

Measuring the risk of foreign supply chain exposure

Yu Zhao,^a Xiang Gao,^{a*} Zheang Chen,^b Cuihong Yang^a

^a Academy of Mathematics and Systems Science, CAS, University of Chinese Academy of Sciences, and Key Laboratory of Management, Decision and Information Systems, CAS, Beijing, 100190, China

^b Renmin University of China, Beijing, 100872, China

Abstract: In view of challenges triggered by the sequential international emergencies, supply-chain resilience has been often valued as the prior objective in building global value chain. And the foreign supply chain exposure has become one of the most focused indicators to reflect the supply-chain resilience. However, the risk of foreign supply chain exposure encompasses not only its magnitude (associated with the impact after foreign supply chain disruption), but also its concentration across import sources (related to the probability of foreign supply chain disruption and the diversity of alternative choices when facing the disruption from a certain supplier). Thus, the paper proposed a comprehensive measure considering both the magnitude of foreign supply chain exposure and its concentration level. For empirical illustration, the paper assessed China's risk of foreign supply chain exposure, and compared the results that only focus on direct imports. The proposed measure is able to clarify the risk exposure hidden in deeper levels of international connections, providing a quantitative pre-assessment for the potential impact from different shocks.

Keyword: Foreign supply chain exposure, Supply-chain resilience, Input-output Modeling

Acknowledgments

This research was supported by the National Natural Science Foundation of China [Grant Numbers 72103184, 71988101].

Declarations of interest: none

1. Introduction

In recent years, economic and trade confrontations occasionally occur between China and the United States, international geopolitical conflicts continue unabated, and the momentum of multilateral economic and trade cooperation has slowed down. Coupled with technological revolution and industrial chain transformation using big data technology, the Internet of Things, artificial intelligence, and other technologies, the global production network is facing major adjustments, even presenting a new trend of regionalization, shortening of chains, and diversification. This undoubtedly poses a serious impact on China, which is the core production member in the global production network.

Although China has the world's largest production capacity and the most complete industrial production system, its industrial chain is generally large but not strong, and large but not stable. China's reliance on overseas imports for key technologies and core components has been long-standing, and the vulnerability of the industrial chain should not be underestimated. For example, in recent years, the United States has used its "long-arm jurisdiction" policy to place some Chinese institutions and individuals on its Entity List, and has cut off cooperation and exchanges with China in some fields, attempting to suppress the market for high-tech products from China. The risk of supply disruption for China in areas such as machinery, supercomputers, semiconductors, aerospace, optical instruments, and specialized software continues to rise, forming a "chokehold" dilemma.

In addition to the high-tech sector, the risks that China faces in the field of bulk commodities cannot be ignored. Energy products are the basic raw materials for kinds of industries, and energy security is crucial for maintaining political stability and economic cycles. The profound lessons from the European energy crisis have elevated energy security to unprecedented levels. However, China's "poor oil, scarce gas" natural resource endowment means it is highly dependent on importing oil and natural gas from the international energy market. The energy market is influenced by many uncontrollable factors such as politics, military, and diplomacy. China mainly imports energy from politically unstable regions such as the Middle East and Africa. Shipping routes pass through sensitive nodes like the Red Sea, Persian Gulf, Indian Ocean, Malacca Strait, and the South China Sea, making it essential to ensure the security of energy imports, which poses significant challenges.

Currently, the Chinese government has clearly stated the goal of accelerating the formation of a new development pattern with the domestic cycle as the mainstay and the domestic and international cycles reinforcing each other. This involves leveraging the potential and advantages of China's super-large-scale market, placing more emphasis on domestic development, and simultaneously promoting both the domestic and international cycles. This aims to better connect the domestic market with the international market, advancing China's opening-up to a higher level (Yu Miaojie, 2020). From the production perspective, the domestic cycle relies on China's industrial upgrading and the enhancement of industrial chain security. Scientifically assessing the resilience and security level of the industrial chain, effectively identifying the degree of vulnerability of China's industrial chain and its changing trends over time, holds significant practical significance. Effectively identifying weak links is the basis for "shoring up weaknesses and strengthening strengths," and is crucial for China to maintain industrial security and stable economic operations, as well as accelerate the dual circulation, which has significant implications.

This paper contributes in three main aspects: Firstly, it proposes the concepts of direct and indirect imports, constructing vulnerability measures using centrality, centrality variance index, and the Herfindahl index, which focus on whether there is a risk of extreme dependence on a few countries for imported intermediate goods at the production perspective.

It also depends on the upstream dependence of the department on foreign sources and the corresponding international market structure. Therefore, this paper focuses on total imports composed of direct and indirect imports to more accurately assess and identify vulnerabilities in the industrial chain supply chain, taking measures to enhance "pre-resilience" and reduce the potential impact. With stronger data support, the research methods in this article can be further expanded to the industry and enterprise levels. Secondly, the research indicators focus on two perspectives: the vulnerability index of the industrial production perspective and the vulnerability index of the product import perspective. The vulnerability index of the industrial production perspective mainly portrays the extent to which a country's specific industry sector depends on all imported intermediate goods, while the vulnerability index of the product import end specifically illustrates the vulnerability when a country imports a particular product. These two perspectives of vulnerability indices each have their own emphasis and complement each other, aiding in a more precise assessment of the industrial chain supply chain risks faced by China. Thirdly, from the perspective of "pre-resilience" of the industrial chain supply chain, based on China's direct and indirect imports, the study focuses on identifying the market position and concentration of China's imported products in the international industrial chain. This research helps in early assessment of the risk exposure of the industrial chain, finding out key sectors, and countries that need special attention, enabling proactive positioning and risk reduction before impacts occur.

2. Literature Review

The current literature primarily uses industry-level direct import and direct export data to study industrial chain risks. A large number of literatures focus on the external exposure of industrial chains, and the autonomous and controllable aspects of industrial chain supply chain security depend on the external exposure and the country structure of this exposure, which greatly affects the resilience of industrial chains. On one hand, the overall high level of external exposure of industrial chains indicates the improvement of efficiency (Wang, 2017a). On the other hand, if the external exposure of an industrial chain is concentrated in links with low substitution elasticity, exposed to a single economy or economic bloc, especially in situations where there are geopolitical risks, the security of the industrial chain will be affected. Currently, some countries are shifting their economic contradictions to other countries, reigniting nationalist sentiments (Baldwin & Freeman, 2020), and the impact of events like the COVID-19 pandemic has increased the risk of "disruption" in industrial chains. The global industrial chain is showing a trend of localization and regional reconstruction (Antràs, 2020; Yan Bingqian and Tian Kailan, 2020; Duan & Jiang, 2021).

