Spatial Economic Networks in China during the COVID-19 Pandemic*

Sho Haneda †

1. Introduction

China faces both opportunities and challenges in terms of economic growth and development. The challenges include unbalanced regional development (e.g., differences between coastal and landlocked provinces), and regional development should be coordinated to enhance economic development (Yu *et al.* 2020).

Following the shift for reform and the opening policy in 1978, China's economy has experienced continuously high growth. However, the driving force behind this was the growth of coastal regions. The three northeastern provinces and many inland regions were left behind economically. The three northeastern provinces were established during the 1990s. Until then, China had achieved economic growth based on state-owned enterprises in heavy industries. However, China was unable to adapt to the changes in industrial structure since the 2000s, resulting in an economic downturn. According to the Liaoning Provincial Statistics Bulletin (2017), the GDP of the Liaoning Province in 2016 decreased by 2.5% when compared with the previous year. Among China's 31 provinces, cities, and municipalities, it was the only one that recorded a negative economic growth rate. Furthermore, owing to the economic downturn, population outflow in the three Northern provinces has significantly increased; according to population data from the National Bureau of Statistics of China, the population was approximately 390,000 in 2018 alone. These alarming events have occurred in spite of the Chinese government announcing the "Northeastern Region's Old Industrial Base" in the three northeastern provinces in 2003. The so-called "Northeastern Region's revitalization" strategy aimed to change the development strategy from points to lines, and then from lines to areas (regions). However, it is difficult to conclude whether this strategy was successful.

The relationship between regional development and international trade has been extensively studied (Lall *et al.* 2006, Hausmann *et al.* 2007, Schott 2008, Xu 2010, Jarreau and Poncet 2012, Thorbecke and Pai 2013, Zhu and Fu 2013). International trade is generally viewed as an engine of growth. However, trade among provinces also contributes to income expansion and regional development through exports, which has not been extensively studied. Some studies focus on trade networks among provinces while its target period seems limited (Li 2020, Yu *et al.* 2020, Jiang *et al.* 2023). Therefore, this study focuses on the economic networks among provinces in China.

In 2020, the spread of coronavirus disease (COVID-19) inflicted enormous damage in many countries. As a

---

* The views expressed in this paper are those of the author and not necessarily those of the College of Law at Nihon University. The authors thank Editage (www.editage.jp) for their English language editing.

† College of Law, Nihon University. Email: haneda.sho@nihon-u.ac.jp

result, restrictions on the domestic and international movement of people and goods were introduced. These shocks may change the spatial economic networks in China, and their impacts may differ among provinces. Therefore, this study also explores the impact of the COVID-19 pandemic on economic networks among provinces in China. The purpose of this study is to quantify the spatial economic networks before and after the COVID-19 pandemic, as well as to explore the impact of the pandemic on these networks, especially in landlocked provinces.

The remainder of the paper is organized as follows: Section 2 explains the model specification; Section 3 present the results; Section 4 discusses the results; and Section 5 concludes the paper.

2. Model specification

2.1 Social network analysis

Social network analysis refers to the analysis of relationship structures between individuals or groups of individuals. For example, interpersonal networks include friendships, networks within project teams, and networks between jobseekers and employers. The networks between groups include international trade networks and population movements (Wasserman and Fause 1994, Kadushin 2003).

In social network analysis, individuals and groups are represented by nodes at the network apex. A network is expressed by connecting the related nodes using lines called edges. The number of edges each node has is called the degree, and a node with a large degree is called a hub (Wasserman and Fause 1994, Kadushin 2003).

This study attempts to visualize trade transaction networks using economic and demographic statistics at the provincial level (target provinces and cities are listed in appendix), as well as distance data between provinces. We employ GDP and GDP per capita from the China Statistical Yearbook as economic statistics. Additionally, we use year-end population statistics from the China Statistical Yearbook. Finally, to calculate the distance between provinces, we use the latitude and longitude of each province's capital city.

