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Does the Opening of High-Speed Railway Improve High-Quality Economic Development in the Yangtze River Delta, China?

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Abstract: The Yangtze River Delta (YRD) is the area with the densest high-speed railway (HSR) network in China, and it leads the high-quality economic development (HQED) in the country. HSR plays an important role in regional development. However, research on the impact of the HSR on HQED is notably limited. Theoretically, this study develops an analytical framework for the mechanism of the HSR's influence on HQED. Empirically, it calculates the HQED index and then investigates the impact of the HSR on HQED and the regional discrepancies across cities in the YRD, based on data from 2011 to 2019 using the difference-in-differences model. The results show: (1) The mechanism lies in that the HSR improves urban accessibility, accelerates the flow of the production factors, and enhances the allocation efficiency of the input factors. (2) The distribution of the HQED level presents an obvious circular pattern, with Shanghai and Suzhou at the centre, showing the prominent principle of distance decay. (3) Both the regression model and the robustness tests show that the HSR significantly promotes HQED in the YRD. Additionally, the economic development, foreign capital spent, financial level, industry advancement, and living standard are conducive to HQED. (4) The results of the heterogeneity test reveal that the HSR has an obviously varied impact on HQED in cities depending on their size and location. The HSR has a significant promotional effect on HQED in cities with a large population and those far away from a provincial city.

Keywords: high-speed railway (HSR); high-quality economic development (HQED); the Yangtze River Delta (YRD); impact mechanism

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1. Introduction

Since sustainable development, which addresses development issues in society, the economy, and the environment in an integrated manner [1], was proposed in the 1980s, relative concepts and practices have attracted attention globally [2]. Economic development quality was proposed at the end of the 20th century as a complementary part of sustainable development [3]. Thomas put forward that in order to obtain and ensure broad-based and long-term growth, combining actions on equality, quality, and sustainability with those for growth should be taken [4]. Boyle and Simms believe that economic growth, the sustainable development of humans and nature, and living standards should be combined into the connotations of economic growth quality [5]. In 2015, the United Nations put forward 17 sustainable development goals to thoroughly solve the development problems regarding social, economic, and environmental development in an integrated way, and to shift to the path of sustainable development [6,7]. In the same year, China proposed a new development philosophy including innovative, coordinated, green, open, and shared development based on sustainable development, and then put forth high-quality economic development (HQED), which embodies the concrete implementation of the five new development

concepts [8]. To achieve a more efficient, equitable, and sustainable form of development, China declared that China's economy had transformed from high-speed development to high-quality development in October 2017. In 2020, the Chinese government reiterated that the theme of economic and social development during the 14th Five-Year Plan (2021–2025) should facilitate HQED. This emphasis is aimed at promoting sustainability of the ecological environment, meeting the aspirations for a better life, and enhancing the economy's overall competitiveness. Compared with the sustainable development goals proposed by the United Nations, the HQED advocated by the Chinese government represents a specific implementation of these development goals tailored to address the challenges faced by China and many other developing countries. The promotion of HQED is not only an essential necessity for maintaining healthy economic development, but also a crucial guarantee for achieving sustainable development.

Against this background, it is particularly important to understand what HQED is and how to promote HQED and, then, promote sustainable development. A number of scholars have conducted research on HQED [9–11], investigating both the comprehensive factors [12] that influence it and the individual influencing factors [13–15]. Notably, some found that transportation is one of the significant influencing factors [16]. As HQED has been gradually implemented, China's high-speed railway (HSR) is also undergoing rapid development. Since 2012, China has added over 3000 kms of HSR lines annually. By the end of 2022, the operating mileage had reached 42,000 kms, significantly impacting the country's socioeconomic development. However, existing research on the impact of HSR on HQED is still insufficient. At this point, further questions are yet to be explored: whether and how HSR improves HQED, what are the detailed impacts, what are the impact mechanisms of the HSR on HQED, and further, if the HSR can drive HQED, is there any heterogeneity in the impact of the HSR on HQED in a specific region? This study aims to explore these questions and empirically test the impact of the HSR on HQED and the regional differences based on 41 cities in the Yangtze River Delta (YRD) region in China, which is one of the three most economically developed regions in China and a pioneer in practising HQED. A deep examination of these questions would be beneficial for amplifying the effect of HSR, enhancing regional HQED, and achieving sustainable development.

The remaining sections in this study are organised as follows. Section 2 presents the literature review. Section 3 defines the connotations of HQED, and builds and illustrates the theoretical mechanism and hypotheses. Section 4 describes the study area, econometric model, variable design, and data sources, as well as the distribution characteristics and spatiotemporal evolution characteristics of the HQED in the YRD. Section 5 presents the empirical testing and the analytical results. Section 6 contains the discussion and policy implications and in Section 7 we make the main conclusions.

