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Trade openness, market integration and economic growth: Evidence from China

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ABSTRACT

Despite the resilience of China's economic growth, the regional disparity between the North and South has become increasingly apparent. The "new economic geography" theory attributes this disparity to trade openness and domestic transportation costs. Based on the aforementioned background, this paper merges the indicators of China's export trade openness, domestic transportation costs, and GDP at the prefecture level. By employing panel data econometric analysis on the merged dataset, the study investigates the impact of export trade openness and domestic transportation costs on the economic disparity between northern and southern regions. The empirical results indicate that the interaction term coefficient is significantly negative, suggesting that higher domestic transportation costs in China diminish the positive effect of export trade openness on regional economic growth. Mechanism analysis indicates that the regional economic growth disparities between the northern and southern regions, driven by the interaction effects of export trade openness and domestic transportation costs, are primarily attributed to "economies of scale" and "industrial linkage effects." In the extension examination section, this paper empirically analyzes the impact of the interaction between export trade openness and domestic transportation costs on the north-south economic gap from the perspectives of domestic market integration and industry heterogeneity. This paper provides a novel perspective, based on trade openness and domestic transportation costs, to explain the phenomenon of the "east-west" economic gap gradually narrowing and the "north-south" disparity increasingly emerging in China's economic development over the past forty years of reform and opening up.

1. Introduction

Over the past forty years of reform and opening-up, China has maintained an average annual economic growth rate of approximately 9.5 %. Its share of global GDP has increased from 1.8 % in 1978 to 16 % in 2019, with its total GDP rising to the second position worldwide. In recent years, alongside this economic growth, significant changes have occurred in China's regional economic "map." The "east-west gap" has gradually narrowed, while the "north-south gap" has become increasingly evident. The focus of China's foreign trade has shifted southward, with the central and southwestern regions transitioning from "inland hinterlands" to "frontiers of openness." In 2020, southern provinces accounted for 73 % of the country's foreign trade, while northern provinces contributed only 27 %. According to the "Top 100 Foreign Trade Cities in China 2019" list released in July 2020, southern cities have an absolute advantage in both the number and competitiveness of listed cities, with a southern-to-northern city ratio of approximately 7:3, reflecting a pronounced "Matthew effect." The central Yangtze River region and the southwestern region, leveraging the Yangtze River Golden Waterway and the new Western Land-Sea Corridor, have accelerated their pace of opening-up. In 2020, the foreign trade share of the four central Yangtze River provinces (Anhui, Jiangxi, Hubei, Hunan) and the four southwestern provinces and municipalities increased from 7.2 % in 2013 to 11.3 %. In summary, the imbalance in the development of foreign trade between the northern and southern regions has become a significant reflection of economic development disparities.

Currently, maritime international trade accounts for over 80 % of all international trade transportation volumes. Compared to land and air transportation, maritime transport offers greater capacity and lower costs, with China's foreign trade predominantly conducted via maritime routes. The Yangtze River, as a representative example, serves as a crucial link between inland regions and maritime transport. In contrast to the northern regions, the southern regions of China have a more developed inland waterway transportation system. Notably, the Yangtze

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and Pearl Rivers in the south feature significant river flow, high velocity, and more than 90 % of river sections remain ice-free, providing substantial navigational capacity and extended navigation times and routes. This advanced waterway system facilitates both domestic and international river-sea transport, thereby reducing domestic transportation costs.

Some papers have identified factor-driven transformation and industrial structural changes as significant reasons for the "north-south" economic divergence in China (Xu & Deng, 2022; Yang et al., 2022). However, the role of "new economic geography" should not be overlooked. Recent high-quality infrastructure development, particularly the acceleration of improvements in Yangtze River inland shipping and the Western Land-Sea New Corridor, has effectively enhanced industrial connections between coastal regions and the "inland hinterland." Consequently, the central and southwestern regions have shifted from "inland hinterland" to "open frontiers," while the "sea-river connectivity" has established new competitive advantages in southern international trade, contributing to the incremental growth of the southern economy. In contrast, northern regions, lacking direct inland shipping connections to the coast, have faced increased trade costs, creating regional asymmetries in trade openness. Given that the north-south economic disparity is a relatively recent phenomenon with limited research, there are fewer studies examining the combined effects of trade openness and transportation costs on this disparity. Against this backdrop, this paper primarily analyzes the interactive effects of export trade openness and domestic transportation costs on the north-south economic gap, exploring the impact mechanisms from the perspectives of industrial linkage effects and economies of scale, and further expanding the analysis from viewpoints such as domestic market segmentation and industrial heterogeneity to identify the optimal path for addressing the north-south economic disparity in China. Compared to previous research, this paper presents the following two innovations.

On one hand, this paper offers an innovative research perspective. China, with its vast territory, exhibits significant natural and geographic differences, and regional comparative advantages depend on two conditions: natural geography and economic geography (Coşar & Fajgelbaum, 2016; Davis & Weinstein, 2003; Gunton, 2003). Maritime transport is a primary mode of international trade, and as China integrates into the global economy, southern cities, being closer to major international shipping lanes, particularly the southeastern coastal areas, have a comparative advantage in participating in international production divisions. Current literature on the north-south economic disparity is scarce, with few studies examining the relationship between trade openness, domestic transportation costs, and this disparity. Existing studies primarily explain the gap through industrial structural differences, which, to a greater extent, are a manifestation of the north-south development disparity rather than its fundamental cause. This paper explores the impact of trade openness and domestic transportation costs on the north-south economic growth gap based on the regional differences in natural and economic geography, thereby expanding and supplementing existing research and providing a novel perspective for further study.

On the other hand, this paper introduces methodological innovations. The construction of indicators for the economic disparity between northern and southern prefecture-level cities in China presents a challenge in this paper. Previous literature on regional economic disparities predominantly employs comprehensive indices such as the Gini coefficient to reflect national economic development differences (Brueckner et al., 2015; Druckman & Jackson, 2008). However, these indices are less effective for measuring the economic disparity between northern and southern prefecture-level cities. This paper innovatively applies the concept of propensity score matching, using cities along the Yangtze and Pearl Rivers as matched samples for northern cities. It selects southern sample cities that are most similar to each northern city in terms of population size, industrial structure, and other factors influencing economic growth. By employing a difference method to construct an indicator of GDP growth disparity between northern and southern cities, this serves as the explained variable for the economic disparity between prefecture-level cities and as a robustness check for the explained variable in this paper. This method aligns closely with the study's perspective based on domestic transportation cost disparities, aiming to "strip away" other factors affecting the north-south economic disparity. It provides a feasible pathway for exploring the interaction effects of trade openness and domestic transportation costs on the north-south economic disparity from a "new geographical" perspective.

The remainder of this paper is organized as follows. Section 2 presents a literature review; Section 3 involves an analysis of typical facts; and Section 4 introduces the data and empirical models; Section 5 conducts baseline regression analysis and robustness checks; Section 6 focuses on mechanism analysis and extended analysis; Section 7 concludes.

1.1. Literature review

Currently, literature exploring the factors influencing the economic disparity between northern and southern China primarily focuses on three perspectives: the "New Geographic View," the "New Industrial View," and the "New Factor View." Specifically, the economic gap between the north and south is a result of the transition in comparative advantages at different development stages. The "New Geographic View," emerging from modern transportation evolution (Chen et al., 2018), the "New Industrial View," related to the shift from traditional to high-tech industries (Zhou et al., 2021), and the "New Factor View," concerning the transition from labor to innovation factors, interact to exacerbate the north-south economic disparity (Li et al., 2020).

There is limited literature directly examining the impact of trade openness on the economic disparity between northern and southern China, with existing studies primarily focusing on the effect of trade openness on regional economic growth. Krugman and Elizondo (1996), based on the assumptions of increasing returns to scale and imperfect competition, developed a new economic geography model grounded in the Dixit-Stiglitz monopolistic competition framework. They emphasized that under closed conditions, industrial agglomeration generates forward and backward linkages, creating centripetal forces that attract further agglomeration of industries and factors, which leads to the emergence of core-periphery structures in many developing countries and exacerbates regional income disparities. Jian et al. (1996) and Kanbur and Zhang (2005) argue that since the onset of economic reforms, coastal regions have leveraged their geographical and resource advantages to achieve rapid economic growth, thereby widening the development gap with inland areas. Factors such as human capital and labor have also contributed to the economic disparity between eastern and western regions. The enhancement of trade openness has further promoted the development of human capital and innovation capabilities in coastal areas, leading to accelerated economic growth (Amirkhalkhali & Dar, 2019; Guo & Sim, 2014). Lim and McNelis (2016) found that trade openness has a threshold effect on regional income growth, with economic capital density serving as a critical threshold, trade openness can effectively promote regional economic growth.

Domestic transportation costs are a crucial component of regional trade costs. In China, exports are primarily conducted via maritime transport. For inland regions, exporting goods to international markets requires transporting them to coastal ports, with the associated costs known as domestic transportation costs (Behrens, 2011). Domestic transportation costs mainly encompass rail transport costs, inland waterway transport costs, and road transport costs. Enhancing transportation infrastructure is a vital means to promote regional economic integration (Faber, 2014). Reductions in domestic transportation costs drive manufacturing enterprises to relocate to surrounding areas of concentration, and some industries in coastal regions are also shifting towards central and western cities (Desmet & Henderson, 2015). Fan (2019) finds that, compared to inland areas, a decrease in domestic transportation costs can foster leapfrog development in coastal regions, leading to the concentration of economic activities in early-developing cities and the eventual formation of megacities in coastal areas. With the high-quality development of China's infrastructure, particularly the Yangtze River inland waterway and the new western land-sea corridor, there has been a significant enhancement in industrial linkages between China's southeastern coastal regions and the "inland economic hinterland." The central and southwestern southern regions have transitioned from being "inland hinterlands" to "open frontiers," contributing to new economic growth in the south (Baum-Snow et al., 2017). Conversely, the northern economic landscape, lacking an effective inland waterway transport system directly connecting to the coast, may have inadvertently increased trade costs in the northern regions, leading to regional asymmetry in China's north-south openness (Banerjee et al., 2020).

The aforementioned literature provides a solid theoretical foundation for this paper, however, existing research still requires further advancement in terms of research perspectives and theoretical mechanisms. This paper focuses on the "New Economic Geography" perspective, aiming to explain the economic trend of "Southern Rise and Northern Decline" that emerged post-China's accession to the WTO through the lens of trade openness and domestic transportation costs. Unlike many studies that may overlook the regional disparities in domestic transportation costs reflected by inland waterway transport, this paper will investigate how these regional differences in transportation costs lead to "asymmetries" in trade openness, subsequently causing disparities in economic growth across regions.

1.2. Typical facts and mechanism analysis

1.2.1. Typical facts of North-South economic disparity

Overall, since China's reform and opening-up, the economic gap between the south and north has shown an overall trend of widening. From 1978 to 1993, the southern economy's share of the national economy exhibited a slow upward trend. From 1993 to 2012, the economic share between the south and north remained relatively stable. After 2012, the southern economy's share rose rapidly, further enlarging the economic gap between the south and the north. In comparison, the economic gap between the east and west first continuously expanded, then gradually narrowed. From 1978 to 1983, the total economic output of the east and west was almost equal. After 1983, the share of the eastern economy consistently increased, rising from 50 % in 1983 to nearly 60 % by 2006. With the further implementation of strategies such as the Western Development and the Rise of Central China after 2006, the share of the eastern economy began to slowly decline, and as of now, it has decreased to 54 %, while the western economy's share has risen to 46 %.