2.2 Modified gravity equation

First, we attempt to simulate the economic transactions between provinces using a modified gravity equation:

$$ET_{ij} = K_{ij}\frac{\sqrt{P_iG_i}\sqrt{P_jG_j}}{(D_{ij}/(g_i - g_j))^b} \quad where\ K_{ij} = \frac{G_i}{G_i - G_j} \tag{1}$$

where ET_{ij} is the estimated trade from province i to province j. P, G, D and g are the population at year-end, GDP, geographical distance, and GDP per capita, respectively. b is the distance attenuation coefficient, which was set to 2 (Yu *et al.* 2020).

2.3 The adjacency matrix

We construct the adjacency matrix using the values calculated by Equation (1). First, we calculate economic network T using the value of ET.

$$T_{ij} = \begin{Bmatrix} 0\ if\ ET_{ij} < \sum_{j=1}^{n} ET_{ij}/31 \\ 1 if\ ET_{ij} > \sum_{j=1}^{n} ET_{ij}/31 \end{Bmatrix} \tag{2}$$

where n is the number of provinces (n=32).

Here, T represents the trade network and takes the value of one if it is larger than the average value from the relevant province to all provinces and zero if it is smaller than the average value. In other words, if the estimated trade from province i to province j is greater than the average estimated trade from province i to all provinces, then an economic network exists. If T_{ij} equals one, there is an economic network between provinces i and j. If there is no economic network, T_{ij} equals zero. The important point here is that T_{ij} does not indicate the presence or absence of actual trades but rather expresses trends in economic transactions through networks.

Second, the adjacency matrix is constructed according to T_{ij}.

$$\begin{bmatrix} T_{11} & T_{12} & \cdots & T_{1n} \\ T_{21} & T_{22} & \cdots & T_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ T_{n1} & T_{n2} & \cdots & T_{nn} \end{bmatrix} \quad (3)$$

2.4 Centrality

Centrality analysis is important for understanding population migration networks. Centrality is an index that evaluates the importance of nodes.

The paper analyzes economic networks using degree and closeness centralities. Degree centrality indicates that nodes with a large number of edges are important. A high degree of centrality implies that a network is formed with many ministries in terms of exports and imports (Wasserman and Fause 1994, Kadushin 2003).

To calculate degree centrality, we use T. In the adjacency matrix, the sum of T has different meanings depending on the rows and columns. The row total measures the network related to exports from province i to other provinces. Here, the total value of the row is defined as the Network of Exports (NE). The greater the NE, the less concentrated the export destinations, and the more export destinations there are networks to multiple provinces.

$$NE_{it} = \sum_{j=1}^{n} T_{ijt} \quad (4)$$

The column total indicates the network related to imports from other provinces to province i. The column total is defined as the Network of Imports (NI). The greater the NI, the more export destinations from other provinces are concentrated in that province.

$$NI_{it} = \sum_{j=1}^{n} T_{jit} \quad (5)$$

Finally, net import centrality (NET) is calculated by subtracting NE from NI.

Closeness centrality is an index indicating the importance of nodes connected to other nodes over short distances. Although detailed calculations are omitted, it is expressed as "1 divided by the average distance between province i and other provinces with economic networks." Here, distance refers to the number of nodes required to reach i. Therefore, if all nodes are directly connected, then the value of all the distances is one. If a particular node can only be reached by passing through one node, the distance between them is two. From this, it is possible to visually understand the economic transaction network, because the larger the value of proximity, the more central it is to the network.

3. Results

This study provides an overview of how the inflow of economic transactions is concentrated in specific provinces and regions using the results of adjacency matrices and centrality. The adjacency matrices are shown in Figure 1.

This study focuses on the provinces in which imports, which are economic transactions, tend to concentrate in. In 2019, which was before the COVID-19 pandemic, the inflow of transactions was concentrated in Beijing, Tianjin, Shanghai, and the Liaoning province. Even in 2022, which was after the pandemic, this trend remained unchanged. In other words, it can be seen that the basic structure of economic networks has not changed significantly.