2. Literature Review

2.1. The Research on High-Quality Economic Development

After the quality of economic development became a concern in the 1990s, some scholars began to focus on it [3,17,18]. Xu argued that an increase in production efficiency is equivalent to a degree of economic quality; that is, the ability of a given input to generate more output [3]. Thomas et al. considered economic growth quality to be a supplement to the speed of the development and that the quality of the economic development should also encompass the distribution of welfare, the ecological environment, risk resistance, and governance [17]. Barro believed that the quality of economic growth should cover the life expectancy, environmental conditions, social welfare, political institutions, and religious beliefs [18].

As Chinese economic development shifted to a new norm (*xinchangtai*) in 2012, there has been increased focus on the quality of economic development. After HQED was introduced in 2015, many scholars have explored its connotations, the measurement methods, and influencing factors. Most researchers consider the connotations of HQED based on the report from the 19th National Congress of the Communist Party of China, which states

that development must adhere to quality first and prioritise efficiency; implement structural reforms on the supply side as the main aim; promote quality, efficiency, and power change in the economic development; and improve total factor productivity (TFP) [14]. The connotations include not only economic factors, but also social, environmental, and some other detailed factors, such as governance, quality of life, livelihood, employment status, education level, and national life expectancy [11,15,19,20]. As the new development concept, namely, innovative, coordinated, green, openness, and sharing are put into practice gradually, the five aspects are regarded as the fundamental pillars of China's HQED [21].

Regarding the measurement of HQED, earlier studies primarily focused on the quality of economic development. Many scholars adopted total factor productivity (TFP) as a measurement method [22]. With the clarification of the HQED concept, some scholars have added green development to TFP [23]. Given the extensive connotations of HQED, it is unscientific to measure it from one aspect. Therefore, more scholars have adopted a multi-dimensional approach to measure high-quality development or HQED. Yang et al. evaluated HQED from the economic structure, economic efficiency, and ecological environment aspects [24]. Pan et al. constructed a high-quality development index from five aspects: economic development, innovation efficiency, environmental impact, ecological services, and people's livelihoods [25]. Liu et al. built a comprehensive indicator system based on the five development concepts to measure the HQED level [26]. Kong et al. built an economic growth quality index system with the dimensions of efficiency, stability, and sustainability [27]. Li et al. set up a multiple-index system to calculate HQED, encompassing five dimensions and 24 detailed indexes, completely corresponding to the five development concepts [15]. Guo et al. constructed an evaluation index system for HQED at the city level from five dimensions, including the industrial structure, inclusive TFP, technology innovation, the ecological environment, and residents' living standards [28]. Li, F. and Li, M. built an evaluation system, including economic operation, social development, and ecological sustainability, to calculate the HQED in 41 cities in the YRD and found that there is a prominent divergence in cities [20].

In addition, there are some studies on the HQED pattern and influencing factors. Researchers have found that the level of HQED is influenced by multiple factors, including transportation, the suitability of the natural environment, the urbanisation level and population agglomeration, the investment pattern, and the digital economy [12,14,15,29].

2.2. The Research on the Effect of High-Speed Railway on Economic Development

The ever-improving HSR network has made a huge impact on social and economic development, and has sparked widespread debate among government, industry, and academia [30,31]. It is widely recognised that the opening of HSR reduces transportation costs and travel time [32], improves accessibility, accelerates the flow of economic factors, stimulates urban economic vitality, and promotes urban economic growth [33–35]. Sasaki et al. [36,37] found that HSR have positive effects on services and manufacturing: it accelerates the growth of tertiary industries and also improves the production efficiency of enterprises or industries, thereby promoting economic growth and development. Sahu and Verma found that productivity was increased by the introduction of HSR at an institutional or industrial level [38]. Moreover, HSR can indirectly promote economic growth by impacting on labour, industrial agglomeration, the stimulation of new consumption and employment, and other aspects [39,40].

Existing literature on the effect of HSR on regional economic development is relatively rich and, among them, some empirical studies have examined the impact of transportation infrastructure improvement on the HQED in cities [41]. Li and Wang [42] investigated the impact of the introduction of HSR on the growth quality of the Yangtze River Economic Belt. Hu et al. [43] discovered that the introduction of HSR or the improvement of access facilities would enhance the mutual effect of urbanisation and socioeconomic growth. Kong et al. [44] studied the influence of HSR on the quality of urban economic growth based on Chinese cities.