In this context, quantitatively measuring the external exposure of industrial chains is of great significance. The external exposure of industrial chains includes the external demand exposure on the export perspective and the external input exposure on the import perspective. The external demand exposure on the export perspective refers to the degree to which products in this industrial chain depend on overseas sales markets. Shen Lisheng et al. (2003) used input-output tables to calculate the contribution rate of each sector's exports

to China's GDP and to GDP growth. Xu Tongseng (2003) compared China's trade dependency with that of other countries, and the results showed that China's actual trade dependency is not high. Li Xin and Xu Dianqing (2013) re-calculated China's foreign trade dependency after excluding duplicate calculations of processing trade and exports owned by foreign capital. The results showed that China's foreign trade dependency is not high, and there is no serious problem of trade imbalance.

In addition to reflecting external exposure from the export side perspective, another branch of literature focuses on studying the external input exposure on the import side and the vulnerability level of the industrial chain from the import side. Autor et al. (2013) used the change in China's exports to the United States and weighted the change in exports by local employment share to calculate the impact of import competition on the local employment market. Acemoglu et al. (2016) used the proportion of imports in domestic market demand for each industry to reflect import trade exposure, and weighted the intermediate input data from input-output tables to calculate the upstream trade exposure considering direct industry links with downstream buyers. Wang et al. (2018) adjusted the weights used in calculating upstream trade exposure and defined downstream trade exposure based on this. Cui Xiaomin et al. (2022) used bilateral product-level trade data to construct global and country-level product vulnerability indicators, analyzing the vulnerability level of China's supply chains.

The aforementioned studies only considered direct consumption relationships, so it is necessary to also calculate indirect consumption. Baldwin & Freeman (2022), based on the Leontief inverse matrix, considered the indirect consumption relationships between industries and constructed the Foreign Exposure Index on the Import side (FPEM). The FPEM is calculated as the proportion of a domestic sector's total requirements that come from foreign sectors, reflecting the degree of an industry chain's dependence on foreign intermediate goods and thereby the level of risk in the industrial chain. However, this paper argues that using the total requirement coefficient as the denominator in the calculation of the FPEM would result in an underestimation of the actual foreign exposure index. This is mainly because the calculation of the total requirement coefficient includes the product itself.

Dhyne et al. (2021) defined the total overseas inputs at the firm level as the sum of direct overseas inputs and the indirect overseas inputs through the firm's upstream suppliers (the calculation method for the firm's exports is similar). They empirically found, using sales data among domestic firms in Belgium and foreign trade data, that for the transmission of foreign demand shocks to company revenues, what matters is how much the company ultimately sells to foreign markets (total exports), rather than whether these sales come from direct or indirect exports. Therefore, from the perspective of shock transmission, the total exports indicator contains more information than direct exports. Similarly, the total import/export indicator also has practical significance for measuring industrial chain security.

Taking the example of China's semiconductor and chip industry, the United States not only restricts direct exports from U.S. companies to China but also limits the exports of products from other countries with a technology content exceeding 10% to China. This policy not only restricts direct imports from the U.S. to China but also imposes strict controls on indirect imports. In 2019, the Netherlands was forced to ban the sale of EUV lithography machines capable of producing 7nm chips to China, while DUV lithography machines capable of producing chips above 14nm could continue to trade freely with China. One possible reason is that the Netherlands can only produce some components of EUV lithography machines, and some

components need to be imported from the U.S. and its allies. Such risks cannot be identified based on the traditional assessment methods using direct import amounts. Therefore, this paper believes that when assessing industrial chain security, the calculation results using the total import indicator are more policy-oriented.

In evaluating industrial chain vulnerability, this paper follows the concept of total imports and focuses on the sector level, while also distinguishing the international trade partners. Total imports of a sector are defined as the intermediate goods purchased directly from overseas markets by the sector, as well as the overseas market intermediate goods contained in the products produced by domestic trading partners that are consumed by the sector. The result of total imports is further used to evaluate the vulnerability of China's industries from two perspectives.

3. Measurement Framework

3.1 Total Imports Calculation

Based on the method of calculating a country's industry's total imports without distinguishing the source country as proposed by Dhyne et al. (2021), we present the calculation of a country's sector's total imports from another country's sector:

$$\begin{aligned}
 Im_{ij}^{total} &= Im_{ij}^{direct} + \sum_{k \in Z_i} s_{ik} [Im_{kj}^{direct} + \sum_{l \in Z_k} s_{kl} (Im_{lj}^{direct} + \dots)] \\
 Im_{ij}^{total} &= Im_{ij}^{direct} + \sum_{k \in Z_i} s_{ik} Im_{kj}^{total} \\
 s_{ij} &= \frac{Z_{ji}}{output_j}
 \end{aligned}$$

Im_{ij}^{total} represents the total imports of sector i from sector j which is also the total exports of sector j to sector i . Im_{ij}^{direct} represents the direct imports of sector i from sector j , and s_{ij} represents the share of sector j 's output that is used as intermediate input in sector i , capturing the inter-industry relationships and reflecting indirect imports. If calculating the total imports of a certain industry in China from all industries in the United States, we sum over j by country:

$$Im_{iUS}^{total} = \sum_{j \in US} Im_{ij}^{total}$$

3.2 Vulnerability Assessment Method

This article constructs two vulnerability indices: the Vulnerability Index of Industrial Production Perspective and the Vulnerability Index of Product Import Perspective. It focuses on whether the production process relies extremely on a few countries for imported intermediate goods. The Vulnerability Index of Product Import Perspective examines whether various industrial sectors in China rely on a few countries for the import of a specified intermediate good needed during production. It also looks at the market share

differences of various countries in the global export market of that intermediate good. The Vulnerability Index of Industrial Production Perspective focuses on whether specific industrial sectors in China rely on a few countries for the import of intermediate goods needed during production (without distinguishing between types of intermediate goods). These two vulnerability indices are constructed based on the following indicators.

Regarding to the global-intermediate goods, the Export Centrality Variation Index (Jiang Xiaorong et al., 2018; Barrat et al., 2004; Korniyenko et al., 2017; Cui Xiaomin et al., 2022) is used to reflect the differences in centrality among countries in the export market of that intermediate good from a global perspective. A larger index indicates greater differences in centrality among countries in the market, suggesting the presence of core exporting countries for that intermediate good. For example, in the crude oil export market, the Middle East region has a high market share, while most countries do not export crude oil. This leads to significant differences in market shares among countries, resulting in a high Export Centrality Variation Index.

The calculation method for the centrality index is as follows:

$$C_{ikt} = \sum_{j \neq i}^{N_{kt}-1} \frac{Im_{jikt}}{(\sum_l Im_{jlkt})/N_{jkt}}$$

Where Im_{jikt} represents the total amount of intermediate goods directly and indirectly imported by country j from country i in sector k in year t , N_{jkt} represents the total number of source countries for intermediate goods directly and indirectly imported by country j in sector k in year t , and N_{kt} represents the total number of countries importing products directly or indirectly from sector k in year t . C_{ikt} can reflect, from a global perspective, the market position of country i in the export market of intermediate goods in sector k in year t .

