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Impacts of COVID-19 pandemic on foreign trade intermodal transport accessibility: Evidence from the Yangtze River Delta region of mainland China

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ABSTRACT

We address the problem of the impacts of COVID-19 pandemic on foreign trade transport by introducing a foreign trade intermodal transport accessibility (FTITA) index. First, we present the definition of FTITA, which combines the convenience of transporting domestic cargoes to overseas regions by an international intermodal transport network and the trade attractiveness of the domestic cargoes in the overseas regions. Second, we analyze the path choice behaviors of domestic shippers and propose the measurement method of the FTITA index. Finally, using the 41 cities in the Yangtze River Delta region in mainland China as origins and eight overseas regions as destinations, we empirically analyze the impacts of COVID-19 pandemic on the FTITA. With the empirical study conducted in the prepandemic and postpandemic years, we analyzed the overall trends of the FTITAs from the YRD region to eight overseas regions, spatial patterns of the distributions of the FTITAs in the YRD region, rankings of average FTITA values for the top ten cities in the YRD region, and the FTITAs for different cargoes. The results indicate that the FTITAs of the YRD region in the prepandemic year are significantly higher than those in the postpandemic year. Moreover, in both the prepandemic and postpandemic years, the FTITAs to North America, Japan/South Korea, Europe, and Southeast Asia are significantly higher than those to Oceania, Middle East, South America, and Africa. Through analysis of the spatial patterns of the FTITAs across cities in the YRD region, we find that the cities with high FTITA are mainly close to Shanghai Port and Ningbo Port; the cities with middle-high FTITA are mainly located in southern Zhejiang and the regions along the Yangtze River; the cities with middle-low FTITA are mainly located in northern Jiangsu; and the cities with low FTITA are located in northern Anhui. Furthermore, comparing the impacts of COVID-19 pandemic on the FTITAs for different cargoes, we observe that COVID-19 has the least impact on foodstuffs and event cargoes. Our findings can guide decision makers in implementing policies for alleviating the impacts of COVID-19 pandemic on foreign trade transport and further promoting the sustainable development of port and shipping industries.

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1. Introduction

As an important engine for economic growth, the development of foreign trade directly affects a country's share in the global trade market and its position in the global industrial chain (Feng et al.,2022). In recent decades, Chinese foreign trade has achieved rapid growth. The Chinese yearbook of 2020 indicates that the total value of Chinese import and export of cargoes increased from 3,927 billion yuan[1] in 2000 to 31,563 billion yuan in 2019. During this period, the proportion of the total value of Chinese imports and exports of cargoes in the world increased from 3.60 % to 11.33 %. This great achievement is mainly due to the rapid development of the Chinese shipping industry, as nearly 90 % of international trade cargoes are transported by maritime shipping (Lane and Pretes, 2020). Currently, the total throughput of Chinese ports ranks first in the world. Moreover, in 2020, seven of the top ten ports in terms of throughput were Chinese ports (Guo et al., 2021).

Considering the critical role of port and shipping industries in promoting foreign trade development, the Chinese government has made great efforts to stimulate the development of port and shipping industries. On the domestic side, decision makers construct railways to connect ports to the national freight railway with the aim of implementing sea-rail intermodal transportation (Zhou et al., 2017). Inland city governments build inland dry ports to offer high-quality service to seaports for shippers in the inland hinterland (Qiu and Lam, 2018). Moreover, the central government actively expands the inland river network (e.g., Yangtze River and Zhu Jiang River) to realize river-sea combined transportation (Witte et al., 2019). On the seaport and international shipping side, the port authorities make substantial investments in expanding port capacity and decrease port fees to attract international main shipping lines to choose Chinese ports as the main transshipment ports in the East Asian region (Qu et al.,2020). As a consequence, the transportation convenience from the Chinese mainland to overseas regions has been greatly improved, which has resulted in the rapid increase in Chinese foreign trade in recent years.

However, the COVID-19 pandemic that occurred in early 2020 has had a great impact on the port and shipping industries (Xu et al., 2021; Menhat et al., 2021). The multidimensional preventive measures against the COVID-19 pandemic have greatly reduced the operational efficiency of global ports and the supply capacity of international shipping services. The COVID-19 pandemic has not only caused heavy congestion in ports, such as the Los Angeles and Long Beach ports in the U.S., but also led to a shortage of shipping capacity and a high shipping freight rate. A recent report by Drewry indicates that the World Container Index (WCI) has reached 10,377, which is the highest point since the index was proposed. Moreover, the pandemic has caused drastic fluctuations in Chinese foreign trade and global trade. Data from the Review of Maritime Transport (2021) indicate that global merchandise trade and seaborne trade declined 5.4 % and 3.8 %, respectively, in 2020 compared to 2019.

In this context, we aim to study the impact of COVID-19 pandemic on foreign trade transport using an intermodal transport accessibility index. To achieve this goal, we first propose a measurement method the index of foreign trade intermodal transport accessibility (FTITA). The FTITA index mainly considers the transport convenience from a domestic origin of a country to an overseas region and the trade attractiveness in the overseas region. We then empirically evaluate the FTITA with the case of the Yangtze River Delta region in mainland China. Finally, we provide policy and managerial implications for guiding decision makers to mitigate the impacts of COVID-19 pandemic prevention measures on foreign trade transport.

To summarize, the contribution of the paper are threefold. First, we propose a novel analytical approach to evaluate the impacts of COVID-19 on foreign trade transport by combining trade attractiveness and transport connectivity in terms of disaggregated cargo categories. In particular, unlike the traditional aggregated foreign trade transport accessibility for a bundle of export cargoes, our index considers disaggregated transport accessibilities for different export cargo categories as different export cargoes differ greatly in the time value and transport cost. Second, compared with existing studies measuring generalized transportation costs, we investigate the impacts of COVID-19 pandemic on generalized transportation costs by incorporating port congestion costs and the time costs of different export cargoes. The port congestion cost is measured by comparing the port congestion time and the waiting time that results from the discrete frequency of the shipping lines. Moreover, the time cost for different cargo types is measured by the time value, which is determined by the market price of the export cargo, depreciation rate, and the annual capital occupancy time. Finally, it can also provide stakeholders in the transport industry with managerial and policy implications to help assess potential strategies to improve intermodal transport accessibility and alleviate the impacts of COVID-19 on foreign trade transport.

The rest of the paper is organized as follows. Section 2 reviews the literature related to port and maritime connectivity and accessibility. Section 3 presents the detailed measurement method of the FTITA index. Section 4 shows the calculation results of the FTITA in the Yangtze River Delta region in mainland China. Section 5 presents the policy implications and concludes the paper.

2. Literature review

Our study contributes to the literature on port or maritime connectivity and accessibility, which have been gaining traction over the past years (Jiang et al., 2015). In this section, we first review the previous research studying port or maritime connectivity. Then, we present the methods for measuring accessibility and the relevant papers studying port or maritime accessibility. Finally, we present our contributions to the literature.

Port or maritime connectivity is used to quantify the transport convenience from a port or inland origin to another port or inland destination through the shipping network. In the literature on port connectivity, Low et al. (2009) developed a network-based

[1] As of 30 March 2022, one US dollar is equal to 6.35 yuan.

connectivity index to evaluate the impacts of various quality characteristics on port choices. With the connectivity index, several key policy insights are derived to improve port competitiveness for hub port authorities. To understand the dynamics of port connectivity and interport relationships in the supply chain, Lam and Yap (2011) propose a new perspective with the examination of the calling patterns of container shipping services. Jiang et al. (2015) introduced an analysis framework for port connectivity from the perspective of a global container liner shipping network and two models for port connectivity from transportation time and capacity. Wang et al. (2016) used an integrated port connectivity index to define the features of dry ports in the hinterland, feeder service networks, and foreign trade traffic. Dadashpoor and Arasteh (2020) used a social network analysis method to explore the spatial structure of port-hinterland commodity relations in Iran. To study the connectivity of Spanish ports in terms of container short sea shipping services, Martínez-Moya and Feo-Valero (2020) proposed a Foreland Port Connectivity Index (FPCI) by incorporating the number of shipping services and destination country factors. By using the measurement of generalized transport cost, Indriastiwi et al. (2021) presented a conceptual framework for studying port connectivity in a multimodal transport network with three perspectives, i.e., maritime connectivity, port connectivity, and port-hinterland connectivity.

There is also a stream of literature regarding maritime connectivity. For example, Wilmsmeier and Hoffmann (2008) adopted principal component analysis and ordinary least-squares regressions to analyze the impacts of port infrastructure and linear shipping connectivity on intra-Caribbean freight rates. Through the consideration of centrality, primary flows, and clustering interactions, Lee et al. (2018) studied the maritime connectivity of ports and shipping networks in the East Sea Economic Rim (ESER) with the aim of promoting international trade in the context of China's Belt and Road Initiative. Cheung et al. (2020) developed a novel max–min integer optimization model to improve shipping network connectivity by investigating the largest eigenvalue and the corresponding eigenvector of the frequency weighted adjacency matrix. According to multi-dimensional scaling (MDS), Guerrero et al. (2021) offered a visualization of the Liner Shipping Bilateral Connectivity Index by focusing on the shipping connections of 10 west European countries. Tovar and Wall (2022) employed a stochastic output distance function to study the empirical relationship between maritime connectivity and port efficiency, including a panel dataset of 16 Spanish ports over the period 2006–2016.

Despite the efforts in previous research, the above review of the current literature of port and maritime connectivity indicates that most studies measure connectivity from a single perspective (e.g., time or cost) and evaluate the transport convenience from one port to another in a shipping network. Few studies have considered the transport convenience from an inland city to an overseas region through an intermodal transport network that contains the shipping network and included the transshipment cost of different transport modes in the calculation of the generalized transport cost. Moreover, the connectivity index can be used only to measure the transport condition in a transport network, and it cannot reflect the impacts of trade flow on the degree of connection of an origin and destination pair. To fill this gap, the accessibility index, which has been widely used in transportation planning, geography, and transport economics (Xi and Miller, 2019; Kotavaara et al., 2021; Januario, 2021), is introduced in our study. Currently, the following three common definitions exist for the accessibility index: (1) the mutual influence or interaction potential between nodes (Widener et al., 2015; Liu and Jiang, 2021); (2) the number of opportunities a node can obtain in a transport network (Cascetta et al., 2016; Basso et al., 2020); and (3) the difficulty for a node to overcome the spatial barrier when reaching another node (Levinson and Wu, 2020). The measurement methods of accessibility are also divided into three types corresponding to the definitions: (1) the gravity model, combining the gravitational scale of supply and demand and considering the spatial effects (Ghorbanzadeh et al., 2021); (2) the cumulative opportunity model, which refers to the number of resources that can be obtained from a certain node and considers facilities and spatial barriers between the supply and demand sides (Kelobonye et al., 2020); and (3) the cost resistance model, which calculates the cumulative resistance to public facilities through the shortest paths (Páez et al., 2020).