Since the implementation of the reform and opening-up policies, China's regional economic development has undergone significant changes. Many economically strong cities that thrived during the planned economy period, such as Changchun, Shenyang, Harbin, and Dalian, have experienced a slowdown in their growth rates. In contrast, southern cities have witnessed a marked increase in economic growth, with Shenzhen standing out as a global industrialization miracle, maintaining a leading position in terms of economic scale in recent years. A comparative analysis of the top ten cities in the northern and southern regions reveals that the economic scale gap is only small between Shanghai and Beijing, while cities of similar rank in the northern and southern regions exhibit nearly a twofold difference in economic size. Overall, the southern region is experiencing robust economic growth, whereas the northern region, with the exception of Beijing, tends to show signs of sluggish economic development, reinforcing the increasingly prominent "strong south, weak north" regional economic pattern. At the city level, southern cities exhibit faster economic growth and more balanced development. As shown in Fig. 2, darker colors indicate higher total economic output in the cities. Overall, from 2000 to 2019, the color distribution of China's urban GDP deepens, reflecting rapid economic growth. Furthermore, the 2000 and 2007 urban GDP distribution maps reveal that the majority of the darker regions are located along the eastern coastal areas, with only Chongqing and Chengdu in the central and western regions showing darker colors. In the 2013 and 2019 urban GDP distribution maps, it is evident that the central and western regions have experienced noticeable economic growth, as indicated by the deeper colors compared to previous years. Finally, the 2019 urban GDP distribution map shows that the overall color in the southern region is significantly darker than that in the northern region, with the GDP in the Beijing-Tianjin-Hebei urban agglomeration and the Shandong Peninsula urban agglomeration being relatively higher in the north. (See Fig. 1.)

1.3. Mechanism analysis

Increasing returns to scale are a crucial driving force for regional economic growth and diffusion, while market scope serves as an essential spatial carrier for the expansion of economic scale (Koster & Thisse, 2024). According to the market scope hypothesis, the larger the market scope, the higher the efficiency of resource allocation within the market, the more refined the product division of labor, and the more significant the economies of scale, leading to higher regional production efficiency. Based on new economic geography theory, transportation costs are a key determinant of industrial geographical distribution; in other words, transportation costs have a decisive impact on regional market boundaries. The opening of export trade has facilitated the division of labor in Chinese society, enhancing the economies of scale. As economies of scale become more pronounced, the competitiveness of Chinese products in the international market strengthens. Domestic transportation costs exhibit significant regional heterogeneity across China's northern and southern regions. The abundant inland waterway system in the southern region significantly reduces transportation costs between southern areas, thereby expanding the space for the growth of economies of scale in the south. In contrast, the northern region suffers from a relatively scarce inland waterway system, and high transportation costs limit the range of industrial distribution. Therefore, compared to the northern region, the interaction between trade openness and domestic transportation costs has promoted the economies of scale in the southern region, thus driving economic growth in the south.

Marshall's externality theory posits that firms concentrate in the same region based on externalities, with industrial linkages serving as a critical source for such geographical concentration. Venables (1996) asserts that industrial linkages are a significant factor influencing the geographic proximity of firms, and that transportation costs have a crucial impact on the geographic proximity of industries with linkages. Krugman and Elizondo (1996), under the assumption of increasing returns to scale and imperfect competition in market structure, developed a new economic geography model based on the Dixit-Stiglitz monopolistic competition model. This model emphasizes the economic forward and backward linkage effects generated by industrial agglomeration under closed conditions, which create centripetal forces that attract further concentration of industries and factors. These forces lead to the emergence of a core-periphery structure in many developing countries, exacerbating regional income disparities. Building upon industrial linkage theory and core-periphery theory, the rapid growth of export trade inevitably stimulates the growth of upstream and downstream industries through forward and backward industrial linkages. Compared to the northern region, the abundant inland waterway system in the southern region results in significantly lower transportation costs, making the geographic scope of trade openness and its induced industrial linkages more extensive in the south. Additionally, the efficiency of resource allocation between industries is higher. Therefore, in contrast to the northern region, the impact of export trade openness and domestic transportation costs through the "industrial linkage effect" on economic growth is more pronounced in the southern region. This is a key reason for the rapid overall economic growth in regions with lower domestic

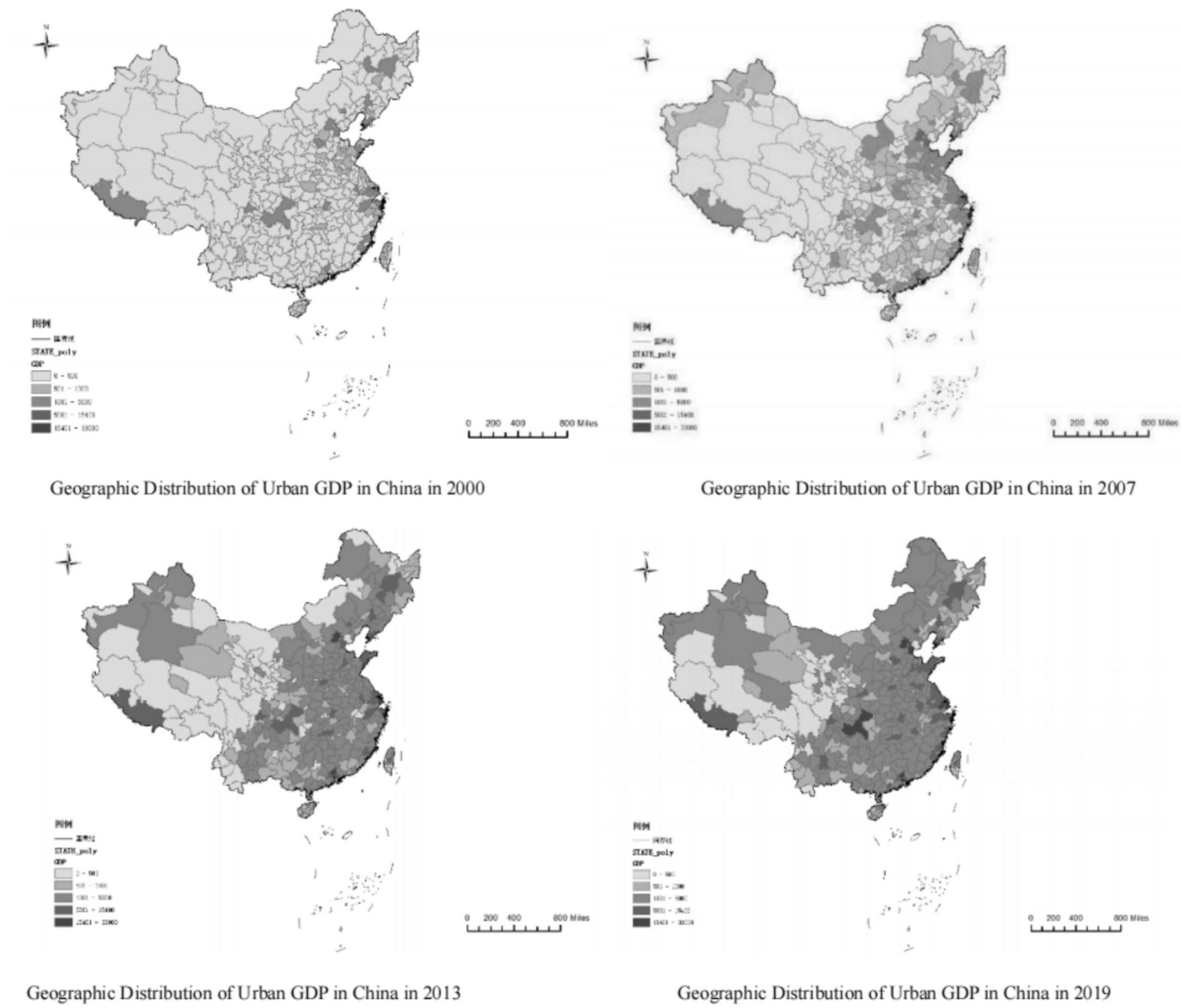

Fig. 2. Geographic distribution of urban GDP in China from 2000 to 2019.
Data Source: China Statistical Yearbook and Google Maps Database.

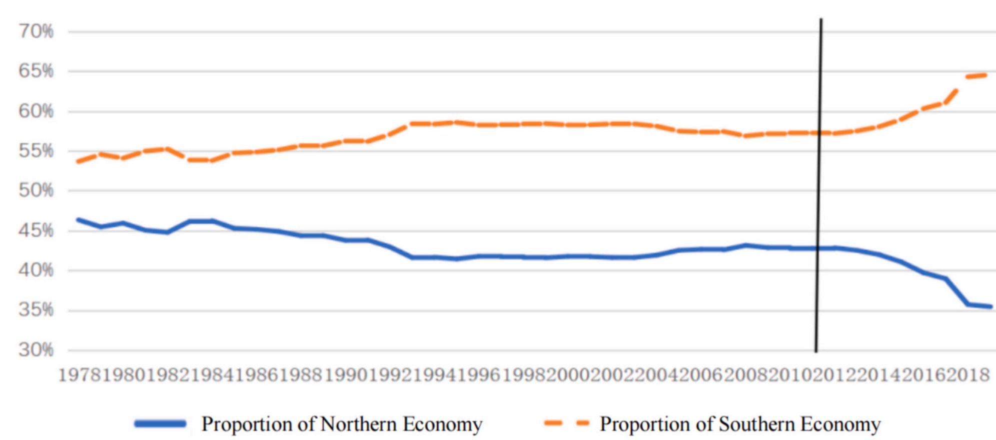

Fig. 1. The temporal trend of economic proportions between Northern and Southern China.
Data source: China Statistical Yearbook.

transportation costs, such as the Yangtze River Delta and Pearl River Delta.

1.4. Establishment of econometric model and data source

1.4.1. Establishment of baseline model

$$GDP_{it} = \beta_0 + \beta_1 \text{tariff}_{it} \times \text{cost}_{it} + \beta_2 \text{cost}_{it} + \beta_3 \text{tariff}_{it} + \beta_4\ Controls + \nu_k + \nu_t + \varepsilon_{it} \tag{1}$$

The subscript i and t are used to denote the city and year, respectively. GDP_{it} represents the economic growth indicator of city i in year t, $tariff_{it}$ represents the level of trade openness of city i in year t in China, where the trade openness index is characterized by both export and import aspects. The import aspect is represented by the weighted average tariff levied on products by China, and the export aspect is represented by the weighted average tariff levied on Chinese products by other economies. The $cost_{it}$ represents the domestic transportation cost faced by city i in year t. The weighted average distance from city i to the nearest coastal port is used as the indicator of domestic transportation cost in this paper. The specific construction method is described in the section of indicator construction of this paper and will not be repeated here.

This paper explores the interactive effects of trade openness and domestic transportation costs on economic growth in the northern and southern regions through the interaction terms. "Controls" represent other control variables that affect regional economic growth, ν_k indicates the provincial-level fixed effects, ν_t represents the time fixed effects, and ε_{it} is the random disturbance term. It is important to note that to control for the impact of provincial-level trade policies and comprehensive transportation network planning, provincial-level fixed effects have been incorporated into the econometric model. The sample time range is from 1999 to 2018.