To further calculate the Centrality Variance Index, which reflects the differences in market positions of different countries globally in sector k of intermediate goods in year t , the standard deviation of centrality for each country in sector k is calculated. A larger index indicates greater differences in market positions among countries. The formula for calculation is:

$$CV_{kt} = \sqrt{\frac{\sum_i (C_{ikt} - \bar{C}_{kt})^2}{N_{kt} - 1}}$$

Where CV_{kt} is the Centrality Variance Index of sector k products in year t , and $\bar{C}_{kt}$ represents the average centrality of sector k products among different countries in year t .

Regarding to the country-intermediate goods, the market concentration index (Herfindahl-Hirschman Index, HHI index) of imports (including both direct and indirect imports) of a specified intermediate good consumed by all industrial sectors of that country during production is used to reflect whether the country's

import of this type of intermediate good relies on a few countries. The formula for calculation is:

$$h_{jkt} = \sum_{i \neq j}^{N_{jkt}} \left(\frac{Im_{j.ikt}}{\sum_{l \neq j} Im_{j.lkt}} \right)^2$$

$$Im_{j.ikt} = \sum_{m \in j} Im_{jmikt}$$

Where h_{jkt} represents the total import concentration index of country j for intermediate goods from different countries in sector k in year t , Im_{jmikt} represents the total amount of intermediate goods directly and indirectly imported by country j from country i in sector k in year t , and N_{jkt} represents the total number of source countries for intermediate goods imported by country j in sector k in year t . If the total import concentration index is closer to 1, it indicates that the import sources for country j are more concentrated. If the total import concentration index is closer to $1/N_{jkt}$, it indicates that the import sources for country j are more diversified. This article considers that when some countries producing intermediate good k are affected, the diversification of import sources for this intermediate good in China is beneficial in resisting such impacts, and the vulnerability of the industrial chain is relatively lower.

Regarding to the country-industry sector, the concentration index of imports from different countries of a specified industry sector during production (without distinguishing between types of intermediate goods) is used to reflect whether the industry sector's production relies heavily on a few countries. The formula for calculation is:

$$h'_{jmt} = \sum_{i \neq j}^{N'_{jmt}} \left(\frac{Im_{jmi.t}}{\sum_{l \neq j} Im_{jml.t}} \right)^2$$

$$Im_{jmi.t} = \sum_{k \in i} Im_{jmikt}$$

Where h'_{jmt} represents the total import concentration index of country j 's sector m for intermediate goods from different countries across all sectors in year t , Im_{jmikt} represents the total amount of intermediate goods directly and indirectly imported by country j 's sector m from country i 's sector k in year t , and N'_{jmt} represents the total number of source countries for intermediate goods imported by country j 's sector m in year t .

Based on three parts: global-intermediate goods, country-intermediate goods, and country-industry sectors, this paper proposes the calculation methods for the Vulnerability Indices of Product Import perspective and Industrial Production perspective.

Industrial Production Perspective Vulnerability Index: This index focuses on depicting the extent to which a specific industry sector of a country relies on all external intermediate goods. It is calculated by multiplying the country-industry sector's import concentration index with the country-industry sector's external exposure.

Product Import Perspective Vulnerability Index: This index focuses on depicting a country's vulnerability when importing a specific product. It is calculated by combining the Centrality Variance Index of vulnerability at the global-intermediate goods level with the product of the country-intermediate goods' import concentration index and the country-intermediate goods' import exposure. This results in a composite vulnerability index for country j 's total import of intermediate goods produced by industry sector k , which is referred to as the Product Import Perspective Vulnerability Index in this paper.

3.3 Assessment of Industrial Chain Vulnerability with Consideration of Processing Trade

For a considerable period since the reform and opening-up, China's trade structure has been quite unique, with a significant proportion of processing trade in the total trade volume. Processing trade enterprises import raw materials, components, and other goods, then proceed with processing, assembly, and production before exporting the final products or intermediate goods. This trade model typically involves the processing and assembly of intermediate products, allowing Chinese enterprises to achieve lower production costs and lower profits. Orders for processing trade mainly come from foreign enterprises or foreign-invested enterprises. The value-added rate of processing trade enterprises is generally low and does not involve cutting-edge technology, thus they are generally not affected by restrictions on imported raw materials and trade sanctions. Considering the heterogeneity between processing trade and non-processing trade, this article distinguishes between these two trade types to re-examine the vulnerability of China's non-processing trade.

3.4 Data Source

This article uses the 2023 edition of the ICIO table published by the OECD for calculations. This table includes input-output relationships between 76 countries and regions and 45 sectors globally from 1995 to 2020.

4. Results of Industrial Chain Vulnerability Assessment

4.1 Product Import Perspective Vulnerability Index

This index can reflect the differences in market positions among different countries in the export market of that intermediate good from a global perspective, as well as whether China relies on a few countries for concentrated imports of that intermediate good. It can be used to predict the potential impact on all of China's industrial sectors' production end when production of that intermediate good is impacted in some countries. This article calculated the Product Import Perspective Vulnerability Index based on complete import data from 1995 to 2018. Table 4.1 lists the vulnerability calculation results for the years 1995, 2000, 2005, 2010, 2015, and 2018. The calculations were not standardized by year or industry, so the results for different years and industries cannot be directly compared. Overall, the service industry's vulnerability is higher than the manufacturing industry. Specifically, the vulnerability of Postal and courier activities, Financial and insurance activities, Land transport and transport via pipelines, Mining and quarrying (energy producing products), and Mining support service activities has consistently remained high.

Over time, there are noticeable differences in the trends of vulnerability changes among different industries. For instance, compared to 1995, the vulnerability of Mining and quarrying (energy producing products) and Mining support service activities, Financial and insurance activities, and transport (including Land transport and transport via pipelines, Water transport, and Air transport) has significantly increased by 2018. On the other hand, compared to 1995, the vulnerability of Education, Motor vehicles, trailers and semi-trailers, and Electrical equipment has significantly decreased by 2018.