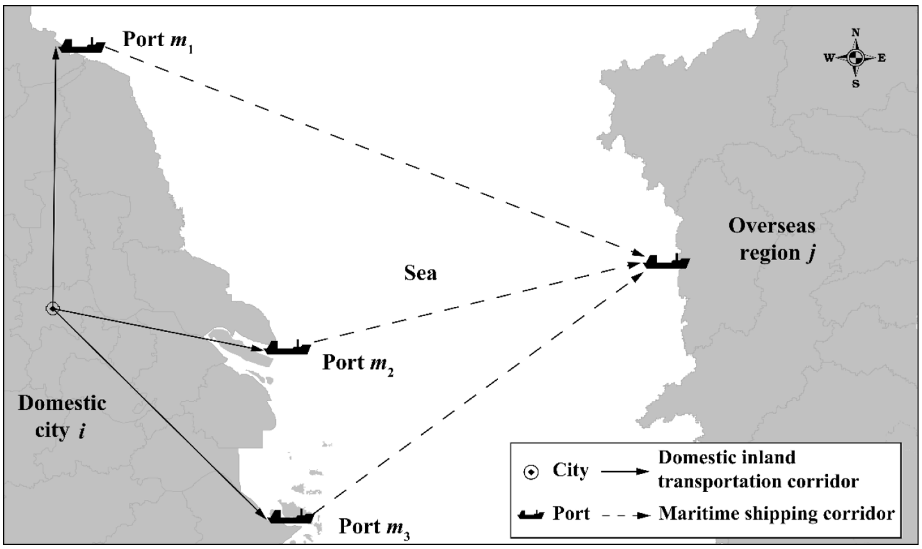


Fig. 1. Paths of foreign trade intermodal transport from a domestic city to an overseas region.

Our work is related to the first measurement method of accessibility (i.e., the gravity model). Previous scholars have applied the gravity model-based accessibility measurement method to the port and shipping industry. For instance, Guo and Yang (2018) proposed foreign trade transport accessibility to evaluate the shipping connectivity from mainland China to overseas regions and the achievable market scales in overseas regions. Guo and Yang (2019) extended the work of Guo and Yang (2018) by using stochastic frontier analysis to study the relationship between shipping accessibility and maritime transport demand. Our study is related to the above two papers, but our work is different from their study in several ways. First, we consider disaggregated transport accessibilities for different export cargoes rather than an aggregated accessibility for a bundle of cargoes, as different export cargoes differ greatly in the time value. Second, we consider the impacts of COVID-19 pandemic on the generalized transportation cost by introducing port congestion cost and the time cost of different export cargoes into the accessibility index. Finally, we propose a more comprehensive indictor to measure trade attractiveness considering the impacts of gross regional product, human capital, and total import trade volumes on trade attractiveness.

3. Measure of foreign trade intermodal transport accessibility

3.1. Definition of foreign trade intermodal transport accessibility

As shown in Fig. 1, the foreign trade intermodal transport of domestic cargoes from a domestic city to an overseas region usually comprises the following three main processes: (1) domestic inland transport from the domestic city to a gateway port by road, rail or inland river; (2) the loading of the export cargoes to a sea ship in the gateway port; and (3) the international maritime shipping from the gateway port to the overseas region. Therefore, the connectivity of the international intermodal transport network directly determines the convenience of the transportation of domestic cargoes to overseas regions. Moreover, as discussed in Guo and Yang (2018), the trade attractiveness for domestic goods in overseas regions impacts the accessibility from domestic cities to overseas regions. If the trade attractiveness of an overseas region is low, the shippers in domestic cities will not choose to transport their cargoes to the overseas region. Hence, we define the foreign trade intermodal transport accessibility (FTITA) of a city as a combination of the convenience of transporting domestic cargoes to overseas regions by an international intermodal transport network and the trade attractiveness for the domestic cargoes in the overseas regions. With this definition, we can propose the calculation method of the FTITA, and the detailed expression is as follows:

$$AC_{ijk} = C_{ijk}^{-\phi} \cdot F_{jk}^{\gamma}, \quad \forall i \in I; j \in J; k \in K \tag{1}$$

where i is the domestic city; j is the overseas region; k is the cargo type; AC is the foreign trade intermodal transport accessibility; C_{ijk} is the weighted average generalized transportation cost from city i to overseas region j for transporting cargo type k, which is used to measure the connectivity of intermodal transport networks; F_{jk} is the trade attractiveness of the overseas region j for transporting cargo type k; I, J, and K are the sets of domestic cities, overseas regions, and cargo types, respectively; and ϕ and γ are constant parameters.

As mentioned above, the international intermodal transport process contains three main processes, and the chosen gateway port directly determines the convenience of the intermodal transport process. Thus, with different gateway ports, multiple transportation paths can be chosen by the shippers. To measure the connectivity of the intermodal transport process, we must first determine the choice probability of each transportation path and then calculate the weighted generalized transportation cost of multiple paths. Therefore, we calculate the path choice probability in Section 3.2 and present the generalized transportation cost of a path in Section 3.3.

3.2. Path choice of the shippers in a domestic city

In Fig. 1, the solid lines represent the domestic inland transportation corridors from the domestic city to gateway ports, and the dotted lines represent the international maritime shipping corridors from gateway ports to overseas regions. When shippers in domestic city i decide to transport their export cargoes to overseas region j, the following three paths can be chosen, namely, path 1: city i → gateway port m_1 → overseas region j; path 2: city i → gateway port m_2 → overseas region j; and path 3: city i → gateway port m_3 → overseas region j. Next, we will analyze the path choice behavior of shippers with the discrete choice model.

As discussed by Oyama and Hato (2017), Duncan et al. (2020), and Wang et al. (2020), the choice of the transportation paths of shippers is usually based on the utilities of the paths. The higher utility of a path can correspond to a higher possibility that the path will be chosen. Hence, we can use the multinomial logit (MNL) model, which is widely used in the discrete choice model, to determine the choice probability of the paths. We use s and S_{ij} to denote the path and set of paths from domestic city i to overseas region j, respectively. Moreover, we use P_{ijk}^{s} to denote the choice probability of path s from domestic city i to overseas region j for transporting cargo type k. Then, based on the MNL model, the calculation method of P_{ijk}^{s} can be expressed as follows:

$$P_{ijk}^{s} = \frac{\exp(\varsigma \cdot U_{ijk}^{s})}{\sum_{s \in S_{ij}} \exp(\varsigma \cdot U_{ijk}^{s})} \tag{2}$$

where U_{ijk}^{s} is the utility of path s from domestic city i to overseas region j for transporting cargo type k, ς is a constant parameter. The utility of a path is directly determined by the generalized transport cost of the path. A lower generalized transportation cost of a path usually means a higher utility of the path. Thus, we can define U_{ijk}^{s} as follows:

$$U_{ijk}^{s} = \frac{\sum_{s \in S_{ij}} C_{ijk}^{s}}{C_{ijk}^{s} \cdot |S_{ij}|} \tag{3}$$

where C_{ijk}^{s} is the generalized transportation cost of path s from domestic city i to overseas region j for transporting cargo type k, and $|S_{ij}|$ is the total number of paths from domestic city i to overseas region j.

After determining the choice probability of the paths, we can derive the weighted average generalized transportation cost C_{ijk} and the corresponding weighted average generalized transportation timeT_{ijk}. The detailed expressions are as follows:

$$C_{ijk} = \sum_{s \in S_{ijk}} C_{ijk}^{s} \cdot P_{ijk}^{s} \tag{4}$$

$$T_{ijk} = \sum_{s \in S_{ijk}} T_{ijk}^{s} \cdot P_{ijk}^{s} \tag{5}$$

3.3. Generalized transportation cost of a path

As mentioned above, the foreign trade transportation of cargoes from domestic cities to overseas regions includes three main processes: domestic inland transportation, port loading, and international maritime shipping. Hence, the generalized transportation cost of path C_{ijk}^{s} consists of the generalized costs in these three main processes. The detailed expression of C_{ijk}^{s} is organized as follows:

$$C_{ijk}^{s} = C_{ijk}^{s.land} + C_{ijk}^{s.port} + C_{ijk}^{s.shipping} \tag{6}$$

where $C_{ijk}^{s.land}$ is the generalized cost of the domestic inland transportation of path s from city i to overseas region j for transporting cargo type k, $C_{ijk}^{s.port}$ is the generalized cost in the gateway port of path s from city i to overseas region j for transporting cargo type k, and $C_{ijk}^{s.shipping}$ is the generalized cost of the international maritime shipping of path s from city i to overseas region j for transporting cargo type k.

3.3.1. Generalized cost of domestic inland transportation

According to the data of the National Bureau of Statistics of China concerning the domestic freight transport market in 2020, the proportions of the volumes of road transport, rail transport, inland river transport, and air transport in the national total freight volumes are 73.93 %, 9.62 %, 16.43 %, and 0.1 %, respectively. We find that due to the high cost and limited capacity of air transport, air transport is not the main transportation mode in the Chinese domestic freight transportation market. Thus, we consider only the main modes of road, rail, and inland river when calculating the generalized cost of domestic inland transportation. We use m and M_{ij} to denote the gateway port in a foreign trade transportation path s and the set of available gateway ports in the paths from domestic city i to overseas region j, respectively. Then, $C_{ijk}^{s.land}$ in Eq. (6) can be calculated as follows[2]:

$$C_{ijk}^{s.land} = \beta_i^{road} C_{imk}^{s.road} + \beta_i^{rail} C_{imk}^{s.rail} + \beta_i^{river} C_{imk}^{s.river}, \forall m \in M_{ij} \tag{7}$$

where$C_{imk}^{s.road}$,$C_{imk}^{s.rail}$, and $C_{imk}^{s.river}$ are the generalized transportation costs of path s from domestic city i to gateway port m for transporting cargo type k by road, rail, and inland river, respectively; andβ_i^{road},β_i^{rail}, and β_i^{river} are the modal splits of road, rail and inland river in domestic city i, respectively.

Since there exists a high frequency of departures in road and rail transport, we then calculate the generalized transportation costs of road and rail, including monetary cost and time cost, as follows:

$$C_{imk}^{s.road} = \delta_{road} \left(R_{im}^{s.road}/R_{road}\right)^{-\theta_{road}} \cdot R_{im}^{s.road} + V_k \cdot R_{im}^{s.road}/v_{raod} \tag{8}$$

$$C_{imk}^{s.rail} = \delta_{rail} \left(R_{im}^{s.rail}/R_{rail}\right)^{-\theta_{rail}} \cdot R_{im}^{s.rail} + V_k \cdot R_{im}^{s.rail}/v_{rail} \tag{9}$$

where $R_{im}^{s.road}$ and $R_{im}^{s.rail}$ are the shortest path distances from domestic city i to gateway port m by road and rail, respectively; R_{road} and R_{rail} are the average transport distance by road and rail in mainland China, respectively; δ_{road} and δ_{rail} are the average unit transport cost per tonnage cargo by road and rail in the Chinese market, respectively; θ_{road} and θ_{rail} are parameters used to capture the 'tapering effect'; V_k is the time value of cargo type k; and v_{road} and v_{rail} are the average running speed of road and rail in the Chinese transport market, respectively.