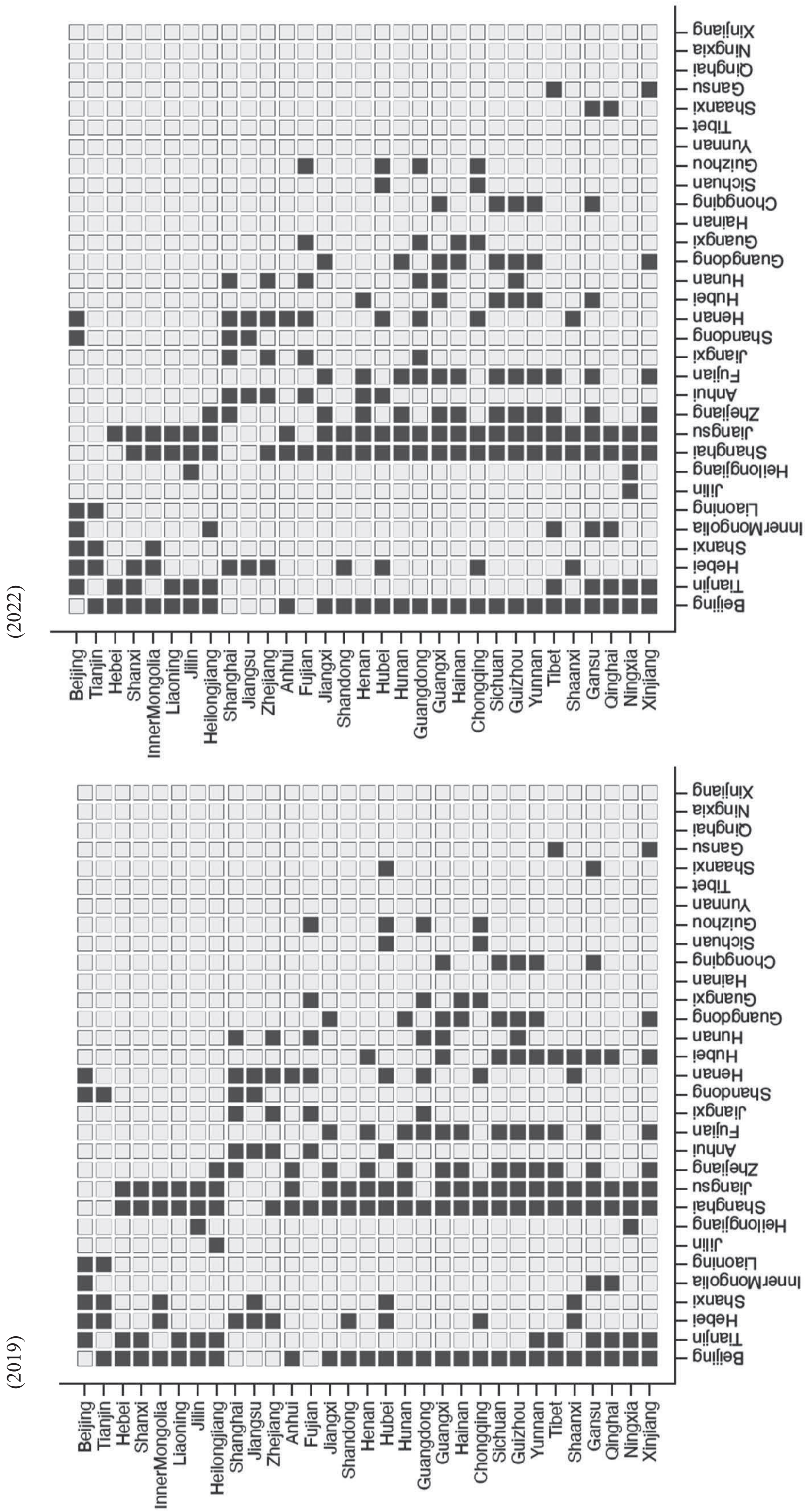
Next, we provide an overview of the network centrality. Here, we focus on NI and NET.