Table 4.1 Product Import Perspective Vulnerability Index for 45 Industries (Based on total Imports)

industry	1995	2000	2005	2010	2015	2018
Agriculture, hunting, forestry	2.2	2.1	3.1	4.2	4.7	4.5
Fishing and aquaculture	3.6	3.8	3.6	4.3	7.8	5.9
Mining and quarrying, energy producing products	27.8	54.6	48.8	55.7	57.7	38.9
Mining and quarrying, non-energy producing products	13.8	11.7	10.2	14.2	15.4	15.5
Mining support service activities	21.0	47.4	48.0	44.8	34.3	43.6
Food products, beverages and tobacco	1.8	1.6	1.4	1.6	2.0	1.6
Textiles, textile products, leather and footwear	10.5	13.6	11.1	13.1	14.1	16.8
Wood and products of wood and cork	3.5	3.2	1.9	2.4	2.9	3.0
Paper products and printing	4.9	4.2	3.2	3.2	3.4	3.1
Coke and refined petroleum products	5.7	4.4	5.0	5.4	4.9	5.2
Chemical and chemical products	8.5	9.9	7.7	7.5	7.9	7.8

Pharmaceuticals, medicinal chemical and botanical products	5.3	4.1	4.8	4.9	5.6	5.9
Rubber and plastics products	9.8	7.5	6.2	7.7	6.8	7.1
Other non-metallic mineral products	3.7	4.3	4.0	4.5	4.0	4.5
Basic metals	8.1	7.5	8.4	8.6	6.2	6.6
Fabricated metal products	5.0	4.9	4.5	4.1	4.9	5.3
Computer, electronic and optical equipment	19.4	14.9	14.3	15.6	21.2	23.6
Electrical equipment	17.1	14.2	13.0	12.9	13.9	14.2
Machinery and equipment, nec	15.5	15.4	14.0	15.2	12.8	14.8
Motor vehicles, trailers and semi-trailers	24.0	24.8	24.3	23.1	16.0	16.0
Other transport equipment	17.0	23.6	17.1	11.5	20.1	16.2
Manufacturing nec; repair and installation of machinery and equipment	7.3	7.9	6.0	4.1	2.3	2.5
Electricity, gas, steam and air conditioning supply	19.8	23.3	22.4	27.3	33.3	30.3
Water supply; sewerage, waste management and remediation activities	26.5	21.4	24.6	23.5	30.5	32.9
Construction	13.8	13.5	11.3	5.4	9.8	7.2
Wholesale and retail trade; repair of motor vehicles	19.4	17.6	12.8	14.8	21.5	21.6
Land transport and transport via pipelines	24.0	25.2	25.0	26.7	35.2	35.1
Water transport	19.4	17.9	6.4	8.2	13.0	28.4
Air transport	23.2	21.9	19.4	22.7	26.2	30.6
Warehousing and support activities for transportation	19.3	17.3	15.1	16.7	20.2	20.1
Postal and courier activities	46.0	46.7	32.7	39.7	48.3	52.0
Accommodation and food service activities	23.6	25.5	22.9	26.4	33.1	31.3
Publishing, audiovisual and broadcasting activities	14.6	11.6	12.8	13.1	22.4	15.7
Telecommunications	20.8	19.5	16.9	18.9	26.5	23.3
IT and other information services	39.3	41.2	34.2	29.7	31.1	30.2
Financial and insurance activities	24.1	29.9	22.9	27.2	36.1	36.9
Real estate activities	25.1	25.1	13.5	17.3	26.3	28.3
Professional, scientific and technical activities	28.9	26.2	21.6	25.5	32.3	30.8
Administrative and support services	40.2	40.7	31.8	31.6	38.6	36.0
Public administration and defence; compulsory social security	10.3	7.4	6.7	4.6	24.2	14.6
Education	27.5	21.1	22.9	7.2	18.1	18.0
Human health and social work activities	11.4	10.8	16.7	11.7	11.6	8.9
Arts, entertainment and recreation	25.0	24.6	23.4	16.7	22.1	23.0
Other service activities	26.7	27.5	31.2	26.6	35.6	21.0

From the perspective of the manufacturing industry, downstream sectors generally exhibit higher vulnerability than upstream sectors. Among them, the sector with the highest vulnerability is Computer,

electronic and optical equipment, and it has shown a fluctuating upward trend from 1995 to 2018. Other sectors with high vulnerability include Motor vehicles, trailers and semi-trailers, Machinery and equipment, nec, and Electrical equipment. Motor vehicles, trailers and semi-trailers and Electrical equipment show a fluctuating downward trend over time. Along the timeline, compared to 1995, Textiles, textile products, leather, and footwear experienced the largest increase in vulnerability by 2018.

At the same time, this paper calculated the vulnerability index based on direct imports and compared it with the vulnerability index based on total imports. Compared to direct imports, the vulnerability level of most sectors based on total imports is higher than that based on direct imports. This indicates that the calculation method that does not consider indirect imports often underestimates the vulnerability level of the industrial chain. Among them, the vulnerability of Mining support service activities increased by 7 times, and the vulnerability of industries such as Computer, electronic and optical equipment, and Electrical equipment in the manufacturing industry increased by over 50%. This suggests that after considering indirect imports, China's demand for products from these industries is more concentrated on a few countries.

Table 4.2 Product Import Perspective Vulnerability Index in 2018 for 45 Industries (Total Imports vs Direct Imports)

industries	Vulnerability Index (total import)	Vulnerability Index (direct import)	total import VS direct import
Agriculture, hunting, forestry	4.5	4.3	5.4%
Fishing and aquaculture	5.9	7.4	-20.1%
Mining and quarrying, energy producing products	38.9	24.9	56.1%
Mining and quarrying, non-energy producing products	15.5	10.8	43.2%
Mining support service activities	43.6	5.0	775.3%
Food products, beverages and tobacco	1.6	1.1	53.4%
Textiles, textile products, leather and footwear	16.8	10.6	58.6%
Wood and products of wood and cork	3.0	2.7	11.9%
Paper products and printing	3.1	2.1	49.2%
Coke and refined petroleum products	5.2	6.2	-14.9%
Chemical and chemical products	7.8	5.8	33.8%
Pharmaceuticals, medicinal chemical and botanical products	5.9	5.9	0.0%
Rubber and plastics products	7.1	5.3	34.0%
Other non-metallic mineral products	4.5	3.6	25.6%
Basic metals	6.6	4.1	61.8%
Fabricated metal products	5.3	4.6	14.9%
Computer, electronic and optical equipment	23.6	14.3	65.3%
Electrical equipment	14.2	9.2	55.2%
Machinery and equipment, nec	14.8	12.9	14.1%
Motor vehicles, trailers and semi-trailers	16.0	14.9	7.2%
Other transport equipment	16.2	20.3	-20.4%