[2] The modal splits for transporting different cargoes in the inland transport system may differ according to the different characteristics of the export cargoes. In our study, we convert the different cargoes to containerized cargo with the suitable rate for the container transport of different cargoes. Then, we calculate the generalized inland transport cost with the single modal split for transporting containerized cargo. Thus, we assume the modal splits for transport different cargoes are the same by considering the containerized conversion of different cargoes and the data availability of the modal splits in empirical analysis.

With regard to domestic cities using the mode of inland river transport, the frequencies of inland river shipping lines are not as high as those of road and rail transport, and thus, the running durations and prices of inland river shipping lines determine the generalized cost of inland river transport. We use l and L_{im} to denote the shipping line and set of available inland river shipping lines from domestic city i to gateway port m, respectively. Then, $C_{imk}^{s.river}$ in Eq. (7) can be expressed as[3]:

$$C_{imk}^{s.river} = V_k \cdot \sum_{l \in L_{im}} T_{im}^{l} / |L_{im}| + \sum_{l \in L_{im}} E_{im}^{l} / |L_{im}| \tag{10}$$

where T_{im}^{l} is the running duration of inland river shipping line l from domestic city i to gateway port m; E_{im}^{l} is the price of inland river shipping line l from domestic city i to gateway port m; and $|L_{im}|$ is the number of inland river shipping lines from domestic city i to gateway port m.

As shown in Eq. (8), Eq. (9), and Eq. (10), the time value V_k is an important factor that affects the generalized transportation cost. However, few previous studies have investigated the effect of the time value of different export cargoes on the generalized transportation cost. According to Tao and Zhu (2020) and Binsuwadan et al. (2021), we define the time value V_k as follows:

$$V_k = \frac{w_k Z_k}{N} \tag{11}$$

where Z_k is the average price of cargo type k in the Chinese market; w_k is the average depreciation rate of cargo type k; and N is the average annual capital occupancy time.

3.3.2. Generalized cost of gateway port

When the shippers transport the export cargoes to the gateway port through domestic inland transportation, the cargoes should be loaded onto the sea ships. At the gateway ports, the generalized cost relates to the waiting time and port charges. For the waiting time, the frequencies of the international shipping lines and port congestion level are the two most important influencing factors. We use L_{mj} to denote the set of maritime shipping lines from gateway port m to overseas region j. Therefore, $C_{ijk}^{s.port}$ in Eq. (6) can be expressed as follows:

$$C_{ijk}^{s.port} = \begin{cases} V_k \cdot (1/\sum_{l \in L_{mj}} (1/f_{mj}^{l})) + F_m, & \text{if} \quad 1/\sum_{l \in L_{mj}} (1/f_{mj}^{l}) > T_m \\ V_k \cdot T_m + F_m, & \text{otherwise} \end{cases} \tag{12}$$

where f_{mj}^{l} is the frequency of maritime shipping line l from gateway port m to overseas region j; T_m is the port waiting time owing to port congestion at gateway port m; and F_m is the charge of gateway port m. In Eq. (12), $1/\sum_{l \in L_{mj}} (1/f_{mj}^{l})$ is used to measure the average waiting time, which is determined by the frequencies of the maritime shipping lines. By comparing $1/\sum_{l \in L_{mj}} (1/f_{mj}^{l})$ and T_m, we can derive the waiting time at the gateway ports.

3.3.3. Generalized cost of international maritime shipping

As in inland river transport, the frequencies and prices of international maritime shipping lines determine the generalized cost of international maritime shipping. Thus, $C_{ijk}^{s.shipping}$ in Eq. (6) can be expressed as follows:

$$C_{ijk}^{s.shipping} = V_k \cdot \sum_{l \in L_{mj}} T_{mj}^{l} / |L_{mj}| + \sum_{l \in L_{mj}} E_{mj}^{l} / |L_{mj}| \tag{13}$$

where T_{mj}^{l} is the running duration of maritime shipping line l from gateway port m to overseas region j; E_{mj}^{l} is the price of maritime shipping line l from gateway port m to overseas region j; and $|L_{mj}|$ is the number of maritime shipping lines from gateway port m to overseas region j.

3.4. Trade attractiveness

Although many factors may affect trade attractiveness, such as economic indicators, population, and import trade volumes, the specific gross regional product, human capital, and total import trade volumes are the key factors that influence trade attractiveness (Su and Liu, 2016; Zhao et al., 2017; Bakshi et al., 2020; Saidi et al., 2020). Moreover, some scholars have investigated the impacts of

[3] Taking the shipping route from Wuhu Port to Shanghai Port along the Yangtze River as an example, there exist two main shipping lines from Wuhu Port to Shanghai Port. The one is the direct shipping line without intermediate port calls, and the frequency, running duration, and price of the shipping line are two days/voyage, two days, and 1,600 yuan/TEU, respectively. The other one is the indirect shipping line with multiple intermediate port calls (e.g., Nanjing Port and Zhenjiang Port). The shipping line's frequency, running duration, and price are one week/voyage, four days, and 1,000 yuan/TEU, respectively. Then, we can use the average running duration and the average price of these two shipping lines to calculate the generalized transportation cost of inland waterway transport.

the three key factors on trade volume or trade attractiveness with quantitative methods. For instance, Masood et al. (2022) found that a 1 % increase in the GDP of an overseas region will result in a 0.5 % increase in total trade volume. Auer (2015) and Ibrahim and Sare (2018) indicated that the human capital elasticity of trade volume is 0.57, namely, a 1 % increase in human capital corresponds to a 0.57 % increase in trade volume. In addition, Feyrer (2021) pointed out that the elasticity of trade attractiveness to trade volume is 0.25. With the above discussion, we thus choose the three main indexes (including gross regional product, human capital, and total import trade volumes) to measure trade attractiveness. The detailed expression is concluded as follows:

$$InF_{jk} = \varepsilon_1 InG_j + \varepsilon_2 InH_j + \varepsilon_3 InQ_{jk} + \varepsilon_4 \tag{14}$$

where G_j is the gross regional product of overseas region j, H_j is the human capital of overseas region j, Q_{jk} is the import trade volume of overseas region j for transporting cargo type k, andε_1,ε_2,ε_3, and ε_4 are parameters.

4. Empirical study

In this section, we first present the study area for conducting the empirical study. Then, we give the related data and data sources for calculating the FTITA. Finally, we present the empirical results of the FTITAs and show the corresponding analysis of the results.

4.1. Study area

As shown in Fig. 2, the Yangtze River Delta (YRD) region in mainland China is chosen for the empirical study. The YRD region is the largest economic zone in mainland China and is an important eastern gateway to the world. With less than 4 % of the national territory, the YRD region accounts for one-quarter of China's total economic output and one-third of the total import and export volume. Forty-one cities (including Shanghai city and 40 other cities in Zhejiang, Jiangsu, and Anhui Provinces) are located in the YRD region. In 2019, the total GDP of the YRD region and the total value of import and export of cargoes reached 23.7 trillion yuan and 11.3 trillion yuan, respectively. The corresponding annual growth rates of total GDP and the total value of the import and export of cargoes reached 6.4 % and 2.5 %, respectively. Due to the impact of COVID-19 pandemic, the annual growth rates of the total GDP in the YRD region in 2020 decreased to 3.2 %. However, the annual growth rates of the total value of import and export of cargoes in the YRD region in 2020 increased to 4.8 %.

Regarding the overseas regions with which the 41 cities in the YRD region traded, we divided the countries that have trade connections with China into eight main overseas regions (including Japan/South Korea, Southeast Asia, Middle East, North America, Latin America, Oceania, Europe, and Africa). To analyze the impact of COVID-19 pandemic on the FTITA, we set 2019 as the prepandemic year and 2020 as the postpandemic year.[4] By comparing the FTITAs of the prepandemic year and the postpandemic year from 41 cities to eight overseas regions, the effect of COVID-19 pandemic on the FTITA can be investigated.

4.2. Data preparation

4.2.1. Cargo type

As mentioned in Section 3, cargo type is an important factor that affects the FTITA. According to the Standard Classification of International Trade (SITC) of UNCTAD, we classify the export cargoes of the YRD region into nine main categories, i.e., food and event cargoes, beverages and tobacco, nonedible raw materials, fossil fuels, lubricants and related raw materials, animal and vegetable fats and waxes, chemicals and related products, light textile products, rubber products, mining and metallurgical products, machinery and transport equipment, and miscellaneous products. The average market prices and time value of the nine types of cargoes are presented in Table 1. In Table 1, the average market price is calculated based on Chinese foreign trade value and trade volumes of different cargo types sourced from the UN Comtrade Database.[5] The time value is calculated based on Eq. (11) where the depreciation rate w_k is sourced from the State Taxation Administration of China and N is set to one year.

4.2.2. Domestic inland transport system

We choose the main highway (shown in Fig. 3), freight railway (shown in Fig. 4), and high-grade inland river networks in the YRD region to construct the inland intermodal network from cities to gateway ports and then calculate the shortest road/rail distances between the cities and gateway ports with the intermodal network. Based on the Annual Report on Highway Freight Transport in China (2019) and the China Road Freight Industry Operation Analysis Report Based on Big Data (2020)[6], we set the truck's average transport speed, the average unit cost of a truck transporting a TEU container, and the average transport distance of highways in the Chinese market in the prepandemic year to 43 km/h, 4.18 yuan/km, and 275 km, respectively. In the postpandemic year, we set the above

[4] The reasons why we set 2019 as the prepandemic year and 2020 as the postpandemic year are explained as follows. On the one hand, the COVID-19 pandemic occurred in early 2020 and had a major impact on international intermodal transport from China to overseas regions for the whole year. Thus, by comparing the FTITAs in 2019 (prepandemic year) and 2020 (postpandemic year), we can easily investigate the main factors that affect transport accessibility. On the other hand, considering the data availability and statistical characteristics regarding the trade data and transport data, we choose yearly data to analyze the COVID-19 pandemic impacts instead of monthly or quarterly data.

[5] https://comtrade.un.org/data/.

[6] https://www.transformcn.com/.

