chain in China: Evidence from the Analysis of I-O and APL Model. *Resour. Conserv. Recycl.* **2019**, *145*, 399–410. [CrossRef]
3. IEA. *Global Methane Tracker 2023*; IEA: Paris, France, 2023. Available online: https://www.iea.org/reports/global-methane-tracker-2023 (accessed on 11 April 2023).
4. Statista. Carbon Dioxide Emissions from Coal Use in China from 1960 to 2021 (In Million Metric Tons). Available online: https://www.statista.com/statistics/1198032/carbon-dioxide-emissions-from-coal-use-in-china/#statisticContainer (accessed on 31 March 2023).
5. IEA. An Energy Sector Roadmap to Carbon Neutrality in China. Available online: https://www.iea.org/reports/an-energy-sector-roadmap-to-carbon-neutrality-in-china (accessed on 13 April 2023).
6. Song, Z.; Niu, D.; Xiao, X. Focus on the Current Competitiveness of Coal Industry in China: Has the Depression Time Gone? *Resour. Policy* **2017**, *51*, 172–182. [CrossRef]
7. U.S. Energy Information Administration. Available online: https://www.eia.gov/international/overview/country/CHN (accessed on 4 April 2023).
8. The Central People's Government of the People's Republic of China. Air Pollution Prevention and Control Action Plan. Available online: https://www.gov.cn/zwgk/2013-09/12/content_2486773.htm (accessed on 14 April 2023). (In Chinese)
9. National Energy Administration. Action Plan for Clean and Efficient Use of Coal (2015–2020). Available online: http://zfxxgk.nea.gov.cn/auto85/201505/t20150505_1917.htm (accessed on 4 April 2023). (In Chinese)
10. National Development and Reform Commission. 13th Five-Year Plan for the Development of the Coal Industry (2016–2020). Available online: https://www.ndrc.gov.cn/xxgk/zcfb/ghwb/201612/t20161230_962216.html (accessed on 29 March 2023). (In Chinese)
11. National Development and Reform Commission. Action Plan For Carbon Dioxide Peaking before 2030. Available online: https://en.ndrc.gov.cn/policies/202110/t20211027_1301020.html (accessed on 13 April 2023).
12. Wang, B. An Imbalanced Development of Coal and Electricity Industries in China. *Energy Policy* **2007**, *35*, 4959–4968. [CrossRef]
13. Liu, Z. Empirical Study of Coal Industry Coordinated Development Path. *Energy Procedia* **2011**, *5*, 1796–1802. [CrossRef]
14. Zhang, Y.; Feng, G.; Zhang, M.; Ren, H.; Bai, J.; Guo, Y.; Jiang, H.; Kang, L. Residual Coal Exploitation and Its Impact on Sustainable Development of the Coal Industry in China. *Energy Policy* **2016**, *96*, 534–541. [CrossRef]
15. Zhang, Y.; Nie, R.; Shi, R.; Zhang, M. Measuring the Capacity Utilization of the Coal Sector and Its Decoupling with Economic Growth in China's Supply-Side Reform. *Resour. Conserv. Recycl.* **2018**, *129*, 314–325. [CrossRef]
16. Wang, G.; Xu, Y.; Ren, H. Intelligent and Ecological Coal Mining as Well as Clean Utilization Technology in China: Review and Prospects. *Int. J. Min. Sci. Technol.* **2019**, *29*, 161–169. [CrossRef]
17. Zhao, L.; Liu, Z.; Cheng, L. How Will China's Coal Industry Develop in the Future? A Quantitative Analysis with Policy Implications. *Energy* **2021**, *235*, 121406. [CrossRef]
18. Zhang, R.; Qie, X.; Hu, Y.; Chen, X. Does De-Capacity Policy Promote the Efficient and Green Development of the Coal Industry? –Based on the Evidence of China. *Resour. Policy* **2022**, *77*, 102717. [CrossRef]
19. Zhong, S.; Lin, D.; Yang, K. Research on the Influencing Factors of Coal Industry Transformation Based on the DEMATEL–ISM Method. *Energies* **2022**, *15*, 9502. [CrossRef]
20. Zhang, L.; Ponomarenko, T. Directions for Sustainable Development of China's Coal Industry in the Post-Epidemic Era. *Sustainability* **2023**, *15*, 6518. [CrossRef]