Manufacturing nec; repair and installation of machinery and equipment	2.5	2.3	12.6%
Electricity, gas, steam and air conditioning supply	30.3	3.6	735.5%
Water supply; sewerage, waste management and remediation activities	32.9	1.9	1609.2%
Construction	7.2	1.2	502.3%
Wholesale and retail trade; repair of motor vehicles	21.6	17.1	26.1%
Land transport and transport via pipelines	35.1	22.9	52.9%
Water transport	28.4	33.3	-14.9%
Air transport	30.6	31.6	-3.0%
Warehousing and support activities for transportation	20.1	17.5	14.4%
Postal and courier activities	52.0	25.4	104.4%
Accommodation and food service activities	31.3	1.2	2427.9%
Publishing, audiovisual and broadcasting activities	15.7	26.8	-41.5%
Telecommunications	23.3	15.1	53.9%
IT and other information services	30.2	33.1	-8.7%
Financial and insurance activities	36.9	26.5	39.2%
Real estate activities	28.3	4.5	530.2%
Professional, scientific and technical activities	30.8	25.6	20.6%
Administrative and support services	36.0	20.6	74.6%
Public administration and defence; compulsory social security	14.6	12.8	14.1%
Education	18.0	7.5	138.8%
Human health and social work activities	8.9	7.8	13.2%
Arts, entertainment and recreation	23.0	12.2	89.3%
Other service activities	21.0	4.7	346.9%

Figure 4.1 analyzes the Product Import Perspective Vulnerability Index for Mining and quarrying, energy producing products, Computer, electronic and optical equipment, and Pharmaceuticals, medicinal chemical and botanical products. Mining and quarrying, energy producing products exhibit relatively high vulnerability, showing a fluctuating upward trend from 1995 to 2013, reaching a peak in 2013 and then rapidly declining, but still remaining at a high level. Its import sources are mainly concentrated in countries with abundant natural resources such as Australia, Saudi Arabia, and Russia.

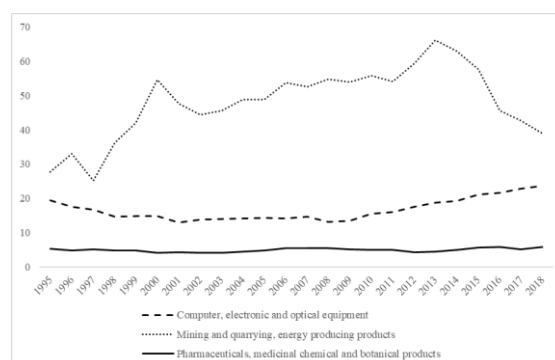


Figure 4.1 Trend Chart of Product Import Perspective Vulnerability Index

The Product Import Perspective Vulnerability Index for Computer, electronic and optical equipment showed a downward trend followed by an upward trend from 1995 to 2018. China's total imports mainly depend on South Korea, Taiwan (Province of China), Japan, Malaysia, and the United States, with a cumulative share of 79.04% in 2018, showing a highly concentrated situation.

The Product Import Perspective Vulnerability Index for Pharmaceuticals, medicinal chemical and botanical products has remained low and fluctuating without a clear time trend. China's total imports mainly come from the United States, Germany, Ireland, Switzerland, and France, with a cumulative share of 59.61% in 2018.

Table 4.3 Source Countries of Total Imports

Countries and Regions	Computer, electronic and optical equipment	Mining and quarrying, energy producing products	Pharmaceuticals, medicinal chemical and botanical products
KOR	35.10%	0.00%	0.63%
TWN	24.34%	0.00%	0.93%
JPN	9.34%	0.00%	3.29%
MYS	5.20%	2.03%	0.09%
USA	5.06%	3.20%	19.32%
SGP	3.21%	0.00%	0.44%
THA	3.08%	0.01%	0.07%
DEU	2.62%	0.00%	14.63%
VNM	2.23%	2.90%	0.02%
PHL	2.05%	0.04%	0.00%
IRL	1.75%	0.00%	10.56%
CHE	1.17%	0.00%	8.21%
CHN	0.89%	0.00%	0.03%
ISR	0.57%	0.00%	0.08%
FRA	0.54%	0.00%	6.89%
IDN	0.31%	4.19%	0.03%
AUT	0.27%	0.00%	0.43%
ROW	0.23%	41.36%	2.67%
HUN	0.20%	0.00%	0.45%
ITA	0.19%	0.00%	3.97%
CAN	0.18%	0.30%	0.77%
NLD	0.17%	0.01%	0.34%
CZE	0.13%	0.00%	0.03%
GBR	0.13%	1.85%	3.41%
IND	0.10%	0.00%	2.13%
FIN	0.10%	0.00%	0.32%
AUS	0.08%	10.54%	2.72%
PRT	0.08%	0.00%	0.01%
MEX	0.08%	0.10%	0.03%
RUS	0.08%	10.39%	0.15%

DNK	0.07%	0.00%	5.65%
MLT	0.06%	0.00%	0.00%
ROU	0.05%	0.01%	0.00%
SWE	0.05%	0.00%	5.03%
BEL	0.04%	0.00%	2.17%
MAR	0.04%	0.00%	0.01%
POL	0.04%	0.00%	0.26%
ESP	0.03%	0.00%	2.35%
NOR	0.03%	0.21%	0.21%
HKG	0.01%	0.00%	0.49%
SVK	0.01%	0.00%	0.00%
BRA	0.01%	4.25%	0.14%
CRI	0.01%	0.00%	0.00%
EST	0.01%	0.00%	0.00%
TUN	0.01%	0.00%	0.00%
ARG	0.01%	0.42%	0.17%
BGR	0.01%	0.00%	0.01%
NZL	0.00%	0.01%	0.13%
SVN	0.00%	0.00%	0.05%
LTU	0.00%	0.01%	0.00%
TUR	0.00%	0.00%	0.01%
MMR	0.00%	0.51%	0.00%
HRV	0.00%	0.00%	0.01%
LUX	0.00%	0.00%	0.00%
KHM	0.00%	0.00%	0.00%
LVA	0.00%	0.00%	0.00%
GRC	0.00%	0.00%	0.36%
ZAF	0.00%	0.47%	0.16%
PER	0.00%	0.04%	0.00%
KAZ	0.00%	0.78%	0.00%
LAO	0.00%	0.00%	0.00%
CHL	0.00%	0.00%	0.03%
ISL	0.00%	0.00%	0.00%
COL	0.00%	1.16%	0.00%
BRN	0.00%	0.09%	0.00%
CYP	0.00%	0.00%	0.07%
SAU	0.00%	15.09%	0.00%

At the same time, the Product Import Perspective Vulnerability Index shows a positive correlation with the total import scale, meaning that the larger the import scale, the higher the vulnerability. Figure 4.2 shows the scatter plot of the Product Import Perspective Vulnerability Index and the total import scale. It can be observed that industries with high total import scales such as Mining and quarrying, energy producing products, Computer, electronic and optical equipment, and Chemical and chemical products also have relatively high Product Import Perspective Vulnerability Index values. On the other hand, industries with

low total import scales such as Wood and products of wood and cork generally have lower Product Import Perspective Vulnerability Index values. Overall, there is a positive correlation.