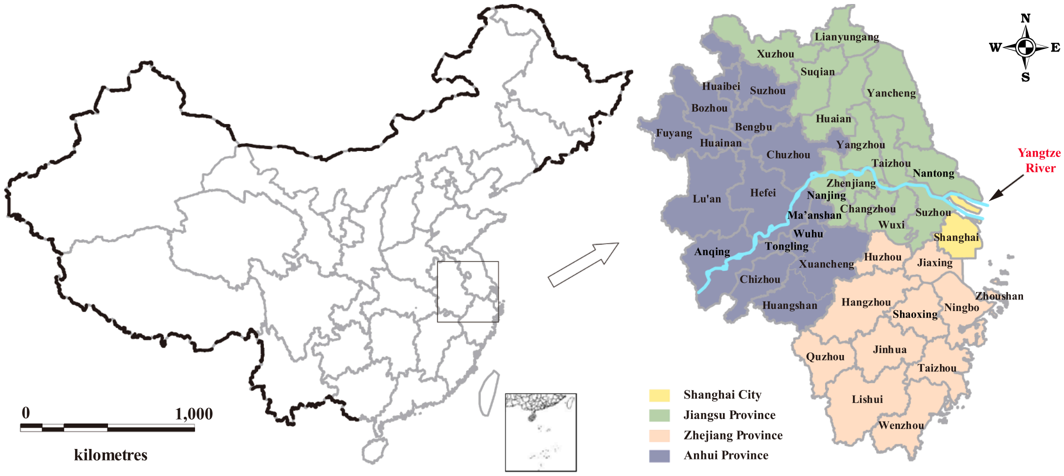


Fig. 2. Location of the YRD region in Mainland China.

Table 1
The average market prices, depreciation rate, and time value of the nine types of cargoes.

Cargo type	Average market price (thousand yuan/ TEU)	Depreciation rate	Time value (yuan/ (TEU*h))
Foodstuffs and event cargoes	343	1.00	39.2
Beverages and tobacco	444	0.50	25.3
Non edible raw materials	156	0.50	8.9
Fossil fuels, lubricants, and related raw materials	207	0.25	5.9
Animal and vegetable fats and waxes	174	0.75	14.9
Chemicals and related products	554	0.50	31.6
Light textile products, rubber products, mining, and metallurgical products	216	1.00	24.7
Machinery and transport equipment	847	0.10	9.7
Miscellaneous products	91	1.00	10.4

three parameters in road transport to 49 km/h, 4.30 yuan/km, and 305 km, respectively.

According to the website of the China Railway, we set the train average transport speed, the average unit cost of a train transporting a TEU container, and the average transport distance by railway in the Chinese market in the prepandemic year to 80 km/h, 1.58 yuan/km, and 688 km, respectively. In the postpandemic year, we set the above three parameters in rail transport to 80 km/h, 1.65 yuan/km, and 601 km, respectively. Based on Guo and Yang (2018), we set parameters ϕ and γ in Eq. (1) and ς in Eq. (2) to 1 in this empirical study. Moreover, according to Oum et al. (1993), the parameter θ in Eq. (8) and Eq. (9) is often set to 0.5 in empirical studies. The modal splits of road, railway, and inland river are determined by the freight volume of various modes in the 41 domestic cities in the prepandemic and postpandemic years.

Regarding the inland river transport network, since the total freight transport volumes transported by the Yangtze River account for 84.6 % of the total volumes in the YRD region, we use the Yangtze River network to calculate the generalized transportation cost of inland river transport. The data on the number of inland river shipping lines, average prices, and running duration of the shipping lines are obtained from the websites of the Chinese inland shipping network and Yangtze River shipping network. The average price and average running duration of the shipping lines from the ports along the Yangtze River Delta region to gateway ports in the pre- and postpandemic years are shown in Table 2.

4.2.3. Gateway port system

In the YRD region, Shanghai Port, Ningbo Port, and Lianyungang Port are the top three main gateway ports. In 2019, the total throughput of these three ports reached 2,018 million tons, which accounted for 86.3 % of the total throughput of the coastal ports in the YRD region. Hence, we choose these three ports as gateway ports to transport the export cargoes from 41 cities to eight overseas regions. We set the port charges of Shanghai Port, Ningbo Port, and Lianyungang Port to 480 yuan/TEU, 490 yuan/TEU, and 460 yuan/TEU, respectively. Due to the impact of COVID-19 pandemic, Shanghai Port and Ningbo Port are experiencing unprecedented port congestion. According to the Supply Chain Disruption Index for the world's ports recently published by Hamburg-Kuehne via the Seaexplorer platform, the average waiting times due to port congestion in Shanghai Port, Ningbo Port, and Lianyungang Port are 98 h, 39 h, and 24 h, respectively.

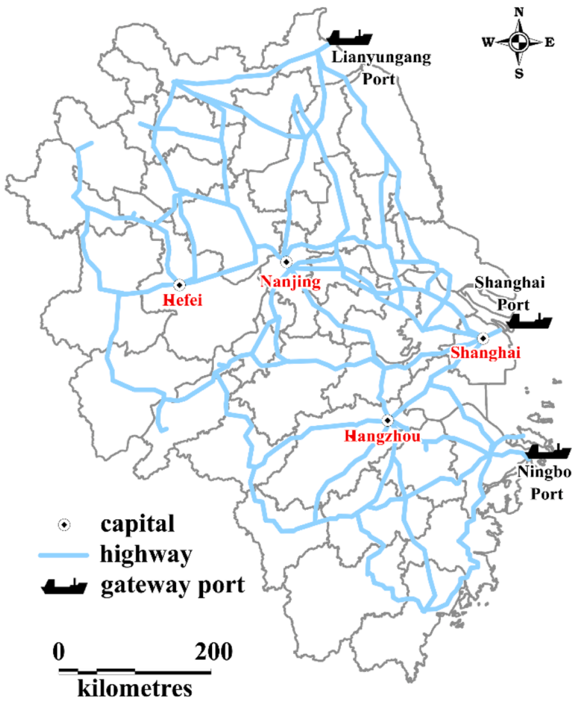


Fig. 3. Main freight highway network of YRD in 2020.

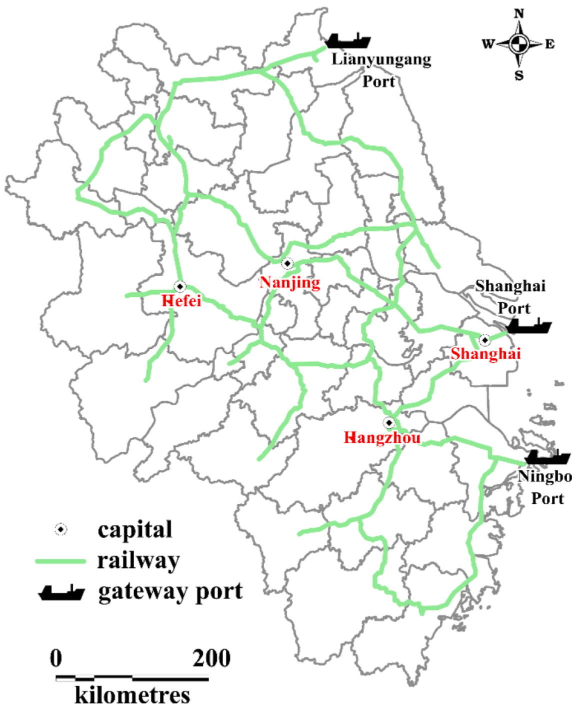


Fig. 4. Main freight railway network of YRD in 2020.

4.2.4. International ocean shipping system

We choose the main international shipping lines from the three gateway ports to eight overseas regions of the top eight liner companies (including MAERSK, MSC, CMA CGM, Hapag-Lloyd, COSCO, APL, EVER GREEN, and CSCL) to construct the international ocean shipping network. The number of shipping lines, average price, and average shipping time from gateway ports to eight overseas

Table 2
The average price and average running duration of the shipping lines from the ports along the Yangtze River region to gateway ports.

Year	Shipping Line	Average Price (yuan/TEU)	Average running duration (h)
Prepandemic	Nantong Port- Shanghai Port	550	6.60
	Wuxi Port- Shanghai Port	680	10.47
	Zhengjiang Port- Shanghai Port	900	18.20
	Nanjing Port- Shanghai Port	1000	23.13
	Ma'anshan Port- Shanghai Port	1080	26.40
	Wuhu Port- Shanghai Port	1150	29.53
	Tongling Port- Shanghai Port	1280	36.47
	Anqing Port- Shanghai Port	1380	42.60
Postpandemic	Nantong Port- Shanghai Port	580	7.87
	Wuxi Port- Shanghai Port	750	12.48
	Zhengjiang Port- Shanghai Port	960	21.70
	Nanjing Port- Shanghai Port	1080	27.58
	Ma'anshan Port- Shanghai Port	1160	31.48
	Wuhu Port- Shanghai Port	1200	35.21
	Tongling Port- Shanghai Port	1360	43.48
	Anqing Port- Shanghai Port	1460	50.79

regions in the pre- and postpandemic years are shown in Table 3. In Table 3, the number of shipping lines and average shipping times are collected based on the official websites of the eight major liner companies. The average prices are obtained based on ShippingChina (2020).

4.2.5. *Trade attractiveness of different overseas regions*

As shown in Eq. (14), to determine the trade attractiveness of the different overseas regions, the parametersε_1,ε_2,ε_3, and ε_4 should be estimated with the existing data regarding the trade attractiveness, GDP, human capital, and import volumes of different cargo types. However, it is difficult to obtain data on the existing trade attractiveness of different overseas regions, and parameter estimation is not the main focus of our study. Thus, we choose to set the parametersε_1,ε_2,ε_3, and ε_4 based on previous literature. According to Ata (2012), parametersε_1,ε_2,ε_3, and ε_4 in Eq. (14) are set to 0.75, 0.65, 0.80, and −6.45, respectively. The data of the trade attractiveness, GDP, human capital, and import volumes of different cargo types are obtained from the database of UNCTAD.

4.3. *Empirical results*

4.3.1. *Overall trend*

With the above data, we calculate the FTITAs from the 41 cities to eight overseas regions with Eq. (1) to Eq. (14). By calculating the mean value of the FTITAs of different cargo types, we derive the overall trend of the FTITAs from the cities in the YRD region to the eight overseas regions in the prepandemic and postpandemic years, and the results are presented in Table 4 and Fig. 5. From Table 4 and Fig. 5, we find that there are significant differences in the FTITAs from the 41 domestic cities to different overseas regions. Overall, the FTITAs to North America, Japan/South Korea, Europe, and Southeast Asia are significantly higher than those to South America, Middle East, Oceania, and Africa. For example, in the prepandemic year, the mean value (=319.82) of the FTITAs for Europe is the highest, while the mean value (=2.45) of the FTITAs to Africa is the lowest. The highest value is approximately 130 times higher than the lowest value. From Fig. 5, we also observe that the curves at the bottom (including the curves of FTITAs to Oceania, South America,

Table 3
The number of shipping lines, average price, and average shipping time from gateway ports to eight overseas regions.