1.5. Measurement of the dependent variable and key explanatory variables

1.5.1. Definition and measurement of prefecture-level city economic growth

A substantial body of research on regional economic growth has been conducted both domestically and internationally, providing a solid theoretical foundation for the construction of economic growth indicators at the prefecture-level city. Among these, regional GDP is the most widely used measure. In addition, some scholars have employed alternative indicators, such as nighttime light data, as proxies for regional economic growth. Building upon prior literature, this paper uses the GDP of prefecture-level cities as the primary indicator to represent economic growth. Furthermore, nighttime light data is utilized as a supplementary indicator for robustness analysis of prefecture-level city economic growth.

1.5.2. Definition and measurement of export trade openness

Unlike previous studies on the impact of trade openness on economic growth, this paper focuses on the effect of export trade openness on the regional economic growth gap between the North and South, based on an analysis of regional heterogeneity in transportation costs for prefecture-level cities. Therefore, constructing an export trade openness indicator for prefecture-level cities is a key aspect of this research. The methodology proposed by Ahsan and Chatterjee (2017) serves as an inspiration for this paper. Ahsan and Chatterjee (2017) used the share of different industries in the total output of a region in India as weights, and through a weighted average of the tariffs on intermediate goods corresponding to those industries, they developed a trade openness indicator at the regional level. This paper adopts and extends this approach by using the proportion of exports from each industry within a prefecture-level city as the weight, thereby constructing a regional export trade openness indicator, as outlined below:

$$outariff_{it} = \sum_{h=1}^{n} \frac{L_{ih}}{\sum_{h}^{n} L_{ih}} \times outariff_{ht} \tag{2}$$

$$outariff_{ht} = \sum_{r=1}^{n} \frac{\text{export}_{rt}}{\text{export}_{t}} \times \frac{\text{export}_{rht}}{\sum_{h=1}^{n} \text{export}_{rht}} \times outariff_{rht} \tag{3}$$

Eq. (2) represents the formula for constructing the export trade openness indicator, where $outariff_{it}$ denotes the tariff imposed by other countries on region i in year t; $outariff_{ht}$ represents the weighted average tariff imposed by other countries on Chinese industry h; the weighted average tariff imposed by other countries on Chinese industry h is calculated by weighting with the proportion of China's exports to other countries, as specified in the formula. Specifically, $export_t$ represents China's total exports in year t, $export_{rt}$ represents the total exports from China to country r in year t, and $export_{rht}$ represents China's exports from industry h to country or region r in year t. $Outariff_{rht}$ represents the tariff rate imposed by country or region r on Chinese industry h in year t. The import trade openness and export trade openness indicators obtained are used to characterize the trade openness level of prefecture-level city i in China for year t. Additionally, it should be noted that the tariff data is sourced from the WITS database, and China's import and export data is derived from the China Customs Database. Since the WITS database provides tariff data at the HS6 product code level, it is important to mention that while the tariff data is product-specific, the employment data is based on national industry classifications. To address this, the study follows previous literature in converting between HS6 product codes and national industry classifications.

1.6. The definition and measurement of domestic transportation costs: based on the regional heterogeneity of transportation costs between Northern and Southern China

The core focus of this paper is to explore the impact of trade openness on regional economic growth, based on the regional heterogeneity characteristics of transportation costs between northern and southern China. In this paper, domestic transportation costs refer to the transportation costs incurred within regions for international trade participation. Currently, both domestic and international scholars primarily use the shortest distance between two locations (the great-circle distance on the Earth's surface) as a measure of transportation distance, which serves as an indicator of transportation costs between regions. This approach assumes homogeneity in the natural geographic characteristics of all regions, disregarding the differences in domestic transportation costs caused by regional heterogeneity in natural features. However, China is vast, with a latitudinal span of up to 49 degrees from north to south, approximately 5500 km apart. This significant latitudinal difference results in substantial variations in climate and natural geographic features between the northern and southern regions. These natural geographical differences have a notable impact on domestic transportation costs. In some prefecture-level cities, natural barriers such as mountains and rivers have inherently led to high transportation costs, while the abundant rainfall in the southern regions has fostered a rich inland river navigation system, reducing transportation costs for regions within river basins that engage in international trade. Low transportation costs are a significant feature of inland river navigation. For instance, the transportation cost of inland river shipping in the United States is only one-fourth that of rail transport and one-fifth that of road transport. Although China's inland river infrastructure requires further development, inland navigation remains highly competitive in terms of transportation costs. For example, the cost of road transport for steel from Hangzhou to Shanghai ranges from 45 to 55 yuan per ton, while inland river shipping costs only 14 to 15 yuan per ton, approximately one-third of road transport costs. According to data published by the Ministry of Transport, the cargo throughput on the Yangtze River mainline reached 2.93 billion tons in 2019, while the railway freight volume during the same period was 4.389 billion tons. The Yangtze River mainline's cargo transport capacity exceeds half of the total national railway freight capacity. Furthermore, the cargo volume on the Pearl River system's inland waterway surpassed 1 billion tons for the first time in 2019, making it the second-largest in the world, after the Yangtze River. These findings clearly demonstrate that the rich inland river navigation system in southern China significantly reduces transportation costs for cities in the river basin participating in international trade, making it a primary cause of the regional differences in domestic transportation costs between the north and the south. This paper fully considers the impact of transportation cost differences across various modes of transport, using the transportation volume and cost of different modes as weights, and the great-circle distance from prefecture-level cities to the nearest coastal ports as the indicator for domestic transportation costs. The detailed content is as follows:

$$Cost_{it} = lndistw_i \times (HFV_{it} + 2/3 \times RFV_{it} + 1/3 \times IWFV_{it})/TFV_{it} \quad (4)$$

In this context, TFP_{it} (Total Freight Volume) represents the total freight volume of prefecture-level city i in year t, HFV_{it} (Highway Freight Volume) represents the highway transport freight volume of prefecture-level city i in year t, RFV_{it} (Railway Freight Volume) represents the railway transport freight volume of prefecture-level city i in year t, and $IWFV_{it}$ (Inland Water Freight Volume) represents the inland waterway freight volume in year t. The factors 1/3 and 2/3 represent the proportion of inland waterway transportation costs and railway transportation costs relative to highway transportation costs, respectively. $Lndistw_i$ denotes the distance from the prefecture-level city to the nearest port, calculated based on the geographic coordinates (latitude and longitude) of the city and the nearest coastal port.

1.7. Explanation of control variables

Regional Industrial Structure Transformation: The industrial structure of a region is an important manifestation of the regional division of labor. Classical industrial structure theory suggests that economic growth is a key outcome of industrial structure transformation. In an unbalanced state, labor and capital tend to shift from low-productivity sectors to high-productivity sectors, thereby driving economic growth. Specifically, the process of industrial structure transformation refers to the reallocation of production factors across different sectors. This transformation, through the reallocation of resources, generates "heightening effects" and "rationalization effects," which promote improvements in sectoral productivity and, consequently, regional economic growth. In this paper, we construct indicators for industrial structure rationalization and industrial structure upgrading to capture the transformation of industrial structure along these two dimensions, using them as control variables.

Investment in Regional Information Infrastructure: Infrastructure development serves as the foundation and a supporting industry for driving economic growth. The relationship between infrastructure development and regional economic growth has long been a key focus for scholars both domestically and internationally. As early as the 1940s, Rodan's "Great Leap Theory" emphasized that infrastructure, such as transportation, should be viewed as social capital, asserting that robust infrastructure is a key prerequisite for rapid economic growth. This paper uses the total postal and telecommunication business volume of prefecture-level cities as an indicator of information infrastructure in these regions, with regional information infrastructure treated as a control variable in the analysis.

Share of Foreign Investment: In the early stages of China's reform and opening-up, the country implemented a "market-for-technology" strategy to attract foreign investment, significantly boosting foreign capital inflows. In recent years, as China's domestic market has expanded, its attractiveness to foreign investment has also increased. Foreign Direct Investment (FDI), as a comprehensive entity of capital stock, technology, and knowledge, promotes regional economic growth through various channels such as alleviating financing constraints, technological spillovers, and industrial linkages. Consequently, FDI has a significant impact on regional economic growth. Thus, this paper incorporates the share of FDI in regional GDP as a control variable.

Regional Human Capital: Human capital generates returns to scale and overcomes the diminishing marginal returns typically observed in physical capital and labor inputs. In particular, education, as a key component of human capital, is a crucial driver of sustained economic growth in modern economies. Endogenous growth theory posits that endogenous technological progress is the decisive factor in long-term economic growth, and human capital serves as the source of this technological progress. The theory also emphasizes the role of knowledge accumulation and specialized human capital. The significant role of human capital in driving economic growth has been widely recognized by scholars worldwide. Therefore, this paper measures human capital by the average years of education of the regional population.

Regional Innovation Efficiency: From neoclassical to endogenous growth theory, both schools recognize that technological progress is a key driver of sustained economic growth, with technological innovation being the root cause of technological progress. From the perspective of how technological innovation drives economic growth, the foundational force of technological innovation lies in its ability to improve current production methods, optimize the allocation of production factors, and enhance the marginal productivity and efficiency of these factors, thereby promoting social productivity. As regional development in China remains imbalanced, disparities in innovation efficiency have become a significant manifestation of regional disparities. However, innovation efficiency plays a crucial role in promoting regional economic growth and enhancing regional competitiveness. Therefore, this paper employs the stochastic frontier approach to measure regional innovation efficiency and incorporates it as a control variable.

1.7.1. Data processing and descriptive statistics

The dependent variable in this paper is the economic growth data of prefecture-level cities, using GDP as the benchmark for the regression model. The data spans from 2000 to 2019, with corresponding years from 1999 to 2018, sourced from the China City Statistical Yearbook. The dataset includes 333 prefecture-level city administrative regions (including sub-provincial cities and plan-managed cities) and 4 municipalities directly under the central government. The city panel data from 1999 to 2018, as organized from the China City Statistical Yearbook, includes various variables such as administrative region codes, city names, years, total population at the end of the year, GDP of primary, secondary, and tertiary industries, levels of foreign capital utilization, fixed asset investment, and cargo volume by different transportation modes. Due to inconsistencies in the statistical indicators across different years, the study eliminates certain variables with significant missing values during the annual merging process. The remaining dataset consists of 249 variables, with the expected number of observations being (333 + 4)*(2018–1999) = 6403. However, due to missing GDP data for earlier years, the study supplements missing GDP data for prefecture-level cities using data from the Foresight Database. Prior to supplementing, the study compares the GDP data for cities common to both datasets, finding that the values are consistent, further verifying the reliability of the data. After supplementation, the final number of observations is 6324. Moreover, given the richness of indicators for regional economic growth, and in consideration of potential statistical and computational errors, as well as the risk of overestimation due to government efforts to enhance economic performance, some scholars have used nighttime light data published by the National Oceanic and Atmospheric Administration (NOAA) as a proxy for regional GDP. Building on prior research, this paper employs nighttime light data as a robust alternative indicator for regional economic growth. Given the availability of two versions of nighttime light data—the 1992–2013 DMSP/OLS dataset and the 2012–2018 VIIRS dataset—since these come from different satellites and cannot be used together directly, this paper uses the integrated 2000–2018 nighttime light data sourced from the Harvard Dataverse for the robustness check of the regional economic growth measurement.