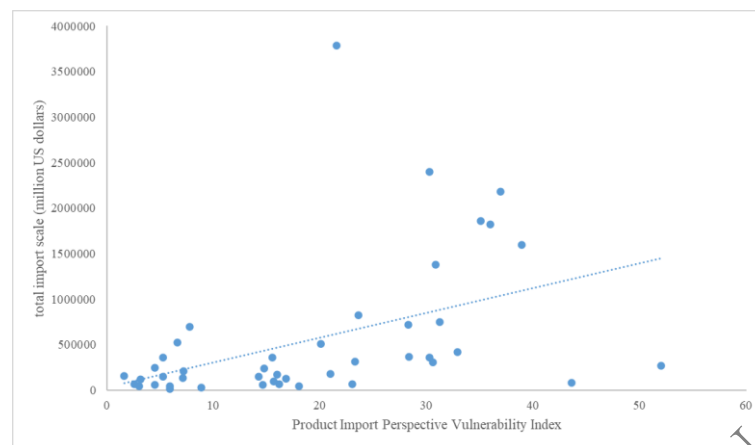


Figure 4.2 Scatter Plot of Product Import Perspective Vulnerability Index and Total Import Scale

4.2 Industrial Production Perspective Vulnerability Index

The China Industrial Production Perspective Vulnerability Index is characterized by the market concentration index at the country-industry. It reflects whether a given industry sector in China extremely relies on a few countries for its total imports of intermediate goods (without distinguishing between types of intermediate goods). This index can be used to describe the risk faced by a specific industry sector in China when subjected to foreign export control policies and other pressures.

This paper calculated the Industrial Production Perspective Vulnerability Index based on total import data from 1995 to 2018. Table 4.4 lists the vulnerability calculation results for the years 1995, 2000, 2005, 2010, 2015, and 2018. A higher vulnerability index indicates that the industry sector relies more on a few countries for its production. The calculations were not standardized by year or industry, so the results for different years and industries can be directly compared. However, the Product Import Perspective Vulnerability Index and the Industrial Production Perspective Vulnerability Index cannot be compared with each other.

Overall, there is no significant difference in vulnerability between the service industry and the manufacturing industry. Among them, Coke and refined petroleum products, Computer, electronic and optical equipment, and Chemical and chemical products show higher vulnerability. Along the timeline, except for Coke and refined petroleum products, Electricity, gas, steam and air conditioning supply, and Water transport, the vulnerability of other sectors has shown a decreasing trend compared to 1995. Among them, the decline in industries such as IT and other information services, Textiles, textile products, leather and footwear is more significant, reaching over 50%.

Table 4.4 Industrial Production Perspective Vulnerability Index for 45 Industries (total import)

industries	1995	2000	2005	2010	2015	2018
Agriculture, hunting, forestry	0.083	0.076	0.066	0.066	0.062	0.057
Fishing and aquaculture	0.085	0.072	0.065	0.067	0.073	0.055

Mining and quarrying, energy producing products	0.096	0.082	0.071	0.065	0.063	0.062
Mining and quarrying, non-energy producing products	0.082	0.069	0.063	0.063	0.061	0.069
Mining support service activities	0.090	0.083	0.072	0.068	0.062	0.063
Food products, beverages and tobacco	0.079	0.069	0.061	0.069	0.064	0.057
Textiles, textile products, leather and footwear	0.115	0.110	0.082	0.070	0.058	0.054
Wood and products of wood and cork	0.077	0.063	0.063	0.065	0.059	0.057
Paper products and printing	0.089	0.078	0.064	0.061	0.056	0.053
Coke and refined petroleum products	0.082	0.146	0.172	0.247	0.195	0.169
Chemical and chemical products	0.088	0.082	0.073	0.078	0.071	0.077
Pharmaceuticals, medicinal chemical and botanical products	0.082	0.077	0.063	0.060	0.058	0.053
Rubber and plastics products	0.097	0.088	0.074	0.072	0.064	0.065
Other non-metallic mineral products	0.086	0.074	0.069	0.067	0.060	0.068
Basic metals	0.078	0.069	0.060	0.071	0.075	0.072
Fabricated metal products	0.084	0.073	0.063	0.061	0.058	0.058
Computer, electronic and optical equipment	0.139	0.114	0.106	0.096	0.101	0.098
Electrical equipment	0.097	0.085	0.069	0.063	0.059	0.058
Machinery and equipment, nec	0.095	0.087	0.072	0.064	0.060	0.060
Motor vehicles, trailers and semi-trailers	0.096	0.095	0.084	0.082	0.067	0.060
Other transport equipment	0.114	0.123	0.110	0.075	0.099	0.064
Manufacturing nec; repair and installation of machinery and equipment	0.096	0.077	0.068	0.060	0.055	0.054
Electricity, gas, steam and air conditioning supply	0.087	0.079	0.074	0.075	0.080	0.089
Water supply; sewerage, waste management and remediation activities	0.090	0.080	0.073	0.065	0.059	0.061
Construction	0.086	0.076	0.066	0.062	0.057	0.059
Wholesale and retail trade; repair of motor vehicles	0.090	0.083	0.074	0.063	0.059	0.056
Land transport and transport via pipelines	0.089	0.077	0.078	0.095	0.070	0.069
Water transport	0.081	0.081	0.093	0.120	0.066	0.082
Air transport	0.094	0.076	0.075	0.105	0.070	0.071
Warehousing and support activities for transportation	0.106	0.080	0.075	0.086	0.062	0.072
Postal and courier activities	0.097	0.076	0.069	0.067	0.063	0.059
Accommodation and food service activities	0.075	0.065	0.059	0.061	0.059	0.051
Publishing, audiovisual and broadcasting activities	0.088	0.077	0.067	0.062	0.056	0.051
Telecommunications	0.115	0.098	0.094	0.072	0.074	0.064
IT and other information services	0.133	0.103	0.095	0.074	0.080	0.063
Financial and insurance activities	0.100	0.090	0.076	0.073	0.066	0.057
Real estate activities	0.091	0.081	0.072	0.066	0.058	0.054

Professional, scientific and technical activities	0.110	0.093	0.089	0.069	0.065	0.058
Administrative and support services	0.097	0.091	0.086	0.068	0.060	0.054
Public administration and defence; compulsory social security	0.099	0.077	0.073	0.063	0.058	0.050
Education	0.096	0.077	0.069	0.062	0.059	0.055
Human health and social work activities	0.089	0.082	0.071	0.064	0.058	0.055
Arts, entertainment and recreation	0.080	0.074	0.068	0.065	0.058	0.046
Other service activities	0.090	0.084	0.076	0.068	0.062	0.058

This paper calculated the vulnerability index based on direct imports and compared it with the vulnerability index based on total import. Compared to direct imports, the vulnerability of most sectors based on total import is lower than that based on direct imports. This indicates that after considering indirect imports, China's industrial sectors have a more diversified demand for intermediate goods. However, the demand for Mining and quarrying, non-energy producing products and Manufacturing nec; repair and installation of machinery and equipment is more concentrated.