However, the combined impact of HSR on HQED, particularly in the YRD region, and its regional differences have been insufficiently studied. In addition, the existing studies have not yet reached a consistent conclusion; some indicate that HSR have no positive effects on the economy and may even have a negative effect [45]. The most noticeable effect is the 'metropolis effect' brought in by the introduction of HSR [46], which promotes business expansion in mega cities, creating a polarising effect, and reducing economic growth rates in the periphery, hence increasing externalisation [47]. An et al. also found that HSR enormously improves the overall connectivity of urban networks in the YRD, while it also aggravates regional economic disparities [34].

The YRD region has the densest HSR network and was among the first to launch HSR. At the same time, the region is one of the most economically dynamic regions in China. It has a pivotal strategic position in the country's modernisation, and it is regarded as a suitable experimental area for comprehensive research on geographical and sustainability science at the trans-regional scale [48].

This study focuses on the impact of HSR on the HQED in the YRD in China, and its contributions are as follows. First, it constructs a comprehensive impact mechanism of HSR on HQED from five dimensions, namely innovation, coordination, green, openness, and sharing. This can enrich the research literature on HQED in general, provide a new perspective for promoting HQED with a new economic norm, and also enlarge the research perspective on the HSR effect.

Second, based on the rich connotations of regional HQED and the present literature, we built an evaluation system which investigates both the input and output sides, and includes six aspects in the second level and 19 detailed indicators in the third level. Based on the evaluation system, we focus on specific cities within the YRD in China, instead of just eastern, central, and western China, as the research scope for a larger scale. We first calculate the HQED index for 41 cities in the YRD from 2011 to 2019, then explore the spatiotemporal evolution characteristics, and find that the HQED improves over time and takes on a distance attenuation law centred on Shanghai and Suzhou. These innovate the existing measurement methods for HQED and also optimise its applicability in practice.

Third, regarding HSR opening as an exogenous shock, we examine the impact of HSR on HQED in the YRD, and carry out heterogeneity tests in the YRD by using the difference-in-differences (DID) model, which effectively strips out the impact of the HSR on HQED. We find that HSR have an obviously different impact on HQED in cities with different locations and sizes. This enlarges the breadth of the present studies on the effects of HSR on HQED. Given that the HQED in the YRD has a benchmarking and leading role in China, it can provide experience for other regions in China, and even other countries, on aspects for amplifying the impact of HSR and promoting HQED.

3. Theoretical Framework and Research Hypotheses

Since the introduction of HQED, its connotations have gradually been refined by a number of scholars from different perspectives and emphases, according to different research motivations [11,14,15,21,23,23,28], yet a unified expression remains elusive. This study also tends to join the debate according to the five new development concepts of "innovation, coordination, green, openness, and sharing" [15]. Among them, innovative development focuses on solving the problem of development momentum and motivation, coordinated development emphasises solving the problem of unbalanced development, green development addresses solving the problem of harmony between human beings and nature, open development means solving the problem of internal and external linkage in the development, while shared development focuses on solving the problem of social justice [49]. In this study, HQED is regarded as a comprehensive development encompassing high economic efficiency, innovation driven, coordination among regions (including urban and rural, developed and underdeveloped areas), harmony between human beings and nature, positive interaction between internal and external linkage, social justice, and

sharing (all people have access to education, health care and other rights, sharing the fruits of social and economic development).

Based on previous studies, this study builds the impact mechanism of HSR on HQED from the five new development concepts and the nature and role of HSR. Compared with other transportation, the HSR has many advantages, including higher speed, larger transportation capacity, better safety, more comfort and convenience, lower energy consumption, and better economic benefits. These advantages reduce the travel time and perceived psychological distance between cities, boost the accessibility of cities and, consequently, hasten the flow of labour, information, knowledge, technology, and capital [50,51]. All economic entities are able to allocate the factors of production on a larger scale, thereby increasing the allocation efficiency of resources. Through the effects of agglomeration and knowledge spillovers, the compression effect of time and space [1] caused by the improvement in accessibility will have a positive impact on regional HQED. The rapid development of HSR leads the factors to flow to fit the market, eliminating geographical constraints and accelerating industry renewal. Simultaneously, the development of HSR will induce changes in the productive efficiency of production organisation [38]. It will also accelerate the transformation and updating of industrial structures and the enhancement of research and development expenditures (R&D) and human capital. This will enhance the quality of economic development in multiple ways. Figure 1 presents the detailed impact mechanism of HSR on the five aspects of HQED.