The core explanatory variables in this paper include two indicators: domestic transportation costs and export trade openness. The indicator for export trade openness is represented by the weighted average tariff imposed by other countries on China, with the tariff data sourced from the WITS database. This database consolidates data from the UNComtrade and WTO databases, providing tariff data for products under HS6 codes across different countries. In this paper, bilateral tariff data between China and other countries for the years 1999–2018 is selected, with the weightings based on the proportion of export value in various sectors of different regions to total exports. These data are obtained from the China City Statistical Yearbook. The weight for the instrumental variable is based on the proportion of employed persons in each sector to the total employment in the region, using data from the 2000 China Population Census. This census data details the industry information of the employed population in different regions. The study constructs the regional sectoral distribution as weights for the regional-level weighted average tariffs by aggregating the sectoral population distribution data provided in the database. The census data used is from the National Bureau of Statistics. Another core explanatory variable in this paper is domestic transportation costs, which are represented by the weighted distance from a prefecture-level city to the nearest port. The distance data is sourced from Google Earth. The weights are based on the product of the proportions of different transportation modes and their corresponding freight cost shares. The transportation volume data for different modes of transportation is drawn from the China City Statistical Yearbook, which records the cargo transportation volume by different transportation modes in different prefecture-level cities. Given the significant missing data on transportation volumes for different modes in the city-level statistical yearbooks, the study substitutes missing data using the freight volume distribution by transportation mode from the corresponding province of the prefecture-level city, to minimize the loss of sample observations.

In addition to the aforementioned core explanatory variables, this paper also includes several control variables, such as regional information infrastructure investment, the share of foreign direct investment, regional human capital, regional innovation efficiency, and regional industrial structure. Regional information infrastructure investment is characterized by the total volume of postal and telecommunications services at the prefecture level, with data sourced from the China City Statistical Yearbook. Regional human capital is represented by the average years of education of the regional population, with this data obtained from the China Statistical Yearbook. The China Statistical Yearbook reports population data for individuals aged six and above, categorized by region, gender, and education level. Most of the data comes from China's sampling surveys. This paper uses the average years of education from the China Statistical Yearbook as an important indicator of regional human capital. Regional innovation efficiency is estimated using the DEA-Malmquist index method, a non-parametric estimation technique implemented through Stata software. The regional innovation output, as a measure of economic benefits, is represented by regional gross domestic product (GDP), with data sourced from the China City Statistical Yearbook. Regional innovation input is reflected by regional research funding and full-time equivalent R&D personnel, including researchers, basic research, applied research, and experimental development. The data for these variables are sourced from the China Science and Technology Statistics Yearbook and the National Bureau of Statistics database. The regional industrial structure is represented by two indicators: the upgrading of industrial structure and the rationalization of industrial structure. The upgrading of industrial structure measures the extent of industrial structure advancement and is represented by the proportion of non-agricultural industries in total output value, with data obtained from the China City Statistical Yearbook. The rationalization of industrial structure is represented by the degree of deviation in industrial structure, with regional industrial and employment data sourced from the China City Statistical Yearbook. Table 1 provides the descriptive statistics for the data used in the empirical analysis of this paper.

2. Analysis of baseline regression results

Based on the mechanism analysis in Section 3, it is evident that the interaction effects of export trade openness and domestic transportation costs have a significant impact on the economic growth disparity between the northern and southern regions. This section will use the per capita GDP data of prefecture-level cities from the China Statistical Yearbook as the dependent variable. The weighted average tariff of each prefecture-level city will be constructed using the WITS tariff database as an indicator of export trade openness. Additionally, the weighted distance from each prefecture-level city to the nearest port will be utilized as an indicator of domestic transportation costs. By establishing an econometric model, this section will analyze the effects of export trade openness and domestic transportation costs on the economic disparity between the northern and southern regions. This section of the study includes three main components of the econometric regression method: baseline regression, robustness tests, and instrumental variable regression.

2.1. Baseline regression

This paper uses the GDP of prefecture-level cities as an indicator to characterize the economic growth of these cities, serving as the dependent variable in the baseline regression, as outlined in the previous section on indicator construction. Weighted tariffs are used as an indicator of export trade openness, and the weighted distance from prefecture-level cities to ports is used to characterize domestic transportation costs. Additionally, interaction terms are introduced to analyze the interactive effects of trade openness and domestic transportation costs on the economic gap between the north and south. The specific regression results are presented in Table 2 below. In this section, columns (1) and (2) in Table 2 present the regression results for export trade openness, domestic transportation costs, and their impact on the north-south economic disparity. Column (1) shows the results of the regression without any control variables, while column (2) presents the results after including control variables such as regional industrial structure, information infrastructure investment, foreign direct investment share, regional human capital, and regional innovation efficiency.

From the regression results above, it can be observed that the export trade openness index, represented by the weighted tariff, has a significantly negative coefficient, indicating that a lower tariff level, which reflects a higher level of trade openness, has a stronger positive effect on economic growth at the prefecture-level city. The domestic transportation cost index, constructed using the weighted distance from the prefecture-level city to the nearest port, has a significantly negative coefficient, suggesting that higher domestic transportation costs create a higher "threshold" for prefecture-level cities engaged in international trade. In other words, the higher the domestic transportation costs faced by a prefecture-level city, the more pronounced the negative effect on economic growth. The interaction term between trade openness and domestic transportation costs has a significantly positive coefficient, indicating that trade openness and domestic transportation costs are substitutes in terms of their impact on economic growth at the prefecture-level city. Specifically, trade openness reduces the inhibiting effect of domestic transportation costs on economic growth, and the positive impact of trade openness is more pronounced in cities with lower domestic transportation costs compared to cities with higher transportation costs. Compared to the northern region, the southern

Table 1
Descriptive statistics of key variables.

Variable Name	Observations	Mean	Standard Deviation	Maximum Value	Minimum Value
Export Trade Openness	6324	7.5907	0.8369	9.9008	5.3206
Domestic Transportation Costs	6324	636.5275	664.6609	3564.5250	1.7745
Market Segmentation Index	6324	0.000458	0.0005	0.00003	0.00802
Regional Industrial Structure	6324	0.9980	0.5556	4.2367	0.4996
Regional Information Infrastructure Investment	6324	139.76	13.652	1370.64	1.1700
Foreign Direct Investment	6324	14.0429	1.3612	16.8404	8.4620
Regional Human Capital	6324	8.8001	0.9799	12.5025	6.5940
Regional Innovation Efficiency	6324	0.3917	0.1624	0.9129	0.0761

Table 2
Regression of trade openness, domestic transportation costs, and the North-South economic gap.

	(1)	(2)
Export Trade Openness	−0.1249*	−0.0920*
	(−1.9128)	(−1.8394)
Domestic Transportation Costs	−0.2526***	−0.1897***
	(−3.3260)	(−3.6113)
Export Trade Openness * Domestic Transportation Costs	−0.3516***	−0.2623***
	(−3.5038)	(−3.9819)
Regional Industrial Structure		0.5196**
		(2.4107)
Regional Information Infrastructure Investment		0.1196***
		(3.0851)
Share of Foreign Direct Investment		0.0144**
		(2.4666)
Regional Human Capital		0.1463***
		(3.7092)
Regional Innovation Efficiency		0.9641**
		(2.9936)
Constant Term	0.1414**	0.7761*
	(2.9027)	(1.9516)
Regional Fixed Effects	Yes	Yes
Time Fixed Effects	Yes	Yes
Observations	6324	6324
R-squared	0.1830	0.1845

Note: Values in parentheses are t-statistics corrected for heteroskedasticity; *, **, and *** denote significance levels of 10 %, 5 %, and 1 %, respectively.

region benefits from a rich inland waterway shipping system, and especially in the Yangtze River Economic Belt, the proportion of cargo transported via inland waterways is significantly higher than in the north. The difference in domestic transportation costs between the northern and southern regions, driven by natural geographic factors, leads to “regional heterogeneity” in the effect of trade openness on economic growth, with the southern region experiencing a more significant positive impact on economic growth due to its superior natural geography and regional advantages. Furthermore, the significant coefficient of regional industrial structure indicates that industrial structure optimization promotes regional economic growth by improving resource allocation efficiency. The significantly positive coefficient for regional information infrastructure suggests that higher levels of investment in information infrastructure promote economic growth at the prefecture-level city. The positive coefficient for the proportion of foreign direct investment indicates that increased foreign investment significantly boosts economic growth at the prefecture-level city. The significantly positive coefficient for regional human capital suggests that human capital remains an important factor in promoting economic growth. The “Peacock Flies Southeast” phenomenon plays a significant role in contributing to the economic disparity between the northern and southern regions. Finally, the significantly positive coefficients for regional innovation efficiency indicate that innovation, through reforms in production methods and optimization of production processes, significantly promotes economic growth at the prefecture-level city.

2.2. Robustness tests

The robustness tests in this paper consist of two parts: the robustness test of the indicator measurement and the robustness test of the econometric methodology. Due to space constraints, the empirical results of the robustness tests are reported in the appendix and are not presented in the main body of the paper.

The robustness test of indicator measurement is mainly achieved through alternative indicators for the dependent and core explanatory variables. The measurement of regional economic growth indicators is divided into two major categories. One category is based on traditional statistical data, which includes per capita GDP, the growth rate of regional GDP, and regional productivity. The other category takes into account the potential statistical and computational errors in traditional statistical indicators, and the possibility of data overestimation due to government efforts to pursue economic performance. In this context, many scholars use adjusted nighttime light data to depict regional economic growth. Nightlight data not only records economic activity in a real and objective manner but also conveys information that traditional economic indicators struggle to reflect, such as the spatial distribution of economic activity and urbanization. Building on previous literature, this paper employs both the traditional statistical regional economic indicators and the adjusted nighttime light data as alternative measures for the robustness test of the dependent variable. The specific regression results are shown in Table A.1.

Considering that most literature uses the spherical distance from the geographical coordinates of a region to the nearest port as an alternative indicator of the domestic transportation cost incurred for international trade, this paper follows the common practice in previous studies by using the distance from the prefecture-level city to the nearest port as a substitute for domestic transportation costs. The impact of export trade openness and domestic transportation modes on the north-south economic gap is empirically analyzed using interaction terms. The specific regression results are shown in Table A.2.

Additionally, based on previous literature, this paper uses the simple average tariff as an alternative indicator of export trade openness. Similar to the weighted average tariff constructed in this paper, the data for the simple average tariff also comes from the WITS tariff database. The simple average tariff applied by other countries to China is used as an indicator of China’s export trade openness. Given that the construction of the simple average tariff and its integration with prefecture-level city economic growth data closely resembles the study’s core explanatory variables, further elaboration is omitted. This paper empirically analyzes the effects of trade openness, domestic transportation costs, and the north-south economic gap by introducing an interaction term between the simple average tariff and domestic transportation costs. The specific regression results are shown in Table A.3.

This paper also conducts a robustness test to control for omitted variable bias. Undoubtedly, neoclassical theory emphasizes that the inherent differences in factor endowments between regions are a significant cause of regional disparities, and numerous scholars have explained the reasons for regional development gaps from the perspective of differences in resource endowments (Costinot & Komunjer, 2007). Based on previous literature, this paper measures resource-based cities by the share of the extractive industry in the total industrial output value of prefecture-level cities. The top 10 % of cities with the highest proportion of extractive industry in industrial output value are selected as resource-based cities. These identified resource-based cities are excluded to eliminate the influence of resource endowment differences on regional development gaps. The regression is then conducted using panel data after excluding resource-based cities, in order to analyze the impact of trade openness and domestic transportation costs on the north-south economic gap. If the regression results show a significantly positive relationship, it suggests that, based on the heterogeneity of domestic transportation costs between the north and south, trade openness has a significant effect on the north-south economic gap, and the results are robust. The robustness test results for this section are presented in Table A.4.