Table 4.5 Industrial Production Perspective Vulnerability Index in 2018 for 45 Industries (Total Imports vs Direct Imports)

industries	Vulnerability Index (total import)	Vulnerability Index (direct import)	total import VS direct import
Agriculture, hunting, forestry	0.057	0.058	-1.4%
Fishing and aquaculture	0.055	0.053	3.8%
Mining and quarrying, energy producing products	0.062	0.071	-13.3%
Mining and quarrying, non-energy producing products	0.069	0.064	7.4%
Mining support service activities	0.063	0.079	-19.6%
Food products, beverages and tobacco	0.057	0.085	-33.2%
Textiles, textile products, leather and footwear	0.054	0.059	-7.5%
Wood and products of wood and cork	0.057	0.065	-11.1%
Paper products and printing	0.053	0.055	-4.2%
Coke and refined petroleum products	0.169	0.229	-26.2%
Chemical and chemical products	0.077	0.082	-6.6%
Pharmaceuticals, medicinal chemical and botanical products	0.053	0.064	-17.2%
Rubber and plastics products	0.065	0.074	-11.9%
Other non-metallic mineral products	0.068	0.073	-6.6%
Basic metals	0.072	0.087	-17.1%
Fabricated metal products	0.058	0.058	-0.1%
Computer, electronic and optical equipment	0.098	0.160	-38.6%
Electrical equipment	0.058	0.071	-17.9%
Machinery and equipment, nec	0.060	0.085	-28.5%
Motor vehicles, trailers and semi-trailers	0.060	0.089	-32.3%

Other transport equipment	0.064	0.101	-36.7%
Manufacturing nec; repair and installation of machinery and equipment	0.054	0.051	4.7%
Electricity, gas, steam and air conditioning supply	0.089	0.145	-39.0%
Water supply; sewerage, waste management and remediation activities	0.061	0.063	-3.2%
Construction	0.059	0.065	-8.6%
Wholesale and retail trade; repair of motor vehicles	0.056	0.065	-12.9%
Land transport and transport via pipelines	0.069	0.073	-5.0%
Water transport	0.082	0.086	-4.8%
Air transport	0.071	0.073	-2.6%
Warehousing and support activities for transportation	0.072	0.070	3.8%
Postal and courier activities	0.059	0.081	-27.1%
Accommodation and food service activities	0.051	0.048	7.8%
Publishing, audiovisual and broadcasting activities	0.051	0.052	-1.6%
Telecommunications	0.064	0.084	-23.4%
IT and other information services	0.063	0.078	-20.3%
Financial and insurance activities	0.057	0.088	-35.9%
Real estate activities	0.054	0.068	-19.6%
Professional, scientific and technical activities	0.058	0.073	-19.8%
Administrative and support services	0.054	0.055	-1.0%
Public administration and defence; compulsory social security	0.050	0.050	0.9%
Education	0.055	0.057	-4.7%
Human health and social work activities	0.055	0.075	-27.3%
Arts, entertainment and recreation	0.046	0.046	0.2%
Other service activities *	0.058	0.061	-5.9%

The Industrial Production Perspective Vulnerability Index shows a negative correlation with the total import scale, meaning that the larger the import scale, the lower the vulnerability. Figure 4.3 shows the scatter plot of the Industrial Production Perspective Vulnerability Index and the total import scale. It can be observed that industries with high total import scales such as Computer, electronic and optical equipment and Electrical equipment also have relatively high Industrial Production Perspective Vulnerability Index values. On the other hand, industries with low total import scales such as Pharmaceuticals, medicinal chemical and botanical products and Mining and quarrying, energy producing products generally have lower Industrial Production Perspective Vulnerability Index values. Overall, there is a negative correlation.

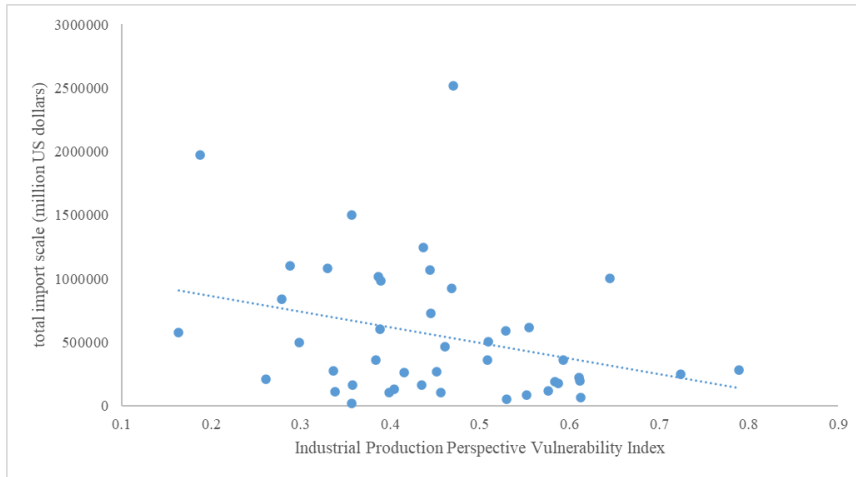


Figure 4.3 Scatter Plot of Industrial Production Perspective Vulnerability Index and Total Import Scale

4.3 Result of Industrial Chain Vulnerability with Consideration of Processing Trade

To be completed

4.4 International Comparison of Industrial Chain Vulnerability

To be completed

4.5 Industrial Chain Vulnerability Classified by Technological Level

To be completed

5. Conclusion and Policy Recommendations

This paper takes the new characteristics of current trade sanctions into consideration and calculates the Product Import Perspective Vulnerability Index and the Industrial Production Perspective Vulnerability Index from the perspectives of direct trade and indirect trade, providing theoretical and empirical support for the formulation of policies related to the security of industrial chains.

The Product Import Perspective Vulnerability Index constructed in this paper reflects, from a global perspective, the differences in market positions of different countries in the export market of the intermediate goods and whether China relies on a few countries for concentrated imports of these intermediate goods. It can be used to predict the impact on the production end of all industrial sectors in China when some countries

producing these intermediate goods are impacted, providing a prior characterization. Additionally, it reflects whether a given industrial sector in China relies on a few countries for total imports of intermediate goods (without distinguishing about types of intermediate goods), providing an assessment of the risk faced by a specific industrial sector in China when subjected to foreign export control policies and other pressures.