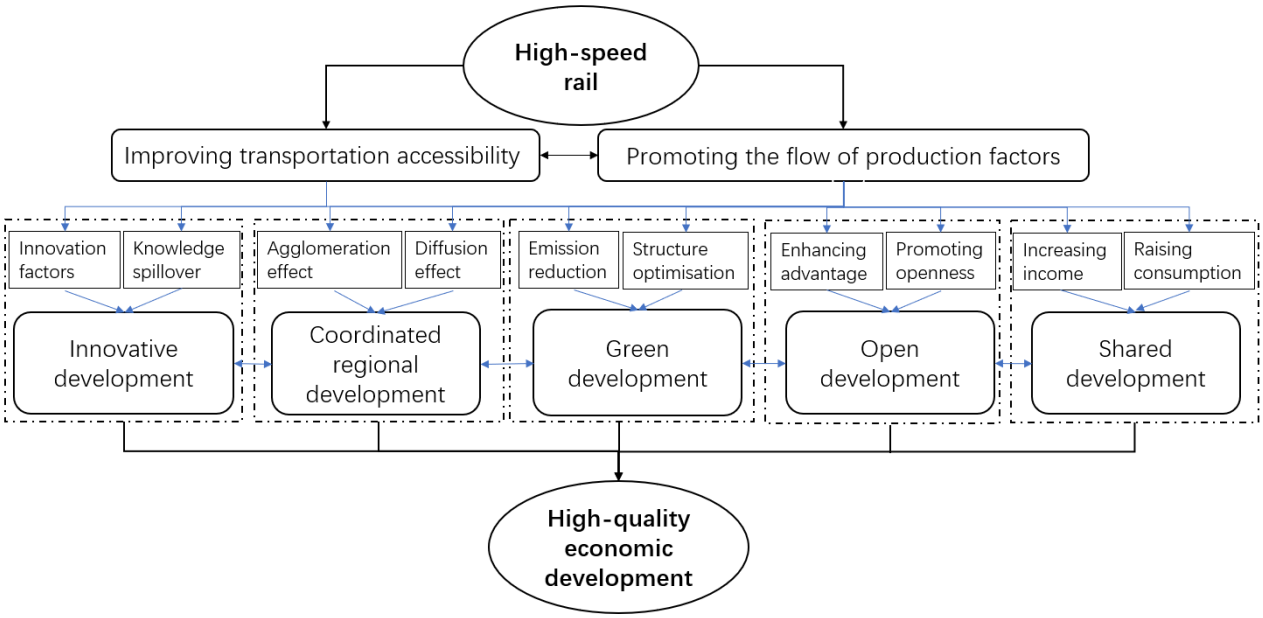

Figure 1. Impact mechanism framework for HSR on regional HQED.

3.1. The Impact of HSR on Innovative Development

The opening of HSR improves regional accessibility and boosts innovative development [52] in two ways. First, it improves the flow efficiency of innovation factors. Second, it promotes knowledge spillovers and enhances knowledge externalities, ultimately enhancing innovative regional development.

HSR will accelerate the concentration of innovation factors, comprised of labour and capital [40], to cities connected by the HSR. This is an important path to promote regional innovation development. HSR attracts more highly educated and skilled talent, along with high-tech industry employees, to flow into enterprises in cities along the HSR. When combined with the improvement in the information environment, these factors promote the innovation in enterprises and promote the cities' innovation [52]. The flow of innovation factors triggered by the HSR may also show a 'syphon effect', which can suppress innovation in peripheral cities. The opening of the HSR saves transportation costs, acceler-

ates the dissemination of elements and technologies, and breaks down regional borders. This process shortens distances between regions and fosters cross-regional collaborative innovation [53], thereby enhancing face-to-face communication and promoting the tacit knowledge spillover among regions, cities, and enterprises along the HSR. Consequently, this increases the patent output and innovation ability of enterprises, further promotes the innovation performance of enterprises and industries, and ultimately regional innovation levels [54].

In general, HSR can effectively improve the spillover of technological innovation and accelerate the high-quality innovation and development of cities. This is realised by promoting agglomeration economy spillovers, learning activities among enterprises, and the flow of human resources and capital, as well as trade and cooperation [55]. Additionally, Hanley et al. also found that HSR increased innovation collaboration between enterprises at the city level [56].

3.2. The Impact of HSR on Regional Coordinated Development

Faber found that HSR links lead to a drop in GDP growth in outlying counties because industrial output dramatically falls in these areas in China. Faber found that transportation connected the central and surrounding cities and reduced trade costs by strengthening communication and exchanges between regions [45], which contributes to coordinated development. HSR significantly improves cities' accessibility, thereby reducing the time and economic costs for transregional economic activities. It enables various production factors to flow more conveniently among regions. The factors gather or diffuse in different cities and regions, trigger the redistribution of economic activities, and affect the coordinated development in the regions. The economic redistribution caused by HSR is manifested in two opposite effects: agglomeration and diffusion. A larger agglomeration effect enlarges the regional development gap, and large cities continue to 'syphon' resources, as well as development opportunities, from small cities. In contrast, a larger diffusion effect narrows the gap between regions and promotes the process of coordinated regional development.