2.3. Instrumental variable regression

Export trade openness and domestic transportation costs are the two core explanatory variables in this paper. The construction of the domestic transportation cost indicator is based on the weighted average of geographic distances. Given that natural geographical features such as geographic distance and climate exhibit high levels of exogeneity and randomness, they are less likely to be influenced by factors like economic growth, thus demonstrating strong exogeneity. However, export trade openness and economic growth at the prefecture-level city may present endogeneity issues due to reverse causality. As discussed earlier, export trade openness promotes economic growth at the prefecture-level city through industrial linkages and economies of scale, while faster economic growth in these cities may strengthen the government's willingness to improve the business environment and enhance trade openness. To address this issue, this paper intends to employ a two-stage least squares (2SLS) method, using an instrumental variable for export trade openness, in order to resolve the endogeneity problem caused by reverse causality.

It is well-known that the key to two-stage least squares is finding appropriate instrumental variables. A significant body of literature has used historical factors to identify instrumental variables that resolve potential endogeneity problems. For example, Acemoglu et al. (2001) used historical colonial mortality rates as an instrumental variable for institutions, effectively addressing the endogeneity problem caused by reverse causality between institutions and regional economic growth. Building on the ideas from these studies, this paper develops an instrumental variable approach by using the regional industry employment share in 2000, as a proportion of national employment in the industry, as a weight. The constructed export trade openness indicator will serve as the instrumental variable for export trade openness in this paper. The reasoning for this approach is as follows:

Firstly, the industry tariff levels faced by Chinese enterprises in exports are identical across regions, meaning that there is no regional heterogeneity in the industry tariffs themselves. The varying levels of export trade openness across different prefecture-level cities are instead attributed to the regional heterogeneity of their industrial structures. The historical industrial structure of a prefecture-level city has a significant impact on its current industrial structure. Factors such as sunk costs and economies of scale contribute to the clear path dependency of regional industrial development, meaning that the historical industrial structure is closely related to the current industrial structure of the city. Moreover, the historical industrial structure does not have a direct correlation with the current economic growth of the prefecture-level city. Therefore, this paper constructs an instrumental variable for export trade openness by using the share of industry employment in the total national employment of that industry from the historical period as a weight. Additionally, the reason for using the 2000 census data from China's fifth national population survey to represent the weights for trade openness is based on several factors. First, the data covers all 31 provinces, municipalities, and autonomous regions, as well as over 340 cities, providing detailed information on employment and industry affiliation. Second, although tariff reductions were uniform at the national level, China's different prefecture-level cities have distinct industrial structures, and the degree of trade openness for various industries also varies significantly. Therefore, regional heterogeneity in trade openness exists across Chinese prefecture-level cities, and the employment share of different regions accurately reflects the regional industrial structure, thus offering a more precise representation of the trade openness indicator at the prefecture level. Third, China's accession to the World Trade Organization (WTO) at the end of 2001 led to substantial tariff reductions in compliance with its WTO commitments. These tariff reductions may have prompted enterprises to adjust their industrial structures. Since the 2000 census data is used in this paper, prior to China's accession to the WTO, businesses could not have accurately predicted the timing of China's WTO membership. Therefore, using data from before China's accession enhances the exogeneity of the instrumental variable. In line with existing literature, this paper introduces the instrumental variable to address potential endogeneity issues, and the specific econometric results are presented in Table 3.

Table 3 presents the regression results using the historically weighted average tariff, with industry employment shares as weights, as an instrumental variable for export trade openness. The coefficient of the interaction term is significantly positive, indicating that the impact of export trade openness on economic growth is more pronounced in prefecture-level cities with lower transportation costs. Moreover, after addressing the endogeneity issue in the econometric model, the results

Table 3
Instrumental variable regression.

	(1)
Instrumental Variable	−0.1164**
	(−2.1651)
Domestic Transportation Costs	−0.1763**
	(−2.1803)
Instrumental Variable * Domestic Transportation Costs	0.1218**
	(2.1654)
Regional Industrial Structure	0.7973***
	(2.7452)
Regional Information Infrastructure Investment	0.4149***
	(2.7815)
Share of Foreign Direct Investment	−0.0442
	(−0.2516)
Regional Human Capital	0.4503***
	(6.7690)
Regional Innovation Efficiency	1.6352***
	(2.6391)
Durbin-Wu-Hausman	201.98
	[0.0000]
Kleibergen-Paap rk LM	35.0000
	[0.0000]
Kleibergen-Paap rk Wald F	1287.692
	{16.38}
Constant Term	0.2300**
	(1.9856)
Regional Fixed Effects	Yes
Time Fixed Effects	Yes
Observations	6324
R-squared	0.2505

Note: The values in parentheses represent t-statistics; *, **, and *** denote significance levels of 10 %, 5 %, and 1 %, respectively; The values in square brackets represent the corresponding *p*-values of the statistics, while the values in curly brackets represent the critical values at the 10 % level from the Stock-Yogo test; The Durbin-Wu-Hausman test is an important method for detecting endogeneity. Rejection of the null hypothesis indicates the presence of endogeneity issues; The Kleibergen-Paap rk LM test is a crucial method for examining the correlation between the instrumental variables and the endogenous variables. Rejection of the null hypothesis suggests that the chosen instrumental variables are appropriate; The Kleibergen-Paap rk Wald F test is used to test whether the instrumental variables are weakly identified. Rejection of the null hypothesis indicates that the selected instrumental variables are valid.

remain robust.

3. Mechanism testing

The mechanism analysis indicates that export trade openness and domestic transportation costs have a significant impact on the North-South economic disparity through economies of scale and industrial linkage effects. This paper conducts an econometric test of the mechanism through the construction of a mediation effect model to examine the influence of trade openness and domestic transportation costs on the North-South economic gap. The detailed results are presented below.

$$M = \gamma_0 + \gamma_1 \text{cost}_i \times \text{tariff}_{it} + \gamma_2 \text{tariff}_{it} + \gamma_3 \text{cost}_i + \gamma_4\ controls + v_k + v_t + \varepsilon_{it} \tag{5}$$

$$GDP_{it} = \omega_0 + \omega_1 \text{cost}_i \times \text{tariff}_{it} + \omega_2 M + \omega_3 \text{cost}_i + \omega_4 \text{tariff}_{it} + \omega_5\ controls + v_k + v_t + \varepsilon_{it} \tag{6}$$

In this context, M represents the mediator variable, which in this paper refers to indicators characterizing economies of scale and industrial linkage effects. The meanings of other variables remain consistent with those in the baseline regression section of this paper. Eq. (5) specifies the mediator variable as the dependent variable and tests whether the interaction effects of export trade openness and domestic transportation costs significantly influence the mediator variable. Eq. (6) builds upon the basic regression model by incorporating the mediator variable to assess whether the mediator variable significantly impacts economic growth. If the coefficients γ_1 in Eq. (5) and ω_1 as well as ω_2 in Eq. (6), are all significant, it suggests the presence of a mediation effect, meaning that export trade openness and domestic transportation costs affect the North-South economic growth disparity through economies of scale and industrial linkage effects. Furthermore, the construction of mediator variable indicators is a necessary condition for testing the mechanism. This paper, based on a review of previous literature, constructs indicators to characterize economies of scale and industrial linkages, as detailed below.

3.1. Mechanism testing of the economies of scale effect

This paper employs parameter estimation methods to derive regional total factor productivity, economies of scale growth, and the rate of technological change. The component representing economies of scale growth is then separated and used as a mediator variable to characterize the economies of scale effect in this paper. An empirical test of the mediation effect is conducted using a mediation model to examine the impact of trade openness and domestic transportation costs on the economies of scale effect in the North-South economic growth disparity. The specific details are outlined as follows:

$$NCRSG_{iht} = \left(1 - V_{sh}^{-1}\right)\left(e_{iKht} \times K_{iht} + e_{iLht} \times L_{iht}\right) \tag{7}$$

$$V_{isht} = e_{iKht} + e_{iLht} \tag{8}$$

$$Q_{iht} = e_{iKht} \times K_{iht} + e_{iLht} \times L_{iht} + TCR_{iht} \tag{9}$$

In this context, $NCRSG_h$ represents the economies of scale component of firm productivity. K and L denote capital and labor, respectively, i refers to the prefecture-level city, and h represents the industry. e_{Kn} and e_{Lh} correspond to the capital and labor output elasticities for industry h, respectively, while V_{sh} represents the sum of the capital and labor output elasticities. The values of e_{Kn} and e_{Lh} are calculated using Eq. (9).

The regression results in Table 4 indicate that in the first stage, the individual coefficients of export trade openness and domestic transportation costs are significantly negative, while the interaction term's regression coefficient is significantly positive. In the second stage, the interaction term's coefficient remains significantly positive, and the coefficient for the economies of scale indicator is also significantly positive. This suggests that in regions with lower domestic transportation costs, the promotion of economic growth through export trade openness via economies of scale is more pronounced. In other words, compared to northern prefecture-level cities, southern prefecture-level cities, which face lower domestic transportation costs, experience a more significant positive effect on economic growth from export trade openness through economies of scale.

Table 4
Mechanism testing of the economies of scale effect.

	Economies of Scale Effect on the Prefecture-Level City		Prefecture-Level City GDP	
	First Stage		Second Stage	
	(1)	(2)	(3)	(4)
Export Trade Openness	−0.3288***	−0.2895***	−0.1237***	−0.0827***
	(−5.1921)	(−4.0748)	(−4.5281)	(−2.8573)
Domestic Transportation Costs	−0.6381***	−0.0450***	−0.2096***	−0.1683***
	(−3.9527)	(−3.0855)	(−5.1416)	(−4.1759)
Export Trade Openness * Domestic Transportation Costs	0.6727***	0.4798***	0.2273***	0.1826***
	(3.9028)	(3.3918)	(5.0560)	(4.1133)
Economies of Scale Effect			0.1675***	0.1018***
			(6.7276)	(3.6347)
Regional Industrial Structure		0.0459**		0.5788***
		(2.1006)		(8.7466)
Regional Information Infrastructure Investment		0.2103**		0.1556***
		(2.0355)		(7.0311)
Share of Foreign Direct Investment		0.0519***		−0.1936
		(3.5695)		(−0.9945)
Regional Human Capital		0.0975		0.1620
		(−0.1150)		(1.2440)
Regional Innovation Efficiency		0.0415***		0.5839**
		(3.5799)		(2.5467)
Constant Term	0.9555***	0.5848***	0.1379***	0.3412
	(8.3234)	(5.2383)	(6.4616)	(1.1219)
Regional Fixed Effects	Yes	Yes	Yes	Yes
Time Fixed Effects	Yes	Yes	Yes	Yes
Observations	6324	6324	6324	6324
R-squared	0.7298	0.7436	0.8323	0.8382

Note: Values in parentheses are t-statistics corrected for heteroskedasticity; *, **, and *** denote significance levels of 10 %, 5 %, and 1 %, respectively.