Year	Overseas regions	Shanghai Port	Ningbo Port	Lianyungang Port
Prepandemic	Japan/South Korea	74/250/48	48/300/72	23/180/84
	Southeast Asia	74/250/240	64/325/192	8/450/264
	Middle East	18/1050/480	18/1025/456	3/1300/480
	North America	38/1880/336	28/1660/360	2/1900/392
	South America	21/1700/768	20/1562/768	–
	Oceania	20/857/408	20/725/366	–
	Europe	60/1275/720	52/1000/720	4/1450/744
	Africa	21/1209/696	20/1175/600	–
Postpandemic	Japan/South Korea	46/270/48	26/320/78	20/200/120
	Southeast Asia	50/850/252	42/725/225	4/900/312
	Middle East	12/2200/528	18/2020/510	–
	North America	18/7300/460	21/7300/496	–
	South America	6/4400/972	6/4400/972	–
	Oceania	14/1950/418	11/1800/408	–
	Europe	31/4350/845	29/4450/828	–
	Africa	4/3300/835	4/3450/762	–

Note: Data are presented as the number of shipping lines/average price (USD/TEU)/average shipping time (h).

Middle East, and Africa) are well balanced without significant volatility, while the curves at the top (including the curves of the FTITAs to Japan/South Korea, Europe, North America and Southeast Asia) fluctuate sharply. These trends occur because overseas regions with high FTITAs (e.g., Japan/South Korea, Europe, North America, and Southeast Asia) are usually well developed, indicating that trade attractiveness is relatively high. Moreover, the transportation cost from the domestic cities to these regions is relatively low, which means the export cargoes can be easily transported to the overseas regions. However, with regard to overseas regions with low FTITAs (e.g., Oceania, South America, Middle East, and Africa), the importing volumes are very low, and the transportation costs from the YRD region to these regions are relatively high, resulting in lower accessibilities to these regions.

Additionally, from Table 4 and Fig. 5, we investigate the effects of COVID-19 pandemic on FTITA by comparing the FTITAs in the prepandemic and postpandemic years. In general, the pandemic reduced the FTITAs to overseas regions, while the impacts varied across overseas regions. The pandemic has the least impact on the FTITA to Middle East, and the average FTITA decreased by 31 %. However, the pandemic led to the greatest impact on the FTITAs in North America and Europe, and the average FTITAs to these two overseas regions dropped nearly 72 %. The high impacts on the FTITAs to North America and Europe arise because pandemic prevention measures had the greatest impacts on these two regions (according to the World Health Organization (WHO), the cumulative number of confirmed cases in Europe and North America in 2020 accounted for 50 % of the world total). The heavy port disruption and congestion significantly reduce the port operational efficiency and increase the waiting time in the ports for export cargoes (the average waiting time in Shanghai Port increased from nearly zero hours in the prepandemic year to 98 h in the postpandemic year). Moreover, the shortage of international shipping line supplies and the substantial growth of shipping prices resulted in a large increase in the generalized transportation cost. For instance, the total number of shipping lines from Shanghai Port to North America fell from 38 in the prepandemic year to 18 in the postpandemic year, while the average shipping price from Shanghai Port to the US increased from $1880/TEU to $7300/TEU.

4.3.2. Spatial patterns

We further investigate the spatial patterns of the FTITAs from the cities in the YRD region to eight overseas regions in the prepandemic and postpandemic years, and the results are presented in Figs. 6–13. In the eight figures, we divide the distributions of the FTITAs to each overseas region into four main patterns with the mean value μ and standard deviation σ of the FTITAs. The four main patterns are pattern I with high accessibility (FTITA $> \mu + \sigma$), pattern II with medium high accessibility ($\mu <$ FTITA $< \mu + \sigma$), pattern III with medium low accessibility ($\mu - \sigma <$ FTITA $< \mu$), and pattern IV with low accessibility (FTITA $< \mu - \sigma$). Moreover, the proportions of each pattern are illustrated in the figures. With respect to the overall trend of the spatial patterns of the FTITAs to overseas regions, we find that the spatial patterns of the FTITAs to Southeast Asia, Middle East, South America, Oceania, and Africa have the same distributions. The distributions of the patterns of FTITAs to North America and Europe are fundamentally the same, while the distributions of the patterns of FTITAs to Japan/South Korea are different from those of the above seven overseas regions. Regarding the patterns in the same overseas regions in the prepandemic and postpandemic years, most of the cities (e.g., Shanghai, Suzhou, Nantong, Wuxi, Jiaxing, and Ningbo) in pattern I are close to Shanghai Port and Ningbo Port; the cities in pattern II are mainly located in southern Zhejiang and the regions along the Yangtze River; the cities in pattern III are mainly located in northern Jiangsu; and the cities in pattern IV are located in northern Anhui.

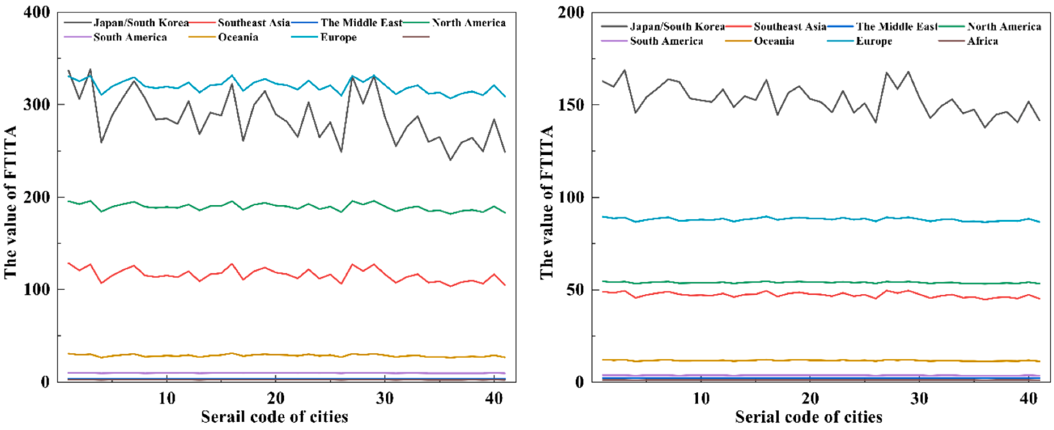
Furthermore, we analyze the distributions of the spatial patterns of the FTITAs to different overseas regions in the prepandemic and postpandemic years. In the prepandemic year, the cities in pattern I to Japan/South Korea are the cities containing hub gateway ports (e.g., Lianyungang, Shanghai, and Ningbo); the other seven overseas regions are mainly located in the regions close to Shanghai and Hangzhou (e.g., Shanghai, Suzhou, Nantong, Wuxi, Jiaxing, and Ningbo). The reasons why these cities have high accessibilities can be explained as follows: on the one hand, they are adjacent to the gateway ports and have a well-developed transportation network (the highway network density in Shanghai is 0.15 km/sq. km, which is three times the average value of the YRD region), indicating that export cargoes can be easily transported to the gateway ports; on the other hand, international ship calls are more frequent in the corresponding gateway ports, which also means that it is more convenient to transport export cargoes to overseas regions through

Table 4
Statistical attributes of the average FTITAs from the YRD to the eight overseas regions[7.]

Year	Statistical attributes	Japan/South Korea	Southeast Asia	Middle East	North America	South America	Oceania	Europe	Africa
Prepandemic	# M	286.23	115.75	3.40	189.33	9.77	28.61	319.82	2.45
	# D	26.32	6.99	0.06	3.96	0.22	1.30	6.93	0.08
Postpandemic	# M	152.87	47.24	2.33	53.91	3.70	11.75	88.07	1.21
	# D	7.93	1.31	0.04	0.40	0.04	0.27	0.85	0.02
	# P	46.59 %	59.19 %	31.47 %	71.52 %	62.16 %	58.95 %	72.46 %	50.40 %

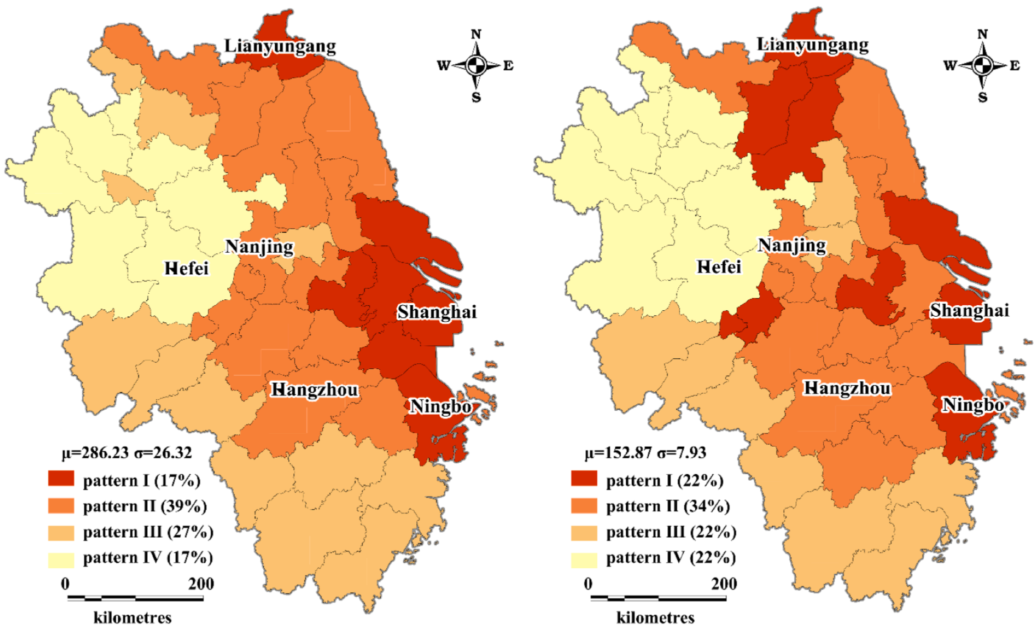
M: Mean (μ); # D: Standard deviation(σ); # P: Decreased proportion of the mean value of FTITAs in the postpandemic year compared to that of the prepandemic year.

[7] The maritime shipping cost accounts for a relatively small proportion in the generalized transportation cost from the cities in the Yangtze River region to Japan/South Korea, as the maritime shipping distance from the Yangtze River region to Japan/South Korea is much shorter than the distance to the other seven overseas regions. Thus, the inland transportation cost from the cities in Yangtze River region to the gateway ports, accounting for a relatively large proportion of the generalized transportation cost, directly determines the generalized transportation cost. The strong fluctuation of the inland transport costs from the cities in the Yangtze River region to gateway ports leads to the strong fluctuation of the FTITAs to Japan/South Korea.



(a) prepandemic (b) postpandemic

Fig. 5. Average FTITAs from the 41 cities in the YRD region to eight overseas regions.