Researchers have made different discoveries on the actual impact of HSR on regional coordinated development. Some found that HSR increases the aggregation effect because HSR induces resources to accumulate in central cities [57]; thus, HSR gradually enlarges regional differences. Other scholars believe that HSR enhances the location advantages of surrounding small cities, causing spillover effects from large cities to small cities, thus narrowing regional differences. Yao et al. found that HSR have consistently reduced interregional and urban–rural inequalities by fostering spillovers from larger urban areas to smaller peripheral areas [58]. Jiang and Kim found that HSR contribute to realise the convergence objectives in China and Korea [59], and gradually promote coordinated regional development.

The agglomeration effect and diffusion effect induced by HSR exist simultaneously. Under different temporal and spatial horizons, the two effects show the tendency for one to be stronger and the other weaker. But, in the long run, the spatiotemporal compression effect provides more opportunities for less developed regions and improves coordinated regional development. Just as Jin and Wang [60] found that during the formation period for the main lines, the agglomeration effect is the main force and strengthens the imbalance in the regional development, while during the branch line construction period, the outflow of factors from developed cities becomes the main trend, which benefits the balance of the regional development. Zhang et al. also proved that HSR improve the inequity at the national and also help to promote provincial economic equity in China [61].

3.3. Impact of HSR on Green Development

The impact of HSR on green development is mainly achieved through carbon reduction and industrial structure optimisation, because HSR have the characteristics of relatively low energy consumption, high cleanliness, green environmental protection, high efficiency, and comfort. Compared to other traditional ground transportation, HSR obtain its driving

force from electricity, which produces less pollution than traditional transportation, thereby reducing energy consumption and vehicle exhaust emissions, air pollutants, and industrial waste [62]. For example, the concentration of PM2.5 in air could decrease about 2.8% after the county connects to the HSR network [63]. Zhang et al. found that HSR are more beneficial to green development and greatly facilitate GTFP (green total factor productivity) by diminishing energy consumption, environmental pollution, and improving technological innovation [64]. For short- and medium-distance travel activities, HSR travel has greatly replaced the use of private cars, coaches, and traditional trains.

The introduction of HSR is conducive of the continuous optimisation of the industrial structure [65], which is not only one of the important ways to reduce environmental pollution and ecological damage, but also one of the cores of HQED. HSR are sensitive to the degree of convenience for passenger transportation in the service industry [66]. HSR have a critical role in accelerating employment and the number of consumers within higher service industries and can also greatly enhance the agglomeration of higher service industries in central cities, and can effectively optimise and upgrade the industrial structure [67]. Since the construction and opening of a large scale HSR networks in China, the employment rate in the service industry has significantly increased and the structure of the industry has shifted from labour intensive to capital intensive.

Of course, the construction of HSR requires intensive consumption of pollutant-intensive resources. In exploring the impact of the opening of HSR on the five dimensions of HQED, Liu et al. found that the coefficient of the impact of HSR on green development is statistically insignificant in both the long and short term [41].

3.4. Impact of HSR on Open Development

The improvement to transportation will decrease the cost of cargo transportation and the cost of time and inventory, allowing enterprises to obtain the price advantage from export products [68]. This can also promote and improve the structure and quality of regional export products. Although HSR are mainly used for passengers, these conclusions cannot simply be transplanted to the analysis on HSR, while HSR can have a positive impact on trade and exports through at least two channels. First, by improving regional accessibility, it facilitates communication between people and corporates, and reduces enterprises' costs for searching for information, communication, outsourcing, and other marginal spending. This enables enterprises to strengthen their ties with outside areas by enhancing matching efficiency with suppliers, thereby improving the performance of enterprises along the route [69,70]. Consequently, it enhances the international competitive advantage of products. Zhou et al. also found that HSR can decrease information barriers and costs to enter the international market and promote the export growth of agriculture-related companies around HSR stations [71]. Charnoz et al. also found that HSR improve commuting efficiency between regions and the exchange of information in French between corporate headquarters and branches [32]. Cosar and Demir discovered that the improvement to domestic transportation has reduced access barriers to international markets, which can help a country take part in the international supply chain, boost international competitive advantages and, hence, contribute to the country's international trade [72].