3.2. Mechanism test of industrial linkage effects

This paper employs input-output analysis to construct relevant indicators of industrial linkages using inter-provincial input-output data from China. It systematically analyzes the interdependence and inter-constraint relationships among various industries from a techno-economic perspective. Furthermore, this paper aims to develop a theoretical framework for value chain decomposition that distinguishes between regional value added and value added from external inflows. Existing literature on the decomposition of backward final product demand provides a practical approach for calculating detailed regional-industry value chain indicators from the perspective of final product usage. However, the foundational data for this decomposition method is derived from the World Input-Output Table, and the decomposition approach is best suited for global input-output databases. Thus, further theoretical and literature support is required to adapt this decomposition theory and methodology to China's inter-provincial input-output table. Previous studies have used input-output tables from eight major regions in China and inter-provincial input-output tables to focus on the synergistic development and coupling relationship between domestic and global value chains. While the emphasis of these studies differs from this paper's focus on regional-industry level value chains and final demand, the preprocessing methods used for China's inter-provincial input-output tables in these studies provide valuable insights for this paper, as outlined below:

This paper simplifies China's regional-industry input-output table into a model with G regions and N industries, as shown in Table 5. From the row perspective, the sum of intermediate usage, final usage, and export values represents the total output of a regional-industry. From the column perspective, the sum of intermediate inputs, imports, and value-added inputs constitutes the total input for a regional-industry, ensuring balance between total input and total output. It should be noted that this paper does not further differentiate between value-added from foreign imports as either re-imported or directly imported value-added.

Z^{sr} represents the $N \times N$ intermediate input matrix, where products from region s are used in region r. Y^{sr} represents the $N \times 1$ final demand vector, where products from region s are used as final demand in region r. X^s represents the $N \times 1$ total output vector of region s, and Va^s represents the $1 \times N$ direct value-added input vector of region s. The input coefficient matrix can be expressed as $A = Z\widehat{X}^{-1}$, where $\widehat{X}$ represents the diagonal matrix. $V = Va\widehat{X}^{-1}$ represents the value-added coefficient vector. Therefore, the total output X can be decomposed into intermediate goods and final goods, $AX + Y = X$. Furthermore, it can be written in the form of the Leontief inverse matrix $X = BY = (I - A)^{-1}$, where I is the identity matrix. The total output can be detailed as follows:

$$X = AX + Y = A^D X + Y^D + A^F X + Y^F = A^D X + Y^D + E \tag{10}$$

Where $A^D = \begin{bmatrix} A^{11} & 0 & \cdots & 0 \\ 0 & A^{22} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & A^{gg} \end{bmatrix}$ is the $GN \times GN$ diagonal matrix of the domestic input coefficients. A^F is the $GN \times GN$ off-diagonal matrix of the foreign input coefficients, and $A^F = A\text{-}A^D$. $Y = \left[\sum_r^G Y^{1r} \ \ \sum_r^G Y^{2r} \ \cdots \ \sum_r^G Y^{gr}\right]'$ represents the $GN \times 1$ final output vector. $Y^D = \left[Y^{11} \ \ Y^{22} \ \ \ldots \ \ Y^{gg}\right]'$ represents the $GN \times 1$ vector of final goods consumed within the region. $Y^F = Y\text{-}Y^D$ represents the $GN \times 1$ final goods outflow vector. $E = \left[\sum_{r\neq 1}^G E^{1r} \ \ \sum_{r\neq 2}^G E^{2r} \ \cdots \ \sum_{r\neq g}^G E^{gr}\right]'$ represents the $GN \times 1$ total outflow vector. Eq. (10) can be further written as:

$$X = \left(I - A^D\right)^{-1} Y^D + \left(I - A^D\right)^{-1} E = LY^D + LE = LY^D + LY^F + LA^F X \tag{11}$$

Where $L = \left(I - A^D\right)^{-1}$ represents the $GN \times GN$ local Leontief inverse matrix. By first multiplying the equation in (11) on the left by the $GN \times GN$ diagonal matrix of the direct value-added coefficients of $\widehat{V}$, then applying the substitution X in the eq. $X = BY$, and finally converting Y^D, Y^F and Y into the $GN \times GN$ diagonal matrices of $\widehat{Y}^D$, $\widehat{Y}^F$ and $\widehat{Y}$ respectively, we obtain:

$$\begin{aligned} \widehat{V}B\widehat{Y} &= \widehat{V}L\widehat{Y}^D + \widehat{V}L\widehat{Y}^F + \widehat{V}LA^F B\widehat{Y} \\ &= \widehat{V}L\widehat{Y}^D + \widehat{V}L\widehat{Y}^F + \widehat{V}LA^F L\widehat{Y}^D + \widehat{V}LA^F\left(B\widehat{Y} - L\widehat{Y}^D\right) \end{aligned} \tag{12}$$

$\widehat{V}B\widehat{Y}$ represents value added by region-industry is either directly or indirectly input into the production of final goods or services within the region's industry. $\widehat{V}L\widehat{Y}^D$ represents the value added produced and consumed within the region itself, which does not flow out of the region throughout the entire production and consumption process. $\widehat{V}L\widehat{Y}^F$ represents the value added of the region that flows out to other regions in the form of final goods and is consumed elsewhere; this value added only flows out once. $\widehat{V}LA^F L\widehat{Y}^D$ represents the value added from other regions consumed within the region, i.e., the value added from intermediate goods flowing into the region, being processed through production, and eventually consumed locally; this value added flows in only once and is considered a simple value chain indicator. $\widehat{V}LA^F\left(B\widehat{Y} - L\widehat{Y}^D\right)$ represents the value added returning to the region and the foreign value added that is re-exported, i.e., the value added from intermediate goods that flow into the region and the value added from intermediate goods that are processed and then exported out for consumption by other regions; this value added involves at least one flow in and one flow out, representing a complex value chain indicator.

Considering the impact of consumption upgrading on the total demand of region-industries, this paper decomposes based on the backward final goods output method. From the perspective of total demand, the final demand of region-industry can be decomposed into five components: local value added, value added flowing out, value added flowing in, value added returning to the region, and foreign value added flowing out again, as shown in Table 6.

Table 5
Inter-regional Non-Competitive Input-Output Table (G regions, N industries).

Output Input			Intermediate Use			Final Use				Total Output
			Region 1	⋯	Region G	Region 1	⋯	Region G	Export	
			Industry 1⋯Industry N	⋯	Industry 1⋯Industry N					
Intermediate Use	Region 1	Industry 1	$Z_{11}^{11} \cdots Z_{11}^{1N}$	⋯	$Z_{1G}^{11} \cdots Z_{1G}^{1N}$	Y_{11}^1	⋯	Y_{1G}^1	E_1^1	X_1^1
		⋯	⋯ ⋯ ⋯	⋯	⋯	⋯	⋯	⋯	⋯	⋯
		Industry N	$Z_{11}^{N1} \cdots Z_{11}^{NN}$	⋯	$Z_{1G}^{N1} \cdots Z_{1G}^{NN}$	Y_{11}^N	⋯	Y_{1G}^N	E_1^N	X_1^N
	⋯	⋯	⋯ ⋯ ⋯	⋯	⋯	⋯	⋯	⋯	⋯	⋯
	Region G	Industry 1	$Z_{G1}^{11} \cdots Z_{G1}^{1N}$	⋯	$Z_{GG}^{11} \cdots Z_{GG}^{1N}$	Y_{G1}^1	⋯	Y_{GG}^1	E_G^1	X_G^1
		⋯	⋯	⋯	⋯	⋯	⋯	⋯	⋯	⋯
		Industry N	$Z_{G1}^{N1} \cdots Z_{G1}^{NN}$	⋯	$Z_{GG}^{N1} \cdots Z_{GG}^{NN}$	Y_{G1}^N	⋯	Y_{GG}^N	E_G^N	X_G^N
	Imports		$\mathrm{Im}_1^1 \cdots \mathrm{Im}_1^N$	⋯	$\mathrm{Im}_G^1 \cdots \mathrm{Im}_G^N$					
Value Added			$Va_1^1 \cdots Va_1^N$	⋯	$Va_G^1 \cdots Va_G^N$					
Total Input			$X_1^1 \cdots X_1^N$	⋯	$X_G^1 \cdots X_G^N$					

Note: $Z_{ij}^{hs}(i,j = 1,2,\cdots,G; h,s = 1,2,\cdots,N)$ represents the amount of intermediate goods used by industry h in region i from industry s in region j; X_i^h, Y_{ij}^h and E_i^h represent the total output of industry h in region i, the amount of industry h in region i used as final demand by industry s in region j, and the total export amount of industry h in region i to other countries, respectively; Im_i^h and Va_i^h represent the import value of goods from other countries involved in the production process of industry h in region i, and the direct value added by industry h from its own region and industry, respectively.

Table 6
Value added decomposition indicators from the perspective of backward demand.

	Decomposition Indicator	Detailed Description
Final Goods (Y)	Local Value Added (D)	The value added produced and consumed within the region-industry.
	Outflow Value Added (RT)	The value added from the region that is exported in the form of final goods to other regions for consumption.
	Inflow Value Added (A)	The value added from other regions consumed within the region.
	Returning Value Added (B)	The value added from the region that, after flowing out, returns to the region.
	Re-exported Foreign Value Added (C)	The value added contained in the products exported from the region, originating from other regions.

It is important to note that authoritative statistics on inter-provincial trade in intermediate goods are currently unavailable. This paper utilizes interregional input-output tables to estimate value-added trade data both within and between regions. This dataset is widely used in research on regional value chain trade. The specific years analyzed are 2002, 2007, 2010, 2012, and 2015. In 2002, the dataset includes 30 regions and 21 industries; in 2007, 2010, and 2012, it comprises 30 regions and 30 industries for the remaining years; and in 2015, it covers 31 regions (with Tibet added) and 42 industries.

In this paper, based on provincial-level input-output tables, final goods are decomposed into the five components outlined in the above table. The value-added portions directly consumed locally or externally, as well as those that are exported in the form of final goods to be consumed in other regions, are "stripped out." The sum of returning value-added and the value-added from other regions is then calculated as a share of the industry's total output (B + C/total industry output) and used as the industrial linkages index to characterize the industry relations mechanism as an intermediary variable for testing. The mediation effect model is employed for regression analysis. It should be noted that because the intermediary variable is three-dimensional (region—industry—year), the dependent variable in this analysis is no longer the regional per capita GDP, but rather the total output at the region-industry-year level. The data is sourced from input-output tables, with corresponding years being 2002, 2007, 2010, 2012, and 2015, and the total number of observations is 4632. The detailed regression results are shown in Table 7.

Columns (1) and (2) in Table 7 present the regression results for the mediating variable—industry linkages, with industry linkages as the dependent variable. Column (1) shows the regression results without any control variables, while Column (2) includes control variables at the regional level. From the regression results in the table, it is evident that the coefficients for export trade openness and domestic transportation costs are both significantly negative when considered individually, whereas the interaction term is significantly positive. This indicates that trade openness has a positive impact on industry linkages across regions. Furthermore, the lower the domestic transportation costs faced by a region, the greater the positive effect of trade openness on its industry linkages. Columns (3) and (4) in Table 7 show the regression results with regional GDP at the provincial level as the dependent variable, where industry linkages, export trade openness, and domestic transportation costs are the explanatory variables. The coefficient for industry linkages is significantly positive, indicating that the effect of industry linkages has a significant positive impact on regional economic growth. In other words, the lower the domestic transportation costs faced by a region in international trade, the more pronounced the role of trade openness in promoting regional economic growth through the enhancement of industry linkages. Compared to northern regions, southern regions have lower domestic transportation costs, and as a result, the interaction effect of trade openness and domestic transportation costs has a greater impact on economic growth in the southern regions through the promotion of industry linkages.