Table 1 summarizes NI (In), NE (Out), and NET values. If NET has a positive value, then the province has more

Table 1. In and out degrees by province (2019-2022)

		2019			2020			2021			2022		
Province	Region	in	out	net	in	out	net	in	out	net	in	out	net
Beijing	Eastern province	26	7	19	26	7	19	26	7	19	26	7	19
Tianjin	Eastern province	12	5	7	11	4	7	11	4	7	11	4	7
Hebei	Eastern province	10	4	6	9	4	5	10	3	7	11	3	8
Shanxi	Central province	6	4	2	4	4	0	3	4	-1	3	5	-2
Inner Mongolia	Western province	3	5	-2	3	5	-2	4	5	-1	5	5	0
Liaoning	Eastern province	2	4	-2	2	4	-2	2	4	-2	2	4	-2
Jilin	Central province	1	5	-4	1	5	-4	1	5	-4	1	5	-4
Heilongjiang	Central province	2	6	-4	2	6	-4	2	6	-4	2	6	-4
Shanghai	Eastern province	27	7	20	27	7	20	26	7	19	26	7	19
Jiangsu	Eastern province	24	5	19	25	5	20	25	4	21	25	4	21
Zhejiang	Eastern province	14	6	8	13	6	7	13	6	7	13	6	7
Anhui	Central province	5	5	0	5	4	1	6	4	2	6	4	2
Fujian	Eastern province	12	7	5	12	7	5	12	7	5	12	7	5
Jiangxi	Central province	4	6	-2	4	6	-2	4	6	-2	4	6	-2
Shandong	Eastern province	4	4	0	3	4	-1	3	4	-1	3	4	-1
Henan	Central province	10	6	4	9	7	2	10	7	3	10	7	3
Hubei	Central province	10	10	0	6	6	0	6	7	-1	6	8	-2
Hunan	Central province	6	6	0	6	6	0	5	6	-1	6	6	0
Guangdong	Eastern province	8	8	0	8	9	-1	8	9	-1	8	9	-1
Guangxi	Western province	4	9	-5	4	8	-4	4	7	-3	4	9	-5
Hainan	Eastern province	0	7	-7	0	7	-7	0	7	-7	0	7	-7
Chongqing	Western province	5	8	-3	6	8	-2	5	8	-3	5	8	-3
Sichuan	Western province	2	8	-6	1	8	-7	1	8	-7	2	8	-6
Guizhou	Western province	4	9	-5	4	9	-5	4	9	-5	4	9	-5
Yunnan	Western province	0	9	-9	0	8	-8	0	8	-8	0	8	-8
Tibet	Western province	0	8	-8	0	7	-7	0	8	-8	0	8	-8
Shaanxi	Western province	2	7	-5	1	4	-3	1	6	-5	2	5	-3
Gansu	Western province	2	10	-8	1	10	-9	2	10	-8	2	10	-8
Qinghai	Western province	0	6	-6	0	5	-5	0	5	-5	0	6	-6
Ningxia	Western province	0	5	-5	0	5	-5	0	5	-5	0	6	-6
Xinjiang	Western province	0	9	-9	0	8	-8	0	8	-8	0	8	-8

Figure 1. The adjacency matrix (2019 and 2022)



networks into which economic activity flows in than outgoing networks. Negative values indicate an inverse relationship. Basically, the value of NET is positive, and it can be understood that provinces with large numbers are concentrated in coastal areas. For the inland provinces, the NET value tends to become more negative toward the west.

Table 2. In and out degrees by region (average; 2019-2022)

	2019			2020			2021			2022		
Region	in	out	net	in	out	net	in	out	net	in	out	net
Eastern province	12.6	5.8	6.8	12.4	5.8	6.5	12.4	5.6	6.7	12.5	5.6	6.8
Central province	5.5	6.0	-0.5	4.6	5.5	-0.9	4.6	5.6	-1.0	4.8	5.9	-1.1
Western province	1.8	7.8	-5.9	1.7	7.1	-5.4	1.8	7.3	-5.5	2.0	7.5	-5.5

Table 2 summarizes the average NI (In), NE (Out), and NET values by region. As previously mentioned, coastal areas have both positive and large NET values. However, compared to the coastal areas, the inland areas have negative values, and the values increase as you move westward. This illustrates China's unbalanced development.