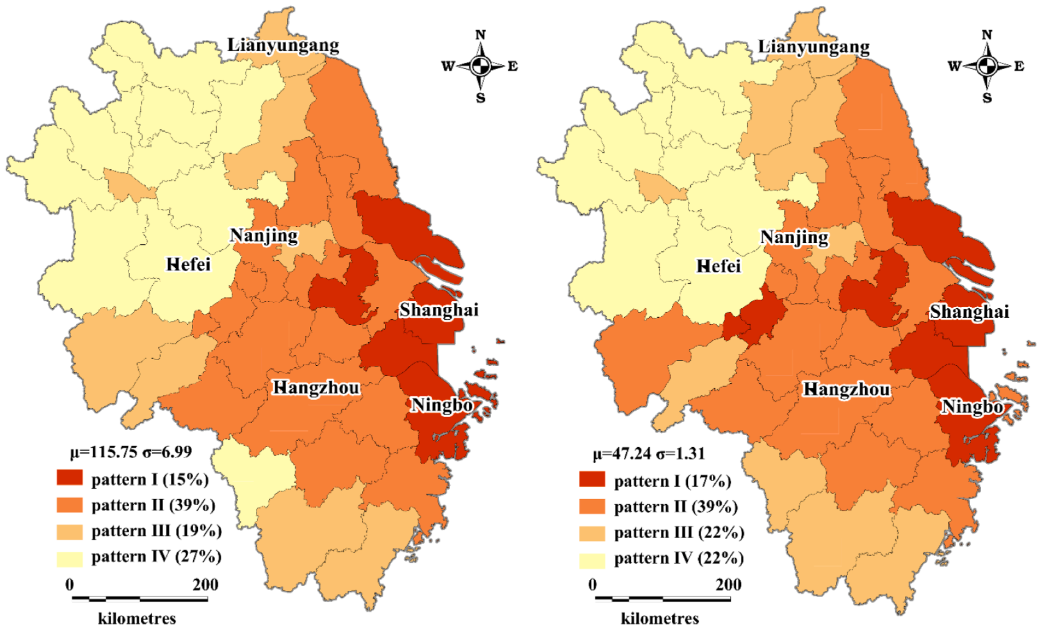


(a) prepandemic (b) postpandemic

Fig. 6. Spatial patterns of the FTITAs to Japan/South Korea.

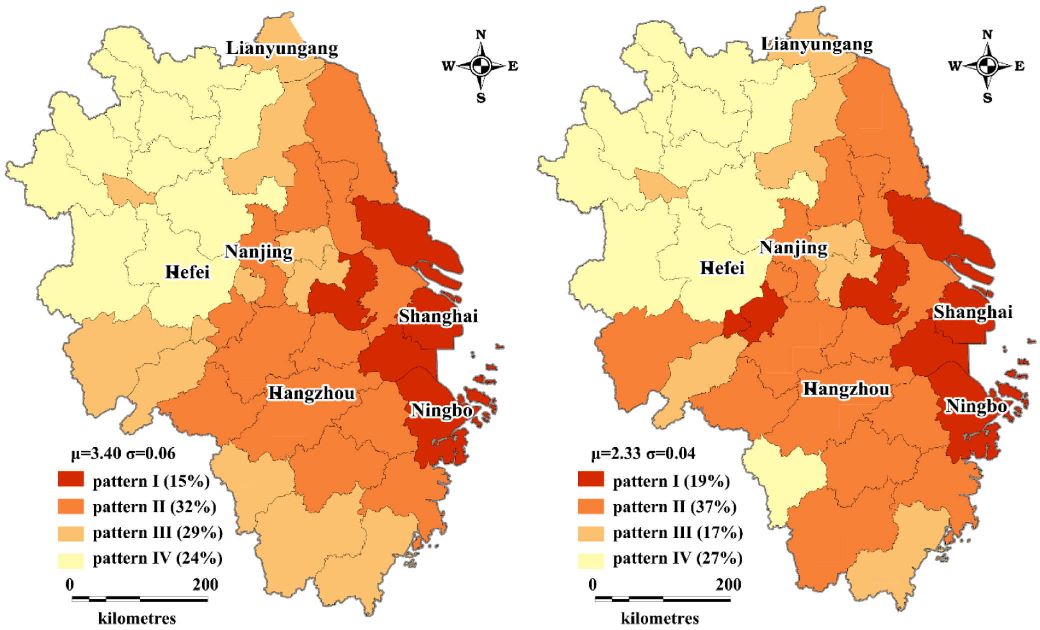
international shipping. With regard to the proportions of the cities in pattern I to different overseas regions, the cities in pattern I to Japan/South Korea, North America, and Europe have the largest proportions, accounting for 17 % of all cities. This may result from the frequent economic activities between the cities in the YRD region and the two overseas regions. In the postpandemic year, the cities in pattern I to Japan/South Korea are the cities close to Lianyungang port and the cities along the Yangtze River (e.g., Wuhu, Ma'anshan, and Tongling), while the cities to the other seven overseas regions are close to Shanghai and Hangzhou (e.g., Shanghai, Nantong, Wuxi, Jiaxing, and Ningbo) and the cities along the Yangtze River (e.g., Wuhu, Ma'anshan, and Tongling). The patterns change with the impact of COVID-19 because the pandemic has not caused heavy congestion in Lianyungang Port compared with Shanghai Port and Ningbo Port, and there are enough international shipping lines from Lianyungang Port to Japan/South Korea. Moreover, the proportion of cities in pattern I to Japan/South Korea is larger than the proportions of cities in pattern I to the other seven overseas regions, and the proportion increased to 22 % after the pandemic.

For the cities in pattern II, in the prepandemic year, the cities in pattern II with regard to Japan/South Korea are mainly located in northern Jiangsu (e.g., Xuzhou, Suqian, and Huaian), coastal regions (e.g., Yancheng, Taizhou, and Zhoushan) and regions along the Yangtze River (e.g., Wuhu, Ma'anshan, and Tongling); the cities in pattern II with regard to the other seven overseas regions are the



(a) prepandemic (b) postpandemic

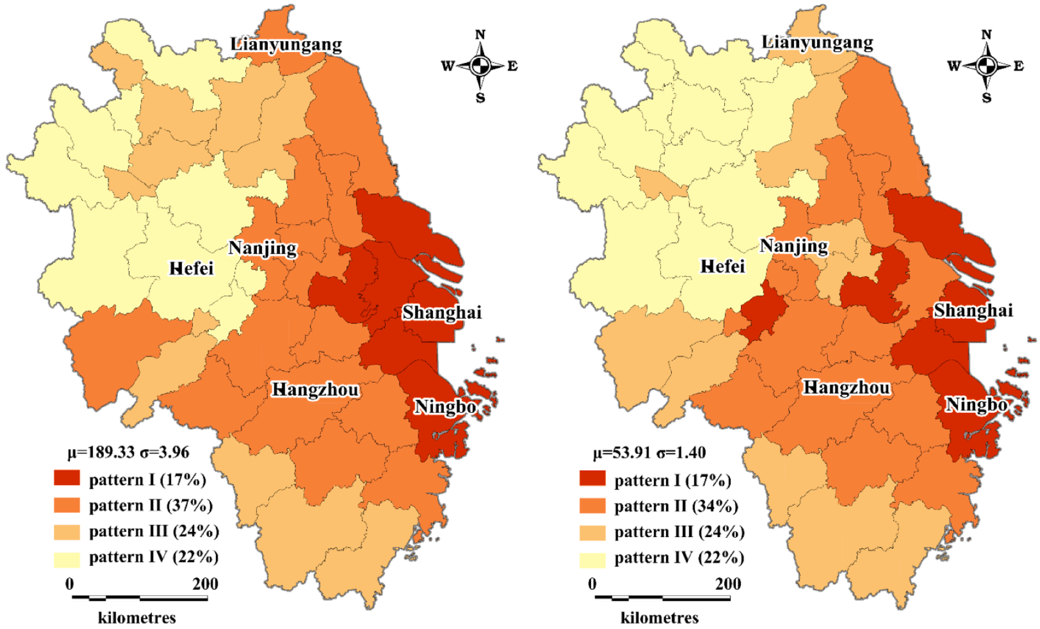
Fig. 7. Spatial patterns of the FTITAs to Southeast Asia.



(a) prepandemic (b) postpandemic

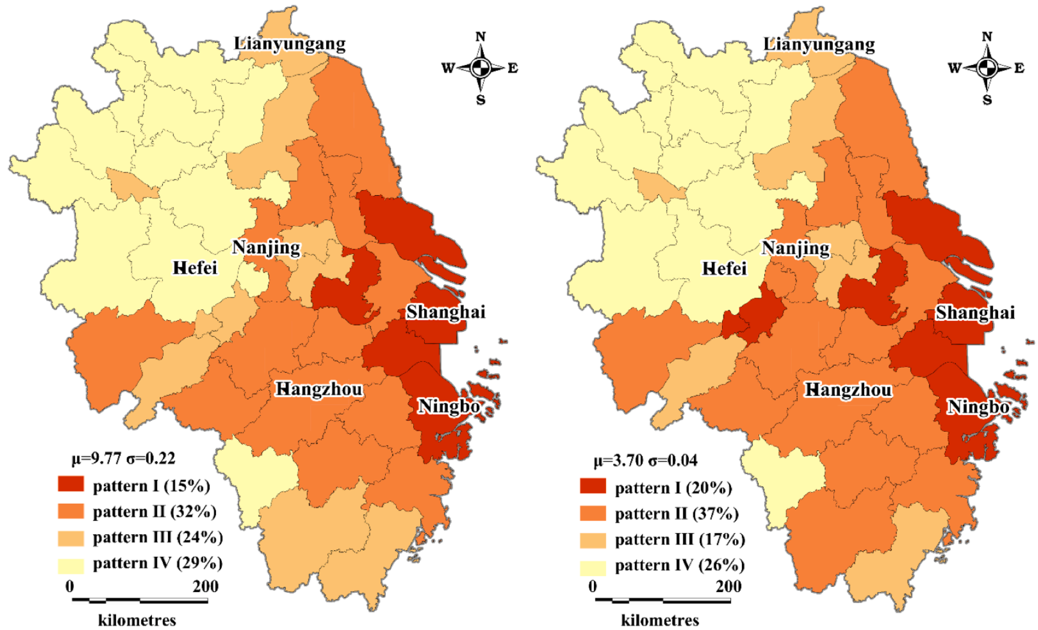
Fig. 8. Spatial patterns of the FTITAs to Middle East.

cities in northern Zhejiang (e.g., Hangzhou, Huzhou, and Shaoxing), coastal cities and cities along the Yangtze River. These patterns occur because the export cargoes in northern Jiangsu can be easily transported to Japan/South Korea via Lianyungang port, as Lianyungang port has 23 main shipping lines to Japan/South Korea. For the cities in pattern II with regard to the other overseas regions (e.g., South America, Oceania, and Africa), since Lianyungang Port has fewer shipping lines than Shanghai Port and Ningbo Port, the cities in pattern II to these overseas regions change from northern Jiangsu to northern Zhejiang. The cities along the Yangtze River