Table 7
Mechanism test of industrial linkage effects.

	Industrial Linkage Effects		Prefecture-Level City GDP	
	First Stage		Second Stage	
	(1)	(2)	(3)	(4)
Export Trade Openness	−0.0318**	−0.0438***	−0.1248***	−0.1650***
	(−2.1617)	(−2.6803)	(−4.5281)	(−4.0859)
Domestic Transportation Costs	−0.5929***	−0.2154***	−0.1562***	−0.1216***
	(−2.6273)	(−2.8649)	(−4.4969)	(−4.4024)
Export Trade Openness * Domestic Transportation Costs	0.7880***	0.2968***	0.2212***	0.1494***
	(2.7151)	(2.9285)	(3.5472)	(4.2150)
Industrial Linkage Effects			0.1473***	0.1018***
			(3.4276)	(3.6347)
Regional Industrial Structure		0.0133***		0.3575***
		(3.9110)		(9.4805)
Regional Information Infrastructure Investment		0.0480**		0.2127***
		(2.2626)		(10.4709)
Share of Foreign Direct Investment		0.0645**		0.1994***
		(2.4211)		(6.7222)
Regional Human Capital		0.0282***		0.6738***
		(4.1835)		(8.9365)
Regional Innovation Efficiency		0.0264**		0.2355***
		(2.1243)		(17.0929)
Constant Term	−0.1099	−0.4468***	0.1379***	−0.9736***
	(−0.9682)	(−3.1841)	(6.4616)	(−6.2436)
Regional Fixed Effects	Yes	Yes	Yes	Yes
Time Fixed Effects	Yes	Yes	Yes	Yes
Observations	4632	4632	4632	4632
R-squared	0.2695	0.3063	0.3476	0.3674

Note: Values in parentheses are t-statistics corrected for heteroskedasticity; *, **, and *** denote significance levels of 10 %, 5 %, and 1 %, respectively.

4. Expanded analysis

4.1. From the perspective of domestic market integration

Trade openness and domestic market integration are two key sources of economies of scale and deepening specialization. Since China's accession to the World Trade Organization (WTO), its participation in global production fragmentation has intensified. The typical characteristics of increasing returns to scale in the industrial sector have promoted industrial agglomeration and scale expansion, which in turn have facilitated the specialization and economies of scale within upstream and downstream industries. As the degree of specialization and scale expand, higher demands are placed on the integration of the domestic market. The higher the level of domestic market integration, the greater the spatial flexibility for industrial agglomeration and specialization, which is more conducive to exploiting economies of scale and industrial linkage effects. Additionally, the factors contributing to market fragmentation are diverse, among which an important yet often overlooked factor is natural market fragmentation. This occurs due to the spatial physical factors that lead to regional market segmentation. Regions with superior infrastructure and lower transportation costs experience stronger spatial spillover effects in economic growth. In other words, the lower the transportation costs between regions, the more likely trade openness will promote domestic market integration through spatial spillover effects, thereby increasing the likelihood of regional balanced growth.

In this context, this paper selects retail price indices for 14 commodities published in the 1999–2018 China Statistical Yearbook, including grain, oil, aquatic products, beverages, tobacco and alcohol, clothing, footwear, textiles, home appliances, daily necessities, transportation and communication products, cosmetics, Chinese and Western medicines, books, newspapers, and magazines, fuel and building materials, and hardware and electrical materials. The specific approach is as follows:

First, the logarithmic values of the price ratios are calculated using the original data of the retail price index for the 14 commodities, followed by first-order differencing to construct an indicator that reflects the process of market integration.

$$\Delta Q_{ijt}^{k} = \ln\left(p_{it}^{k}\Big/p_{jt}^{k}\right) - \ln\left(p_{it-1}^{k}\Big/p_{jt-1}^{k}\right) = \ln\left(p_{it}^{k}/p_{it-1}^{k}\right) - \ln\left(p_{jt}^{k}\Big/p_{jt-1}^{k}\right) \tag{13}$$

In the above formula, i, j and k represent the local region, domestic trading partner regions, and commodity types, respectively. Therefore,

$$\Delta Q_{ijt}^{k} = -\Delta Q_{jit}^{k} \tag{14}$$

Next, to avoid the influence of regional ranking differences on $Var\left(\Delta Q_{ijt}^{k}\right)$, we take the logarithm of ΔQ_{ijt}^{k}, resulting in $\left|\Delta Q_{ijt}^{k}\right|$. $\left|\Delta Q_{ijt}^{k}\right|$ is influenced by two factors: one is related to the commodity itself, and the other is the random disturbance factor unrelated to the commodity, i.e., $\left|\Delta Q_{ijt}^{k}\right| = a^{k} + \varepsilon_{ijt}^{k}$. To account for $\left|\Delta Q_{ijt}^{k}\right|$, we subtract the average value of the k type commodity in year t from the region-to-region value $\left|\Delta \overline{Q}_{t}^{k}\right|$, as follows:

$$q_{ijt}^{k} = \varepsilon_{ijt}^{k} - \overline{\varepsilon}_{ijt}^{k} = \left|\Delta Q_{ijt}^{k}\right| - \left|\Delta \overline{Q}_{t}^{k}\right| \tag{15}$$

Finally, by calculating the variance within the region-to-region pairs, we obtain the market segmentation data at the regional level:

$$\mathrm{var}\left(q_{nt}^{k}\right) = \left[\sum_{i\neq j}\mathrm{var}\left(q_{ijt}^{k}\right)\right]\Big/N \tag{16}$$

This paper adopts the perspective of domestic market integration and, based on previous literature, employs the price index method to characterize the regional market segmentation index. Building upon this, an empirical analysis is conducted to examine the impact of trade openness, domestic transportation costs, and the interaction between market segmentation indices on regional economic growth. The econometric model is as follows:

$$\begin{aligned} GDP_{it} = {} & \beta_0 + \beta_1 tariff_{it} \times cost_i \times Integ_{it} + \beta_2 tariff_{it} \times cost_i + \beta_3 cost_i \times Integ_{it} \\ & + \beta_4 tariff_{it} \times Integ_{it} + \beta_5 tariff_{it} + \beta_6 cost_i + \beta_7 Integ_{it} + \beta_8 Controls \\ & + v_k + v_t + u_{it} \end{aligned} \tag{17}$$

Where i represents the prefecture-level city, t denotes the year, GDP_{it} refers to the regional GDP of city i in year t, $cost_i$ represents the domestic transportation costs for city i, $Integ_{it}$ is the market segmentation index of region i in year t, and $tariff_{it}$ is the trade openness indicator constructed using the weighted average tariff rate at the "city-year" two-dimensional level. v_k and v_t represent the fixed effects at the provincial and time levels, respectively.

The regression results presented in Table 8 indicate that the coefficient of the provincial market segmentation index is significantly negative. Additionally, the interaction terms between export trade openness, domestic transportation costs, and the market segmentation index, as well as those between import trade openness, domestic transportation costs, and the market segmentation index, are also significantly negative. This suggests that as the level of market integration decreases, the positive effect of trade openness and domestic transportation costs on economic growth becomes weaker. In other words, lower market integration leads to a diminished impact of trade openness on economic growth in regions with low transportation costs. This phenomenon can be attributed to the fact that higher levels of market segmentation result in lower efficiency in resource allocation, thereby leading to higher production costs for firms, which in turn reduces production efficiency. Moreover, a higher degree of market segmentation reduces the scope for industrial division of labor, as it limits the extent of specialization in production across regions. This reduction in production cooperation efficiency among firms further inhibits regional economic growth.

Table 8
Expansion analysis of domestic market domestic integration market.

	(1)
Export Trade Openness	−0.5396***
	(−3.4913)
Domestic Transportation Costs	−0.1634***
	(−3.1682)
Export Trade Openness * Domestic Transportation Costs	0.0228***
	(3.0343)
Provincial Market Segmentation Index	−0.6931**
	(−2.0664)
Export Trade Openness * Domestic Transportation Costs*Provincial Market Segmentation Index	−0.7308***
	(−3.4068)
Regional Industrial Structure	0.5575***
	(7.3735)
Regional Information Infrastructure Investment	0.1195***
	(5.0893)
Share of Foreign Direct Investment	0.0149***
	(7.5706)
Regional Human Capital	0.1216
	(0.8959)
Regional Innovation Efficiency	0.9762***
	(4.2603)
Constant Term	0.5031*
	(1.9601)
Regional Fixed Effects	Yes
Time Fixed Effects	Yes
Observations	6324
R-squared	0.8379

Note: Values in parentheses are t-statistics corrected for heteroskedasticity; *, **, and *** denote significance levels of 10 %, 5 %, and 1 %, respectively.

4.2. From the perspective of industry heterogeneity

Transportation costs, as a core component of new economic geography theory, play a decisive role in the distribution of regional economic activities. However, as an important component of trade costs, their impact on international trade is more pronounced in the trade of tangible goods. International service trade differs fundamentally from international goods trade, with existing literature noting that service trade faces almost zero transportation costs compared to goods trade. This suggests that there is a clear industry heterogeneity in the interaction effects between trade openness and domestic transportation costs. Therefore, exploring the different impacts of trade liberalization and domestic transportation costs on the manufacturing and service sectors is crucial for promoting balanced regional economic development.

Due to the limited availability of service sector data at the regional level, this paper uses the proportion of service sector employment in total employment in a prefecture-level city as a proxy indicator to represent the development of the service sector at the city level. Based on this, the study analyzes the interaction effects of trade openness and domestic transportation costs on the service industry. The econometric model is as follows:

$$Service_{it}=\beta_0+\beta_1 tariff_{it}\times cost_{it}+\beta_2 tariff_{it}+\beta_3 cost_{it}+\beta_4 Controls+v_k+v_t+u_{it} \quad (18)$$

Where $Service_{it}$ represents the service sector employment in prefecture-level city i in year t, with the core explanatory and control variables being consistent with those in the baseline regression, which will not be further elaborated here.

As shown in Table 9, the interaction term between domestic transportation costs and trade openness is not statistically significant. In other words, unlike the manufacturing sector, the interaction effect of trade openness and domestic transportation costs does not have a significant impact on the economic growth of the service sector. This can primarily be attributed to the characteristics of industry heterogeneity. Unlike manufacturing, service products are characterized by intangibility, differentiation, inseparability, and non-storability. Inseparability refers to the fact that production and consumption cannot be easily separated and must occur simultaneously, while non-storability means that services cannot be stored as easily as goods. The unique nature of service products means that transportation costs are not a major limiting factor for service trade, which provides a feasible pathway for regions with high transportation costs to stimulate economic growth through trade liberalization.

5. Conclusion and policy recommendations

5.1. Research findings

Regional coordinated development is a crucial means to narrow regional development disparities and achieve common prosperity, serving as a fundamental basis for constructing high-quality territorial space development. Currently, with the implementation of strategies such as the rise of central China and the western development initiative, the gap between eastern and western China is gradually narrowing. However, the economic disparity between northern and southern China is increasingly prominent. This paper, based on the growing economic divide between the north and south of China, explores the impacts of trade openness and domestic transportation costs on this gap from the perspective of natural geographical features.