Second, the substitution effect on traditional transportation releases transportation resources for freight transportation. It increases the efficiency of freight transportation and the availability of cargo space, thereby reducing the cost of cargo transportation and enhancing the competitiveness of products for enterprises. HSR also make it easier for manufacturers to find more suitable suppliers to maximise their profits, which, in turn, significantly promotes exports [73]. Additionally, HSR will significantly promote the trade opening of Chinese cities through the tariff transmission mechanism [74]. Overall, the opening of HSR can promote competitive advantages, increase the scale and quality of exports [71,75], and further boost open development.

3.5. Impact of HSR on Shared Development

HSR meet the needs of the public for fast travel because it reduces travel time and increases the public's opportunities to travel. The introduction of HSR also affects two detailed aspects of shared development, income, and consumption. According to Gil-Pareja et al. [76], HSR have both direct and indirect impacts on the income of urban residents along the railway lines. Direct impacts include increasing investment and business income, creating more employment opportunities, and reducing the time cost of tourist travel. Indirect impacts are mainly reflected in employment and income aspects through resource reallocation, which is caused by changes in high-speed transportation. Researchers have found that HSR can reduce income inequality in China [77] and Italy [78].

From the perspective of general consumption, HSR promote consumption by reducing circulation costs and commodity prices. The opening of HSR generally contributes to the growth in consumption expenditure and the upgrading of consumption structures in cities along the railway line [44,79]. HSR also push consumption-related industries to decrease their prices for market competition [80]. Of course, the promotional impact of HSR on consumption varies depending on the station location and the scale of the city [81]. At the same time, by compressing the spatiotemporal distance, some residents' working, living, and consumption needs across cities are met. In total, HSR enlarge the overall consumption by expanding the scope of consumption [82].

It is worth noting that the above five dimensions are not absolutely isolated, rather, they are interrelated and reinforced in some ways. From a horizontal perspective, among the five dimensions, innovative development is the driving force of HQED [49]. It plays an important role in the development of the other four dimensions and, conversely, the other dimensions also rely on the driving force of innovation. Coordinated development focuses on the coordinated development of urban/rural areas and developed/developing regions from a spatial perspective, and shared development aims to include people in sharing the fruits of development and, ultimately, realising common prosperity [8]. These two dimensions are highly complementary to each other, and are also the ultimate goals of HQED, leading the development of the other three dimensions. Green development is reflected in all aspects of economic growth and social development [8], which is both the inheritance of sustainable development [6] and the concrete embodiment of sustainable development in China. This dimension runs through the other four dimensions and is also an important symbol of China's economic development, shifting from the pursuit of speed to the pursuit of quality [23]. Open development aims to foster extensive engagement in the global industrial division of labour and cooperation, while upholding a diverse and stable international economic pattern and economic and trade relations. It serves as a key guarantee for achieving innovative, coordinated, green, and shared development. Taking the interactive relationship between innovative development and green development as an example, the opening of HSR accelerates the flow of talent and knowledge within wider regions, and then improves the level of regional innovation and human capital. This further promotes the improvement of pollution control technology and the progress of green and environmental protection production technology, and it realises the suppression effect of HSR on air pollution. Meanwhile, the innovative development caused by HSR promotes the transformation and upgrading of industries, which, in turn, contributes to energy conservation and pollution emissions reduction and further accelerates green development and sustainable development. Similar interactions among other dimensions exist. According to this theoretical analysis on the mechanism, the study puts forward two research hypotheses, as follows:

Hypothesis 1. *The opening of HSR has a significant positive impact on regional high-quality economic development.*

Hypothesis 2. *There are significant regional differences in the impact of HSR on regional high-quality economic development.*

4. Research Design

4.1. Study Area

The study area, the Yangtze River Delta (YRD), is located in the lower reaches of the Yangtze River in China, including four provincial-level administrative units, those of the Shanghai municipality, Jiangsu province, Zhejiang province, and Anhui province, containing forty-one prefectural-level cities, covering an area of 358,000 square km^2. The YRD is one of the most economically developed and innovative regions in China. By the end of 2022, this area had a permanent population of 231 million and a total GDP of CNY 29.03 trillion. With an area less than 4% of the whole country, this region produces nearly one-fourth of the total economic output and one-third of the total imports and exports in China. The YRD is the only super-large urban agglomeration in China that ranks among the top six in the world. It plays a pioneering and exemplary role in HQED in China. At the same time, the YRD has the highest density of HSR networks in China with over 13,749.7km of railway, of which more than 6700 km and nearly 30 routes (Figure 2) are HSR [2]. Thus, the YRD has become a model region for exploring the impact of HSR on HQED.