This study has theoretical value and practical significance. It improves the vulnerability assessment method based on direct import data, calculates both direct and indirect imports through the input-output relationships between industries, and evaluates the vulnerability of China's industrial chain based on this.

From the perspective of the Product Import Perspective Vulnerability Index, the vulnerability of the service industry is higher than that of the manufacturing industry. The vulnerability of downstream sectors is generally higher than that of upstream sectors, with Computer, electronic and optical equipment being the most vulnerable. Compared to direct imports, the vulnerability of most sectors based on total imports is higher.

An analysis of the original countries of total imports for some products in China was conducted. It was found that Computer, electronic and optical equipment mainly depend on South Korea, Taiwan Province of China, Japan, Malaysia, and the United States. Resource products mainly rely on Australia, Saudi Arabia, and Russia, while Pharmaceuticals, medicinal chemical and botanical products mainly rely on European and American countries.

From the perspective of the Industrial Production Perspective Vulnerability Index, there is no significant difference in vulnerability between the service industry and the manufacturing industry. However, Coke and refined petroleum products, Computer, electronic and optical equipment, Chemical and chemical products, and other products have higher vulnerability levels. Looking at the trend over time, the vulnerability of most industries is declining.

Against the backdrop of prevailing trade protectionism, it is particularly important to clarify the degree of external dependence of the industrial chain production end and guard against overseas policy risks. Based on the above research, this paper proposes the following policy recommendations:

1. Balance industrial chain security and efficiency, considering the constantly changing international political environment, cultivate alternative supply chains, and enhance the industrial chain's independent and controllable capabilities in key areas. Focus on the changes in vulnerability of resource products and downstream manufacturing industries, as the current vulnerability of China's resource products and downstream manufacturing products represented by Computer, electronic and optical equipment remains high. If China's related products are impacted in the import market, it will be extremely difficult to find substitutes in the short term. Therefore, proactive measures should be taken to diversify import suppliers.

2. Continue to strengthen support for key manufacturing industries, enhance policy support and research support for critical components and other 'bottleneck' areas, strengthen national strategic scientific and technological capabilities, optimize the allocation of innovation resources, fill in the gaps in the industrial chain, develop advanced and applicable technologies, and improve the supply chain system.

3.Enhance the endogenous power and reliability of the domestic circulation, improve the quality and level of international circulation, accelerate the modernization of the industrial chain structure.

Reference list:

- Antràs P, Chor D, Fally T, et al. Measuring the upstreamness of production and trade flows[J]. American Economic Review, 2012, 102(3): 412-416.
- Autor D H, Dorn D, Hanson G H. The China syndrome: Local labor market effects of import competition in the United States[J]. American economic review, 2013, 103(6): 2121-2168.
- Acemoglu D, Autor D, Dorn D, et al. Import competition and the great US employment sag of the 2000s[J]. Journal of Labor Economics, 2016, 34(S1): S141-S198.
- Baldwin R, Freeman R, Theodorakopoulos A. Horses for courses: measuring foreign supply chain exposure[R]. National Bureau of Economic Research, 2022.
- Bosma N S, Romero Luna I, Dietzenbacher E. Using average propagation lengths to identify production chains in the Andalusian economy[J]. Estudios de Economía Aplicada, 23(2), 405-422., 2005.
- Dhyne E, Kikkawa A K, Mogstad M, et al. Trade and domestic production networks[J]. The Review of Economic Studies, 2021, 88(2): 643-668.
- Duan Y. W., Jiang X. M. Pollution haven or pollution halo? A re-evaluation on the role of multinational enterprises in global CO2 emissions[J]. Energy Economics. 2021, 97: 105181.
- Fally T. Production staging: measurement and facts[J]. Boulder, Colorado, University of Colorado Boulder, May, 2012: 155-168.
- Hummels D, Ishii J, Yi K M. The nature and growth of vertical specialization in world trade[J]. Journal of international Economics, 2001, 54(1): 75-96.
- Johnson R C, Noguera G. Accounting for intermediates: Production sharing and trade in value added[J]. Journal of international Economics, 2012, 86(2): 224-236.
- Koopman R, Wang Z, Wei S J. Tracing value-added and double counting in gross exports[J]. American economic review, 2014, 104(2): 459-494.
- Stehrer R. Trade in value added and the valued added in trade[R]. wiiw Working paper, 2012.
- Wang Z, Wei S J, Yu X, et al. Characterizing global value chains: production length and upstreamness[R]. National Bureau of Economic Research, 2017b.
- Wang Z, Wei S J, Yu X, et al. Measures of participation in global value chains and global business cycles[R]. National Bureau of Economic Research, 2017a.
- Wang Z, Wei S J, Yu X, et al. Re-examining the effects of trading with china on local labor markets: A supply chain perspective[R]. National Bureau of Economic Research, 2018.
- Cui Xiaomin, Xiong Wanting, Yang Panpan, et al. Measurement of Global Supply Chain Vulnerability: An Analysis Based on Trade Network Methods [J]. Statistical Research, 2022, 39(08): 38-52.
- Huang Hanquan. "Taking Multiple Measures to Enhance the Autonomous and Controllable Ability of Industrial Chain and Supply Chain" [N]. China Economic Times, 2020-12-31 (003).
- Yu Miaojie. "The 'Great Change' and the New Pattern of China's Economic 'Dual Circulation' Development" [J]. Journal of Shanghai University of Finance and Economics, 2020, 27(06): 19-28.
- Li Xin, Xu Dianqing. "Re-estimation of China's Trade Dependence and Imbalance: Value-added Trade in Global Value Chains" [J]. Social Sciences in China, 2013(01): 29-55+205.

Liu Zunyi, Chen Xikang, Yang Cuihong, et al. "Non-competitive Input-Output Model and Its Application: A Perspective on China-US Trade Surplus" [J]. Social Sciences in China, 2007(05): 91-103+206-207.

Shen Lisheng, Wu Zhenyu. "Contribution of Exports to China's GDP Growth: An Empirical Analysis Based on Input-Output Tables" [J]. Economic Research Journal, 2003(11): 33-41+70-92.

Xu Tongsheng. "Assessment of China's Actual Trade Dependence and International Comparison" [J]. Economic Perspectives, 2003(08): 17-20.

Yan Bingqian, Tian Kailan. "The Impact of the Evolution of Industrial Layout under the Global Value Chain Division of Labor on China's Value-added and Employment" [J]. China Industrial Economics, 2020, 393(12): 121-139.

Zhu Kunfu, Yu Xindeng, Wei Shangjin, et al. "Measurement of Multinational Corporation Activities and Value-added Attribution in Global Value Chains" [J]. Economic Research Journal, 2022, 57(03): 136-154.

DRAFT: NOT FOR PUBLICATION