21. Zhang, M.; Wang, W.; Sun, X. Measurement and Multiple Decomposition of Total Factor Productivity Growth in China's Coal Industry. *Sustainability* **2023**, *15*, 2230. [CrossRef]
22. Kwak, S.; Yoo, S.; Chang, J. The Role of the Maritime Industry in the Korean National Economy: An Input–Output Analysis. *Mar. Policy* **2005**, *29*, 371–383. [CrossRef]
23. Lee, M.; Yoo, S. The Role of Transportation Sectors in the Korean National Economy: An Input-Output Analysis. *Transp. Res. Part Policy Pract.* **2016**, *93*, 13–22. [CrossRef]
24. Zhao, B.; Wu, H.; Wang, N. Changing Characteristics of the Industrial Correlation and Economic Contribution of Air Transport in China: An Input–Output Analysis. *J. Air Transp. Manag.* **2022**, *104*, 102275. [CrossRef]
25. Wang, Y.; Wang, N. Exploring the Role of the Fisheries Sector in China's National Economy: An Input–Output Analysis. *Fish. Res.* **2021**, *243*, 106055. [CrossRef]
26. Morrissey, K.; O'Donoghue, C. The Role of the Marine Sector in the Irish National Economy: An Input–Output Analysis. *Mar. Policy* **2013**, *37*, 230–238. [CrossRef]
27. Johansen, U.; Bull-Berg, H.; Vik, L.H.; Stokka, A.M.; Richardsen, R.; Winther, U. The Norwegian Seafood Industry—Importance for the National Economy. *Mar. Policy* **2019**, *110*, 103561. [CrossRef]

28. Han, S.; Yoo, S.; Kwak, S. The Role of the Four Electric Power Sectors in the Korean National Economy: An Input–Output Analysis. *Energy Policy* **2004**, *32*, 1531–1543. [CrossRef]
29. Tang, X.; Zhang, B.; Feng, L.; Marswan, M.; Afshin, H. Economic Impacts and Challenges of China's Petroleum Industry: An Input–Output Analysis. *Energy* **2011**, *36*, 2905–2911. [CrossRef]
30. Chun, D.; Woo, C.; Seo, H.; Chung, Y.; Hong, S.; Kim, J. The Role of Hydrogen Energy Development in the Korean Economy: An Input–Output Analysis. *Int. J. Hydrogen Energy* **2014**, *39*, 7627–7633. [CrossRef]
31. Lee, S.; Kim, J.; Yoo, S. Role of Natural Gas Supply Sector in the National Economy: A Comparative Analysis between South Korea and Japan. *Appl. Sci.* **2023**, *13*, 1689. [CrossRef]
32. Stilwell, L.C.; Minnitt, R.C.A.; Monson, T.D.; Kuhn, G. An Input–Output Analysis of the Impact of Mining on the South African Economy. *Resour. Policy* **2000**, *26*, 17–30. [CrossRef]
33. San Cristóbal, J.R.; Biezma, M.V. The Mining Industry in the European Union: Analysis of Inter-Industry Linkages Using Input–Output Analysis. *Resour. Policy* **2006**, *31*, 1–6. [CrossRef]
34. Kim, K.; Kim, J.; Yoo, S. An Input-Output Analysis of the Economic Role and Effects of the Mining Industry in South Korea. *Minerals* **2020**, *10*, 624. [CrossRef]
35. Lei, Y.; Cui, N.; Pan, D. Economic and Social Effects Analysis of Mineral Development in China and Policy Implications. *Resour. Policy* **2013**, *38*, 448–457. [CrossRef]
36. Leontief, W.W. Quantitative Input and Output Relations in the Economic Systems of the United States. *Rev. Econ. Stat.* **1936**, *18*, 105. [CrossRef]
37. Zhao, B.; Wang, N.; Wang, Y. The Role of Different Transportation Modes in China's National Economy: An Input–Output Analysis. *Transp. Policy* **2022**, *127*, 92–102. [CrossRef]
38. Drejer, I. Input-Output based measures of interindustry linkages revisited-A Survey and Discussion. In Proceedings of the 14th International Conference on Input-Output Techniques, Montreal, QC, Canada, 10–15 October 2002; pp. 1–35.
39. National Bureau of Statistics. Input-Output Tables for China. Available online: http://www.stats.gov.cn (accessed on 2 January 2023).
40. National Bureau of Statistics. 2017 Industrial Classification for National Economic Activities (GB/T 4754-2017). Available online: http://www.stats.gov.cn/xxgk/tjbz/gjtjbz/201710/t20171017_1758922.html (accessed on 1 December 2022).