Table 3. Coefficient of variation by region (average; 2019-2022)

	2019			2020			2021			2022		
Region	in	out	net	in	out	net	in	out	net	in	out	net
Eastern province	36.9	4.9	22.9	48.8	9.6	28.2	42.5	9.2	25.8	42.1	8.8	25.4
Central province	1.9	7.1	-0.1	1.2	3.4	-0.2	1.3	3.4	-0.3	1.4	3.8	-0.3
Western province	1.8	7.8	-5.9	1.7	7.1	-5.4	1.8	7.3	-5.5	2.0	7.5	-5.5

The coefficients of variation for the NI (In), NE (Out), and NET values by region are reported in Table 3, which illustrates the dispersion within each region. The absolute value of the coefficient of variation was highest in the coastal area, followed by the western region. Therefore, NET vary among coastal provinces, and a detailed network is not necessarily constructed. Furthermore, because there are some variations within the western region, discussions need to be had on a province-by-province basis rather than on a regional basis.

This study also analyzed whether there were any changes in this unbalanced development before and after the COVID-19 pandemic. Table 4 summarizes the differences in the NI (In), NE (Out), and NET values for each province between 2019 and 2022. The provinces with increasing NET numbers were Hebei, Inner Mongolia, Jiangsu, Anhui, Yunnan, Shaanxi, and Xinjiang, all showing increases of one or two. However, NET values decreased in Shanxi, Shanghai, Zhejiang, Shandong, Henan, Hubei, Guangdong, and Ningxia, and the changes were small for provinces other than Shanxi, which was -4. Thus, there were no major changes in the network before or after the pandemic.

The differences in NI (In), NE (Out), and NET values by region are reported in Table 5. Similar to the results presented in Table 4, no significant changes were observed. It can be seen that the coastal area has not changed on average, maintaining the pre-coronavirus network. Changes were observed in the inland central and western regions; however, differences were also observed between these two regions. In the central region, NET values

Table 4. Change in "in and out degrees" by province (2019-2022)

		change (2019-2022)		
Province	Region	in	out	net
Beijing	Eastern province	0	0	0
Tianjin	Eastern province	-1	-1	0
Hebei	Eastern province	1	-1	2
Shanxi	Central province	-3	1	-4
Inner Mongolia	Western province	2	0	2
Liaoning	Eastern province	0	0	0
Jilin	Central province	0	0	0
Heilongjiang	Central province	0	0	0
Shanghai	Eastern province	-1	0	-1
Jiangsu	Eastern province	1	-1	2
Zhejiang	Eastern province	-1	0	-1
Anhui	Central province	1	-1	2
Fujian	Eastern province	0	0	0
Jiangxi	Central province	0	0	0
Shandong	Eastern province	-1	0	-1
Henan	Central province	0	1	-1
Hubei	Central province	-4	-2	-2
Hunan	Central province	0	0	0
Guangdong	Eastern province	0	1	-1
Guangxi	Western province	0	0	0
Hainan	Eastern province	0	0	0
Chongqing	Western province	0	0	0
Sichuan	Western province	0	0	0
Guizhou	Western province	0	0	0
Yunnan	Western province	0	-1	1
Tibet	Western province	0	0	0
Shaanxi	Western province	0	-2	2
Gansu	Western province	0	0	0
Qinghai	Western province	0	0	0
Ningxia	Western province	0	1	-1
Xinjiang	Western province	0	-1	1

Table 5. Change in "in and out degrees" by region (average; 2019-2022)

	change (2019-2022)		
Region	in	out	net
Eastern province	-0.2	-0.2	0.0
Central province	-0.8	-0.1	-0.6
Western province	0.2	-0.3	0.4

decreased slightly. In contrast, in the western region, NET values increased slightly. In other words, although there were no major structural changes, the COVID-19 pandemic may have improved the NET in the western region and decreased the networks in the central region.