4.2. Methodology

4.2.1. Model Construction

The method of difference-in-differences (DID) can validly control the endogenous problems in policy variables and acquire an unbiased net effect for policy evaluation [67], and it has been used to examine the effect of HSR between an HSR city and a non-HSR city [83]. This study identifies cities that have implemented HSR as the treatment group and those that have not implemented HSR as the control group, based on panel data collected from 41 prefecture-level cities in the YRD during the period of 2011–2019. The grouping dummy variable D_{it} is used as a proxy: $D_{it} = 1$ means that city i launched HSR in year t, and $D_{it} = 0$ means that city i did not launch HSR in year t. The staging dummy variable T_{it} is also set, $T_{it} = 1$ denotes the period subsequent to the commencement of the HSR, whereas $T_{it} = 0$ denotes the period preceding the commencement of the HSR. The focus of the study is on the interaction term $D_{it} \times T_{it}$, which indicates the actual impact of the HSR opening on the level of the quality of the economic development in the city. Since the time of opening of the HSR varies across the prefectures, this paper replaces the interaction term $D_{it} \times T_{it}$ with the variable $treat_{it}$, which indicates whether city i was affected by the shock of opening the HSR in year t. If city i opened the HSR in year t, its corresponding $treat_{it}$ value is 1, otherwise $treat_{it} = 0$. Based on the theoretical analysis and Liu et al. [39], we constructed the following multi-period DID model.

$$Hq_{it} = \alpha + \beta treat_{it} + \gamma X_{it} + \mu_i + \tau_t + \varepsilon_{it} \quad (1)$$

In Equation (1), the explanatory variable Hq_{it} denotes the level of HQED in city i in year t, $treat_{it}$ is the product of $D_{it} \times T_{it}$. X_{it} represents several other control variables that have an impact on the HQED in the city, μ_i is an individual fixed effect, τ_t is the time fixed effect, and ε_{it} is the random disturbance term. The coefficient β in Equation (1) is the focus in this study, which indicates the cumulative impact of the inauguration of the HSR on the HQED in the city. β is greater than 0 if the opening of the HSR boosts the HQED in the city, otherwise it is less than 0. In order to estimate the degree of impact of the opening of the HSR on the HQED, this study adds five control variables X, namely the level of economic development, openness, financial level, industrial advancement, living standard, and innovation; where the level of economic development (lrgdp) is represented as the gross domestic product per capita in logarithmic form [24], the openness (lforeign) is characterised by taking the (log) actual amount of foreign capital spent in the year from Xu and Pan [84], the expression of the financial level (lfin) is derived from the (log) year-end deposit balance of the financial institutions based on Li and Wang [42], and the industry advancement (ind) is measured by the Theil index from [28], the living standard (lwage) is

represented by the (log) average employee salary from [34], and the innovation level (linn) is expressed as the logarithm of the number of patent applications from [14].

Figure 2. The distribution of HSR in the Yangtze River Delta in 2022. Source: The website of the National Railway Administration and the Special Issue on Railway Passenger and Cargo Transport.

The reasons for selecting these variables are: (1) the level of economic development is one of the most important macroeconomic indicators that objectively reflects the dynamics of economic and social development, and "GDP per capita" measures the main material basis for the per capita income and living standard of a country's residents. (2) Improving the level of openness and constructing a new open economic system at a higher level can promote HQED in the YRD, and because the YRD's export trade volume and outward investment rank among the top in the country, it is necessary to include openness in the control variables. (3) The financial level reflects the marginal productivity of capital, which is an important manifestation of the optimal allocation of capital. Increasing financial support in key areas can consolidate and strengthen the foundation of the real economy. (4) Industrial advancement has a "structural dividend" on economic growth, which helps to improve the green total factor productivity growth rate and is, overall, conducive to promoting high-quality development in the YRD. The high-quality development of the economy needs to satisfy the growing needs of the people. (5) HQED is supposed to meet the people's growing needs for a better life, and it is necessary to include the living standard in the control variables. The "average worker's wage" is a suitable indicator of the living standard. (6) The HQED of the YRD economy needs to realise the shift from the primary factors of production to scientific and technological innovation. As the first driving force for development, innovation is the engine of HQED.

4.2.2. Data Sources and Data Processing

As mentioned in the literature review, HQED has rich connotations, and researchers believe that more attention should be paid to improving the economic structure, including the industrial structure, consumption structure, import and export structure, and openness [85]. The measurement index should cover various aspects, and many scholars have built index systems including three, five, or six aspects [15,24,27,28,65]. For example, Kong et al. constructed an index system including three dimensions of efficiency, stability, and sustainability [27]. Li et al. built an index system including the aspects of the economic growth structure and economic efficiency, the ecological environment, and social coordination [20]. Guo and Sun set up an evaluation index including 6 primary indexes, namely economic growth, innovation, coordination, green, openness, and sharing [21].