This paper, while fully considering the regional heterogeneity of domestic transportation costs, constructs relevant indicators for domestic transportation costs based on the proportion of different transportation modes. Additionally, it builds indicators for export trade openness from the perspective of regional industrial structure differentiation. By employing interaction terms, this paper analyzes the interaction effects of export trade openness and domestic transportation costs on the economic gap between northern and southern China.

The findings indicate significant regional heterogeneity in the effect of trade openness on the economic development of China's prefecture-level cities. Trade openness has a more substantial promotional effect on economic growth in southern regions with relatively lower domestic transportation costs compared to northern regions with higher domestic transportation costs. These conclusions remain robust even after conducting tests by replacing core explanatory variables and dependent variables. The impact of export trade openness and domestic transportation costs on the north-south economic gap is mainly driven by "economies of scale" and "industrial linkages" effects.

Furthermore, from the perspective of domestic market integration, this paper explores the impact of trade openness and domestic transportation costs on the economic disparities between northern and southern regions. The findings reveal that domestic market integration is a key factor in optimizing industrial distribution. The higher the level of domestic market integration, the more pronounced the promotional effect of the interaction between trade openness and domestic transportation costs on regional economic growth. From the viewpoint of industry heterogeneity, it is found that trade openness and domestic transportation costs have a more significant impact on the manufacturing industry in northern and southern China, while the interaction effects of trade openness and domestic transportation costs do not significantly contribute to the economic gap between the north and south in the services sector.

5.2. Policy recommendations

Firstly, the analysis of the econometric regression benchmark results can provide empirical evidence for enriching international trade transportation modes. Efforts should be focused on addressing the shortcomings of the domestic transportation network in northern regions by constructing a railway network system. Key international land transport corridors, such as the "China-Europe Railway Express," the New Eurasian Land Bridge, and the Central Asia-Middle East routes, should be prioritized to accelerate the development of diversified international transportation channels. This will support the construction of major transit hubs and corridors in northern regions, optimize hub layouts in western areas, and promote the development of international freight trains, enhancing the facilitation of international cargo transportation in the west. This will foster an open, bidirectional pattern of cooperation between the east and the west. The approach should be guided by integrated planning, improving freight transportation capacity in northern regions while focusing on the effective coordination between different modes of transport. Efforts should be made to integrate road, rail, and waterway transportation systems and optimize the national transportation network by strengthening infrastructure construction along the Beijing-Hangzhou Grand Canal, which serves as a crucial connection between the north and south, enhancing its capacity to facilitate north-south cargo transport. Additionally, enhancing the efficiency of the domestic transportation network and improving infrastructure networks in regions with high transportation costs—such as railways, highways, and waterways—will contribute to the overall improvement of the transportation system.

Secondly, based on the expansion analysis, and in line with the recommendations for domestic market integration, empirical evidence can be provided for the construction of the domestic transportation

Table 9
Expansion analysis of industry heterogeneity.

	Service Sector Employment (1)
Export Trade Openness	−0.0012***
	(−8.9056)
Domestic Transportation Costs	−0.0317
	(−1.4766)
Export Trade Openness * Domestic Transportation Costs	0.4918
	(1.6357)
Regional Industrial Structure	0.0374
	(1.1886)
Regional Information Infrastructure Investment	0.1753***
	(4.5635)
Share of Foreign Direct Investment	0.0165
	(1.4123)
Regional Human Capital	1.6282**
	(2.2984)
Regional Innovation Efficiency	0.0006***
	(5.8341)
Constant Term	−0.4438***
	(−3.3856)
Regional Fixed Effects	Yes
Time Fixed Effects	Yes
Observations	6324
R-squared	0.8212

Note: Values in parentheses are t-statistics corrected for heteroskedasticity; *, **, and *** denote significance levels of 10 %, 5 %, and 1 %, respectively.

network system. A comprehensive transportation infrastructure is essential to breaking down regional barriers, promoting the spatial reallocation of resources and goods, expanding economic development space, and facilitating the smooth operation of the domestic circulation. Therefore, further expansion of the domestic freight transport network, particularly for north-south transportation routes, is necessary. Key initiatives include the development of major water transport corridors along north-south basins and the establishment of vertical corridors such as the Beijing-Hangzhou Grand Canal and the Jiang-Huai trunk line. This will further enhance the domestic water transport network, boosting internal economic circulation between northern and southern regions. According to the extension analysis of industry heterogeneity, evidence can also be provided for adjusting the structure of international trade products. Given the inconvenient transportation access in northern regions, industrial development in the north could adopt alternative approaches by shifting focus to industries with lower transportation dependencies, such as service trade and digital trade. For example, establishing cloud data centers could replace traditional transportation networks with data and information networks, thus strengthening connections between the northern and southern regions and facilitating resource exchange and economic mutual benefit.

Credit author statement

Chenyang Yu: Methodology, Writing - review & editing.
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Appendix A. Appendix

A.1. Results of robustness test

Columns (1) and (2) of Table A.1 report the regression results where the dependent variable is replaced with the GDP of prefecture-level cities. Column (3) presents the results from a regression using nightlight data to exclude statistical errors. As shown in the table, regardless of whether per capita GDP, productivity, or nightlight data is used as a substitute for the GDP of prefecture-level cities, the interaction term between export trade openness and domestic transportation costs is significantly positive. This suggests that, compared to prefecture-level cities with high transportation costs, trade openness has a more pronounced positive effect on the economic growth of regions facing lower domestic transportation costs for international trade, and the results are robust.

Table A.1
Robustness test of the dependent variable.

	Prefecture-level City GDP	Prefecture-level City Productivity	Nighttime Light Data
	(1)	(2)	(3)
Export Trade Openness	−0.6674***	−0.2513***	−0.5963***
	(−3.1478)	(−3.4653)	(−3.7687)
Domestic Transportation Costs	−0.2139***	−0.1423***	−0.0059***
	(−3.9448)	(−3.5690)	(−2.9347)
Export Trade Openness * Domestic Transportation Costs	0.2870***	0.2410***	0.7594***
	(3.8804)	(2.8152)	(2.8730)
Regional Industrial Structure	0.6871***	0.8151**	0.1641***
	(9.3576)	(2.2877)	(3.0300)
Regional Information Infrastructure Investment	0.1466**	0.0497	1.8471
	(2.3678)	(1.0267)	(0.4897)
Share of Foreign Direct Investment	0.1049***	0.2118***	0.5543***
	(2.6212)	(3.8050)	(2.8743)
Regional Human Capital	0.3870***	0.0107**	0.1917**
	(3.0878)	(2.0334)	(2.2574)
Regional Innovation Efficiency	0.7649***	0.0388***	0.2798**
	(3.8764)	(3.8440)	(2.1984)
Constant Term	−0.7834	1.2752**	2.6561*
	(−0.0373)	(2.2355)	(1.7791)
Regional Fixed Effects	Yes	Yes	Yes
Time Fixed Effects	Yes	Yes	Yes
Observations	6324	6324	6324
R-squared	0.1817	0.1876	0.0936

Note: Values in parentheses are t-statistics corrected for heteroskedasticity; *, **, and *** denote significance levels of 10 %, 5 %, and 1 %, respectively.

The regression results in Table A.2 indicate that, when the great-circle distance from prefecture-level cities to the nearest port is used as an alternative indicator for domestic transportation costs, the interaction term between export trade openness and the domestic transportation cost, as represented by distance, remains significantly positive. Furthermore, the individual coefficients for export trade openness and transportation costs are significantly negative. This once again highlights that the positive effect of export trade openness on economic growth is more pronounced in prefecture-level cities with lower domestic transportation costs. Specifically, compared to the northern regions, the natural geographical advantages of the southern regions lead to a regional heterogeneity in domestic transportation costs, which is a key factor explaining the regional asymmetry in the impact of trade openness on economic growth between the northern and southern regions.

Table A.2
Robustness test using the distance from prefecture-level cities to the nearest port as an alternative indicator for domestic transportation costs.

	(1)
Export Trade Openness	−0.5017***
	(−2.8303)
Distance from Prefecture-level City to the Nearest Port	−0.1306**
	(−2.1007)
Export Trade Openness * Distance from Prefecture-level City to the Nearest Port	0.4372***
	(3.0720)
Regional Industrial Structure	0.5199**
	(2.3289)
Regional Information Infrastructure Investment	0.1190
	(1.0863)
Share of Foreign Direct Investment	0.0139**
	(2.4992)
Regional Human Capital	0.8365
	(0.4085)
Regional Innovation Efficiency	0.1088***
	(3.0372)
Constant Term	−0.8163**
	(−2.8158)
Regional Fixed Effects	Yes
Time Fixed Effects	Yes
Observations	6324
R-squared	0.1840

Note: Values in parentheses are t-statistics corrected for heteroskedasticity; *, **, and *** denote significance levels of 10 %, 5 %, and 1 %, respectively.

The results in Table A.3 show that both the individual coefficients of the simple average export tariff and the simple average import tariff are significantly negative, while the interaction terms between these tariffs and domestic transportation costs are significantly positive. This suggests that, compared to regions with relatively higher domestic transportation costs, tariff reductions have a more pronounced effect on economic growth in regions with lower domestic transportation costs. In other words, compared to the northern regions, trade openness has a more significant effect on economic growth in the southern regions, where transportation costs are lower.

Table A.3
Robustness test of the simple average tariff as an alternative indicator of trade openness.

	(1)
Simple Average Export Tariff	−0.2619***
	(−16.2460)
Domestic Transportation Costs	−0.2002***
	(−3.1898)
Export Trade Openness * Domestic Transportation Costs	0.2643***
	(3.1681)
Regional Industrial Structure	0.5545***
	(7.2421)
Regional Information Infrastructure Investment	0.1202***
	(5.0101)
Share of Foreign Direct Investment	0.0133***
	(6.3768)
Regional Human Capital	0.1155
	(0.7782)
Regional Innovation Efficiency	0.7563***
	(3.2690)
Constant Term	0.1979***
	(7.8941)
Regional Fixed Effects	Yes
Time Fixed Effects	Yes
Observations	6324
R-squared	0.1840

Note: Values in parentheses are t-statistics corrected for heteroskedasticity; *, **, and *** denote significance levels of 10 %, 5 %, and 1 %, respectively.

Table A.4 presents the regression results after excluding resource-based cities. As observed from the table, the coefficient of the interaction term remains significantly positive, indicating that the regression results continue to hold even after the removal of resource-based prefecture-level cities. This further reinforces the robustness of the regression results in this paper.

Table A.4
Robustness test for controlling omitted variables.

	(2)
Export Trade Openness	0.7099***
	(5.1460)
Domestic Transportation Costs	0.4159***
	(10.6564)
Export Trade Openness * Domestic Transportation Costs	0.6859***
	(4.3549)
Regional Industrial Structure	0.5153***
	(8.0637)
Regional Information Infrastructure Investment	0.4482***
	(17.3748)
Share of Foreign Direct Investment	0.1677***
	(3.4873)
Regional Human Capital	0.0294
	(0.1274)
Regional Innovation Efficiency	2.6117***
	(10.0263)
Constant Term	−0.1271
	(−0.6577)
Regional Fixed Effects	Yes
Time Fixed Effects	Yes
Observations	5691
R-squared	0.1688

Note: Values in parentheses are t-statistics corrected for heteroskedasticity; *, **, and *** denote significance levels of 10 %, 5 %, and 1 %, respectively.

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