4. Discussion

To understand the changes in networks after the COVID-19 pandemic, it is necessary to understand the inflow and outflow of economic transactions. First, in the coastal area, there was no change in NET as both In and Out decreased at the same level, which implies that China's overall economic network is becoming slowly.

In the central region, both In and Out decreased, but the decline in In was greater. Therefore, NET decreased, that is, the inflow of economic activity declined. For the western region, there was no change in In, but Out decreased. Therefore, NET decreased. This was expected because of the pandemic's impact.

In both cases, there was no change in the structure of the economic network observed in NET, indicating that the impact of the pandemic was limited. However, the values of In and Out are declining overall, suggesting that China's domestic economic network may be weakening.

The following issues remain for future research: it is necessary to consider factors such as provincial trade values (input-output table), determinants of spatial economic network centrality, city-level analysis, zero-COVID policy, and distance measures.

5. Concluding remarks

China's economy has continued to experience high growth despite unbalanced regional development. The results indicate that eastern provinces play a key role in spatial economic networks in China, whereas other regions tend to be separated from the center of the network. In addition, the impact of the COVID-19 pandemic on spatial economic networks in China appears to be limited. This indicates that China may still experience unbalanced regional development. China requires economic policies to achieve this issue. Therefore, the Chinese government should reconsider its regional policies to solve these problems and enhance economic growth.

References

Hausmann, R., Hwang, J. and Rodrik, D. (2007). "What You Export Matters," *Journal of Economic Growth*, 12, pp.1-25.

Jarreau, J. and Poncet, S. (2012). "Export sophistication and economic growth: Evidence from China," *Journal of Development Economics*, 97(2), pp.281-292.

Jiang, Y., Li, Y., Li, Y., Xu, Y. and Veglianti, E. (2023). "Research on the structural characteristics and influencing factors of global environmental services trade networks," *Environmental Science and Pollution Research*, 30, pp.1-14.

Kadushin, C. (2012). *Understanding Social Networks*. Oxford University Press, New York, NY, USA.

Lall, S., Weiss, J. and Zhang, J. (2006). "The "Sophistication" of exports: a new trade measure," *World Development*, 34 (2), pp.222-237.

Liaoning Province (2018). *Liaoning Provincial Statistics Bulletin 2017.*

Li, A. (2020). "Spatial relation of regional economy in Xiangxi Autonomous Prefecture based on gravity model," *China Circulation Economy*, 13, pp. 88-90.

Schott, P. (2008). "The relative sophistication of Chinese exports," *Economic policy*, 23(53), pp.5-49.

Thorbecke, W. and Pai, H. (2013). "The Sophistication of East Asian Exports," *RIETI Discussion Paper Series*, 13-E-092, pp.1-37.

Wasserman, S. and Fause, K. (1994). *Social Network Analysis: Methods and Applications*. Cambrige University Press, Cambrige, UK.

Xu, B. (2010). "The sophistication of exports: Is China special? ," *China Economic Review*, 21, pp.482-493.

Yu, G., He, D., Lin, W., Wu, Q., Xiao, J., Lei, X., Xie, Z. ans Wu, R. (2020). "China's Spatial Economic Network and Its Influencing Factors," *Conplexity*, 2020, pp.1-13.

Zhu, S. and Fu, X. (2013). "Drivers of Export Upgrading," *World Development*, 51, pp.221-233.

Appendices

A. List of provinces

id	province	id	province
1	Beijing	16	Henan
2	Tianjin	17	Hubei
3	Hebei	18	Hunan
4	Shanxi	19	Guangdong
5	Inner Mongolia	20	Guangxi
6	Liaoning	21	Hainan
7	Jilin	22	Chongqing
8	Heilongjiang	23	Sichuan
9	Shanghai	24	Guizhou
10	Jiangsu	25	Yunnan
11	Zhejiang	26	Tibet
12	Anhui	27	Shaanxi
13	Fujian	28	Gansu
14	Jiangxi	29	Qinghai
15	Shandong	30	Ningxia
		31	Xinjiang