(a) prepandemic (b) postpandemic

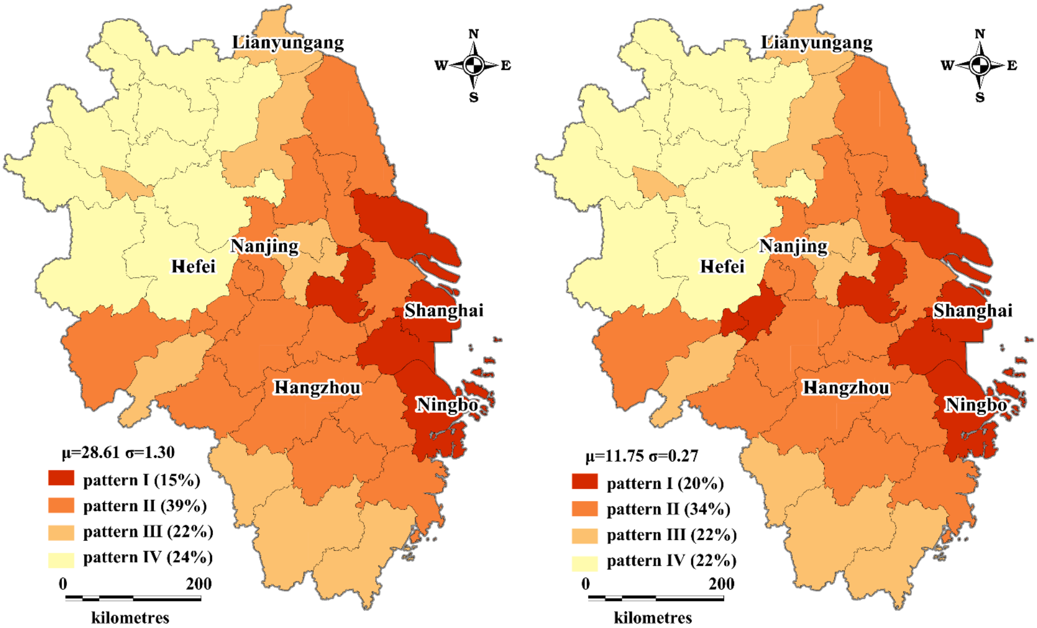
Fig. 9. Spatial patterns of the FTITAs to North America.



(a) prepandemic (b) postpandemic

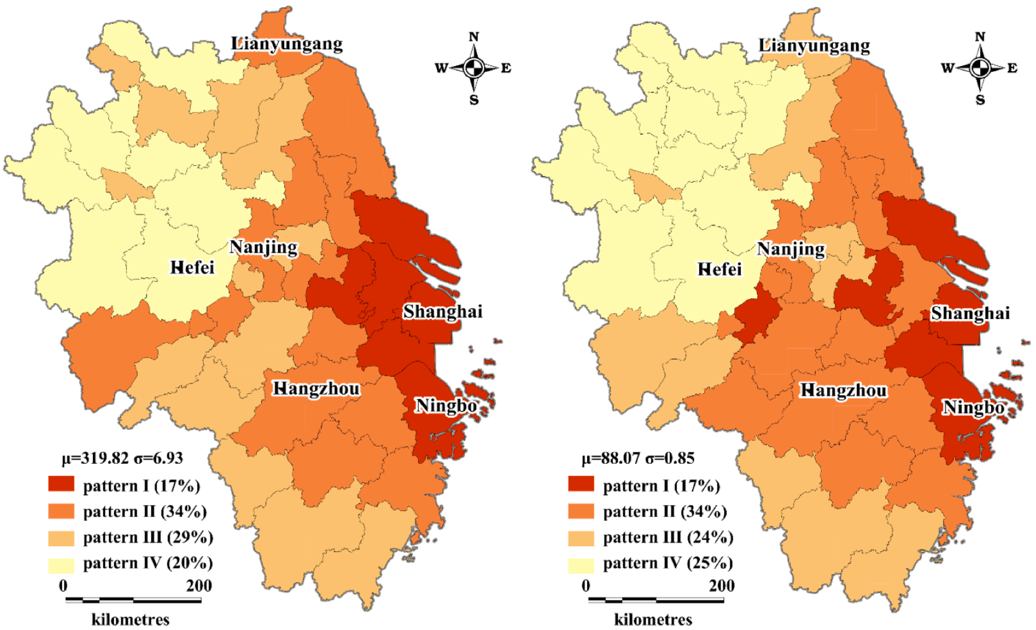
Fig. 10. Spatial patterns of the FTITAs to South America.

present pattern II because the Yangtze River represents a remedy to the capacity shortage in the heavily congested road transport and rail transport, and it reduces the generalized transportation cost from the cities to the overseas regions. Moreover, the proportions of the cities in pattern II with regard to Japan/South Korea, Southeast Asia, and Oceania are the largest, accounting for 39 % of the YRD region. In the postpandemic year, since the decreases in the shipping lines from Shanghai Port and Ningbo Port to Japan/South Korea are larger than those of Lianyungang Port and more shippers choose Lianyungang Port as the gateway port, the patterns of the FTITAs



(a) prepandemic (b) postpandemic

Fig. 11. Spatial patterns of the FTITAs to Oceania.



(a) prepandemic (b) postpandemic

Fig. 12. Spatial patterns of the FTITAs to Europe.

of northern Jiangsu (e.g., Suqian and Huaian) change to pattern I. However, with the decrease in the number of shipping lines from Lianyungang Port to Middle East, North America, and Europe, the pattern of the FTITA of Lianyungang changes to pattern III.

Finally, for the cities in pattern III and pattern IV, the total proportions of cities in pattern III and pattern IV to all eight overseas regions account for nearly 50 % of the YRD region. In the prepandemic year, the cities in pattern III to North America and Europe are located in southern Zhejiang (e.g., Quzhou, Lishui, and Wenzhou), northeast Anhui (e.g., Suzhou and Bengbu), and regions along the

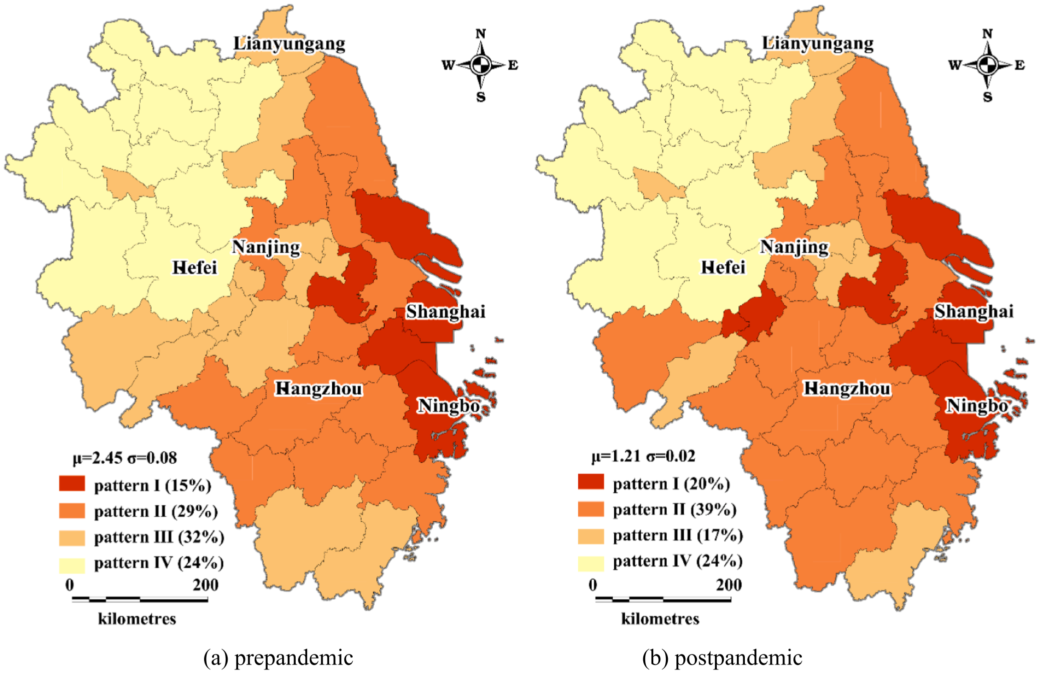


Fig. 13. Spatial patterns of the FTITAs to Africa.

Yangtze River in Anhui Province (e.g., Anqing and Chizhou); the other six overseas regions are located in southern Zhejiang (e.g., Quzhou, Lishui, and Wenzhou), regions along the Yangtze River in Anhui Province (e.g., Anqing and Chizhou), and Huainan. The cities presenting pattern IV with regard to all eight overseas regions are located in northern Anhui (e.g., Hefei, Huaibei, and Fuyang). The reasons why these cities present pattern III and pattern IV are as follows: on the one hand, they do not have a well-developed domestic transportation network to gateway ports; on the other hand, their economies mainly focus on the domestic market, and their export-oriented economies are not as developed as those of coastal cities.

4.3.3. Ranking of average FTITA values for the top ten cities in the YRD region

Table 5 shows the ranking of the average FTITAs for the top ten cities in the YRD region. It is found that in both the prepandemic year and the postpandemic year, the top ten cities ranked in terms of accessibility are almost all coastal cities, which is in accordance with the city rankings by economic indicators (e.g., GDP, total export volumes). However, for a specific city, the rankings of FTITA may

Table 5
Ranking of average FTITAs for top the ten cities in the YRD region.

Year	Rank	Japan/South Korea	Southeast Asia	Middle East	North America	South America	Oceania	Europe	Africa
Prepandemic	1	Shanghai	Ningbo	Shanghai	Shanghai	Ningbo	Ningbo	Shanghai	Ningbo
	2	Ningbo	Shanghai	Ningbo	Ningbo	Shanghai	Shanghai	Ningbo	Shanghai
	3	Wuxi	Wuxi	Wuxi	Wuxi	Nantong	Nantong	Wuxi	Nantong
	4	Lianyungang	Nantong	Nantong	Nantong	Wuxi	Wuxi	Nantong	Wuxi
	5	Nantong	Jiaxing	Jiaxing	Jiaxing	Jiaxing	Jiaxing	Jiaxing	Jiaxing
	6	Jiaxing	Zhoushan	Suzhou	Suzhou	Zhoushan	Zhoushan	Suzhou	Zhoushan
	7	Suzhou	Suzhou	Zhoushan	Zhoushan	Suzhou	Suzhou	Zhoushan	Suzhou
	8	Taizhou	Taizhou	Taizhou	Taizhou	Shaoxing	Shaoxing	Taizhou	Shaoxing
	9	Zhoushan	Huzhou	Huzhou	Huzhou	Huzhou	Huzhou	Huzhou	Huzhou
	10	Huzhou	Nanjing	Nanjing	Nanjing	Hangzhou	Hangzhou	Nanjing	Hangzhou
Postpandemic	1	Ningbo	Ningbo	Ningbo	Ningbo	Ningbo	Ningbo	Ningbo	Ningbo
	2	Shanghai	Shanghai	Shanghai	Shanghai	Shanghai	Shanghai	Shanghai	Shanghai
	3	Lianyungang	Nantong	Nantong	Nantong	Nantong	Nantong	Nantong	Nantong
	4	Nantong	Wuxi	Wuxi	Wuxi	Wuxi	Wuxi	Wuxi	Wuxi
	5	Wuxi	Jiaxing	Jiaxing	Jiaxing	Jiaxing	Jiaxing	Jiaxing	Jiaxing
	6	Suqian	Wuhu	Wuhu	Wuhu	Wuhu	Wuhu	Wuhu	Wuhu
	7	Huai'an	Tongling	Tongling	Tongling	Tongling	Tongling	Tongling	Tongling
	8	Wuhu	Zhoushan	Zhoushan	Zhoushan	Zhoushan	Zhoushan	Zhoushan	Zhoushan
	9	Tongling	Suzhou	Suzhou	Suzhou	Suzhou	Suzhou	Suzhou	Suzhou
	10	Yancheng	Shaoxing	Shaoxing	Shaoxing	Shaoxing	Shaoxing	Shaoxing	Shaoxing

differ. Although Shanghai and Ningbo are always the top two cities in terms of FTITA rankings to all eight overseas regions, the rankings differ in the prepandemic year and the postpandemic year. In the prepandemic year, Shanghai ranks first in terms of the FTITA to Japan/South Korea, Middle East, North America, Europe, and Ningbo ranks first in terms of the FTITA to the other four overseas regions. In the postpandemic year, Ningbo ranks first in terms of the FTITA to all eight overseas regions. These ranking changes may be because Shanghai Port suffered heavy congestion in the postpandemic year, resulting in a large increase in the generalized transportation cost. Moreover, Lianyungang ranks among the top ten only for the FTITA to Japan/South Korea, and it ranks outside the top ten for the FTITAs to the other seven overseas regions. These different rankings may be because there are enough shipping lines from Lianyungang to Japan/South Korea compared to the shipping lines to the other seven overseas regions, and these shorten the waiting time at the gateway port and further reduce the generalized transportation cost. It is worth noting that no cities in Anhui Province rank in the top ten in the prepandemic year, indicating that the development of the transport industry in Anhui Province is not as good as that in Jiangsu Province, Zhejiang Province, and Shanghai. However, this situation has changed in the postpandemic year; two cities (including Tongling and Wuhu) along the Yangtze River in Anhui Province rank in the top ten for the FTITAs to the eight overseas regions. This change occurs because inland river transport suffers less impact than road transport and rail transport due to the COVID-19 pandemic in the YRD region.

4.3.4. Analysis of FTITAs for different cargoes

Table 6 presents the FTITA of different cargo types from the YRD region to different overseas regions. Overall, the FTITAs of non edible raw materials, fossil fuels, lubricants and related raw materials, chemicals and related products, and machinery and transport equipment are much higher than those of foodstuffs and event cargoes, beverages and tobacco, animal and vegetable fats and waxes, light textile products, rubber products mining and metallurgical products, and miscellaneous products. Regarding the FTITAs from the YRD to a certain overseas region for different cargoes, the FTITAs to Japan/South Korea, North America, and Europe always have the largest values, and these trends are mainly because the US, Japan, South Korea, and EU are the top four trade partners for mainland China, which means that these four regions have a high trade attractiveness for Chinese products. Moreover, the transport impedances from the YRD region to these three countries are relatively low, and both of these factors result in higher FTITAs to Japan/South Korea and North America. Comparing the impact of COVID-19 pandemic on the FTITA for different cargoes, we conclude that COVID-19 has the least impact on foodstuffs and event cargoes because the demand for foodstuffs and event cargoes for all eight overseas regions is very low. In addition, the impacts of COVID-19 pandemic on non edible raw materials, fossil fuels, lubricants and related raw materials, chemicals and related products, and machinery and transport equipment are smaller than those of the other four cargo types except foodstuffs and event cargoes. These different impacts exist because the generalized transportation costs for transporting non edible raw materials, fossil fuels, lubricants and related raw materials, chemicals and related products, and machinery and transport equipment are not sensitive to COVID-19 prevention measures.

Table 6
FTITAs to the eight overseas regions for different cargoes.

Year	Cargo type	Japan/ South Korea	Southeast Asia	Middle East	North America	South America	Oceania	Europe	Africa
Prepandemic	Foodstuffs and event cargoes	0.007	0.003	0.001	0.010	0.014	0.016	0.012	0.004
	Beverages and tobacco	1.233	1.722	0.007	0.863	0.153	0.377	1.583	0.019
	Non edible raw materials	16.731	18.781	0.055	20.644	0.913	2.414	17.144	0.132
	Fossil fuels, lubricants and related raw materials	36.754	16.664	0.266	18.879	5.547	23.605	29.868	2.149
	Animal and vegetable fats and waxes	0.388	0.124	0.003	19.078	2.776	0.169	0.529	0.006
	Chemicals and related products	47.537	17.753	2.949	26.522	0.086	0.574	27.469	0.034
	Light textile products, rubber products mining and metallurgical products	7.708	0.374	0.019	4.176	0.165	0.871	2.806	0.053
	Machinery and transport equipment	168.015	59.833	0.094	96.383	0.116	0.542	235.746	0.049
	Miscellaneous products	7.863	0.492	0.004	2.777	0.003	0.043	4.663	0.001
Postpandemic	Foodstuffs and event cargoes	0.003	0.002	0.000	0.009	0.012	0.009	0.007	0.003
	Beverages and tobacco	0.968	1.144	0.002	0.246	0.105	0.155	0.537	0.009
	Non edible raw materials	12.976	5.168	0.090	6.014	0.318	0.531	5.517	0.108
	Fossil fuels, lubricants and related raw materials	27.138	7.006	0.314	7.784	1.979	10.208	6.583	0.996
	Animal and vegetable fats and waxes	0.277	0.080	0.002	8.056	1.126	0.121	0.206	0.005
	Chemicals and related products	26.914	9.132	1.671	8.421	0.037	0.233	10.691	0.037
	Light textile products, rubber products mining and metallurgical products	4.771	0.244	0.026	1.852	0.086	0.304	1.147	0.038
	Machinery and transport equipment	74.511	24.262	0.204	21.014	0.032	0.159	62.039	0.017
	Miscellaneous products	5.313	0.198	0.019	0.517	0.001	0.026	1.340	0.001

5. Conclusions and policy implications

In this paper, we have studied the impacts of COVID-19 pandemic on foreign trade transport by introducing an index of foreign trade intermodal transport accessibility. We provide the definition and measurement method of the FTITA by incorporating the convenience of the transportation of domestic cargoes to overseas regions and the trade attractiveness of the overseas regions. By using the Yangtze River Delta region in mainland China and eight overseas regions to conduct empirical analysis in the prepandemic and postpandemic years, we analyzed the overall trends of the FTITAs from the YRD region to eight overseas regions, spatial patterns of the distributions of the FTITAs in the YRD regions, the rankings of average FTITA values for the top ten cities in the YRD region, and the FTITAs for different cargoes. The empirical results indicate that the FTITAs of the YRD region in the prepandemic year are significantly higher than those in the postpandemic year. Moreover, in both the prepandemic and postpandemic years, the FTITAs to North America, Japan/South Korea, Europe, and Southeast Asia are significantly higher than those to Oceania, Middle East, South America, and Africa. Through analysis of the spatial patterns of the FTITAs across cities in the YRD region, we found that the cities with high FTITA are mainly close to Shanghai Port and Ningbo Port; the cities with middle-high FTITA are mainly located in southern Zhejiang and the regions along the Yangtze River; the cities with middle-low FTITA are mainly located in northern Jiangsu; and the cities with low FTITA are located in northern Anhui. Furthermore, comparing the impact of COVID-19 pandemic on the FTITA for different cargoes, we find that the COVID-19 has the least impact on foodstuffs and event cargoes, and the impacts of COVID-19 pandemic on non edible raw materials, fossil fuels, lubricants and related raw materials, chemicals and related products, and machinery and transport equipment are smaller than those of the other four cargo types except foodstuffs and event cargoes.

In addition, we can propose some managerial and policy implications based on the FTITA index and the empirical results. First, in the postpandemic era, to block large-scale population movements and mitigate the impacts of COVID-19, the government's blockade of road transport has become a common emergency measure. Since road transport accounts for the largest proportion of freight transport volumes from domestic cities to gateway ports, prevention measures will greatly decrease the freight transport convenience from domestic cities to gateway ports. However, the above empirical results report that the COVID-19 pandemic has not led to great impacts on rail transport and inland river transport compared to road transport as these two transport modes are characterized by fixed schedules and paths from origins to destinations. With these advantages in mind, we recommend that decision maker formulate useful policies to stimulate the development of rail-sea and river-sea combined transport in port hinterland access systems in the post-pandemic era.

Second, as shown in the empirical study, the heavy congestion in Shanghai Port and Ningbo Port in the postpandemic year has substantially reduced the accessibilities from the cities in the YRD region to the overseas regions. To alleviate the impacts of port congestion on foreign trade transport, port governors should enhance port resilience in the postpandemic years, adopting the following possible measures: better coordination among port stakeholders, adjustment of the utilization policies of port equipment and related resources for improving port system performance, and capacity sharing and information sharing among ports in the regional port cluster. Last, as mentioned earlier, the shortage of shipping capacity and high freight rate in the postpandemic years have greatly increased the maritime shipping cost for shippers, and thus, an increase in the empty container repositioning efficiency, reoptimization of shipping line schedules and fleet deployments, and conversion of bulk ships to container ships provide useful guidance for mapping the future of the shipping industry.

There are several directions for future research. First, we set parametersε_1,ε_2,ε_3, and ε_4 in Eq. (14) based on a previous study. Including a calibration method of the parameters and a sensitivity analysis of the impacts of these parameters on the FTITA could be considered in the future. Second, extending maritime shipping to broad transport modes (including international railway transport and land bridge transport) in international freight transport could further reveal the impacts of COVID-19 on the other transport modes. Finally, the trade tariff cost could be considered to enrich the measurement of the generalized transportation cost for transporting cargoes to overseas regions.

CRediT authorship contribution statement

Weilu Hou: Methodology, Formal analysis, Writing – original draft. **Qin Shi:** Conceptualization, Formal analysis, Writing – review & editing, Project administration. **Liquan Guo:** Conceptualization, Formal analysis, Writing – original draft, Writing – review & editing, Validation, Project administration, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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