Based on the previous literature, this study further expands the index system for HQED, mainly originating from the five dimensions of HQED, also considering factor input efficiency. Besides, we also try to cover the sustainable development goals [6] proposed by the United Nations that are closely related to the reality in China. Of course, when determining specific indicators, we fully consider the availability of the data. Table 1 shows the specific evaluation system, which includes three levels, with 2 dimensions in level 1, namely the input index and output index, 6 indexes in level 2, namely the factor input and innovative development, coordinate development, green development, open development, and shared development, and 19 indicators in level 3 (see Table 1).

According to Li and Li [20], Guo et al. [28], Liu et al. [41], and Kong et al. [44], the entropy value method is applicable to comprehensively evaluate the HQED in the YRD in this study. After standardising the data, calculating the weight of the samples for each indicator, the entropy value and coefficient of variation for each indicator are derived. After calculating the weights of each indicator in Table 1, the comprehensive score for the HQED is further estimated according to the weights of each indicator and standardised statistics.

The original data are from the China City Statistical Yearbook, the China Statistical Yearbook, the yearbooks of each province, and the website of the National Bureau of Statistics. The opening information on HSR (Figure 2) comes from the State Railway Administration and the Special Issue on Railway Passenger and Freight Transportation (available on request).

Table 1. Index system for regional HQED.

Level 1 Index	Level 2 Index	Level 3 Index		Attribute
		Specific Measurement Index	**Index Interpretation and Index Unit**	
Input index	Factor input efficiency	Labor input	Total number of employees in the whole society/GDP	Positive
		Capital input	Total fixed assets investment/GDP	Positive
		Government investment	Government expenditure/GDP	Positive
Output index	Innovative development	R&D investment intensity	R&D expenditure/GDP (%)	Positive
		Number of invention patents owned by 10,000 people	Authorised number of invention patents/resident population at the end of the year (pieces/10,000 people)	Positive
		Science and technology investment intensity	Fiscal expenditure on science/total fiscal expenditure (%)	Positive
	Coordinated development	Urban–rural income ratio	Urban per capita disposable income/rural per capita disposable income (%)	Negative
		Coordinated pressure index	Unemployment rate + CPI (%)	Negative
	Green development	Green coverage rate of built-up area	Green coverage rate of built-up area (%)	Positive
		Harmless treatment rate of domestic garbage	Harmless treatment rate of domestic garbage (%)	Positive
		Sewage treatment rate	Sewage treatment quantity/total sewage quantity (%)	Positive
		Energy consumption per unit, GDP	Total energy consumption/GDP (tonne/CNY 10,000)	Negative
		Industrial wastewater discharge per unit, GDP	Industrial wastewater discharge/GDP (tonne/CNY 10,000)	Negative
	Open development	Openness to foreign capital	Actual utilisation of foreign investment/GDP	Positive
		Foreign trade dependence degree	Total import and export/GDP	Positive
	Shared development	Per capita disposable income	Per capita disposable income (CNY 10,000)	Positive
		Per capita consumption expenditure	Per capita consumption expenditure (CNY 10,000)	Positive
		Per capita expenditure on education and culture	Per capita expenditure on education and culture (CNY 10,000)	Positive
		Intensity of medical and health investment	Medical and health expenditure of local finance/general finance budget expenditure (%)	Positive

Notes: Among the 17 goals on sustainable development, number 8 and number 16 relate to decent work and economic growth, and institutional justice, respectively, part of 8 and the government function corresponding to the factor input efficiency. Number 9 relates to industrial technology innovation, part of 8 and 9 corresponding to innovative development. Number 10 relates to reducing inequality, so part of 8 and 10 corresponding to coordinated development. Number 6 refers to clean drinking water, 7 refers to clean energy, 11 refers to sustainable communities, 12 refers to sustainable supply, ensuring responsible production and consumption, 13 refers to climate action, 15 refers to the protection of ecosystems, all these corresponding to green development. Number 17 relates to the partnership for implementation and revitalisation of global sustainable development, corresponding to open development. Number 3 is about health and well-being, 4 is about quality education, these two goals and part of 10 correspond to shared development.

Based on the above methods, we calculated all the HQED indexes for the 41 prefecture-level cities in the YRD region from 2011 to 2019 and selected 2011, 2015, and 2019 as the years to analyse the spatiotemporal evolution characteristics (Figures 3–5).

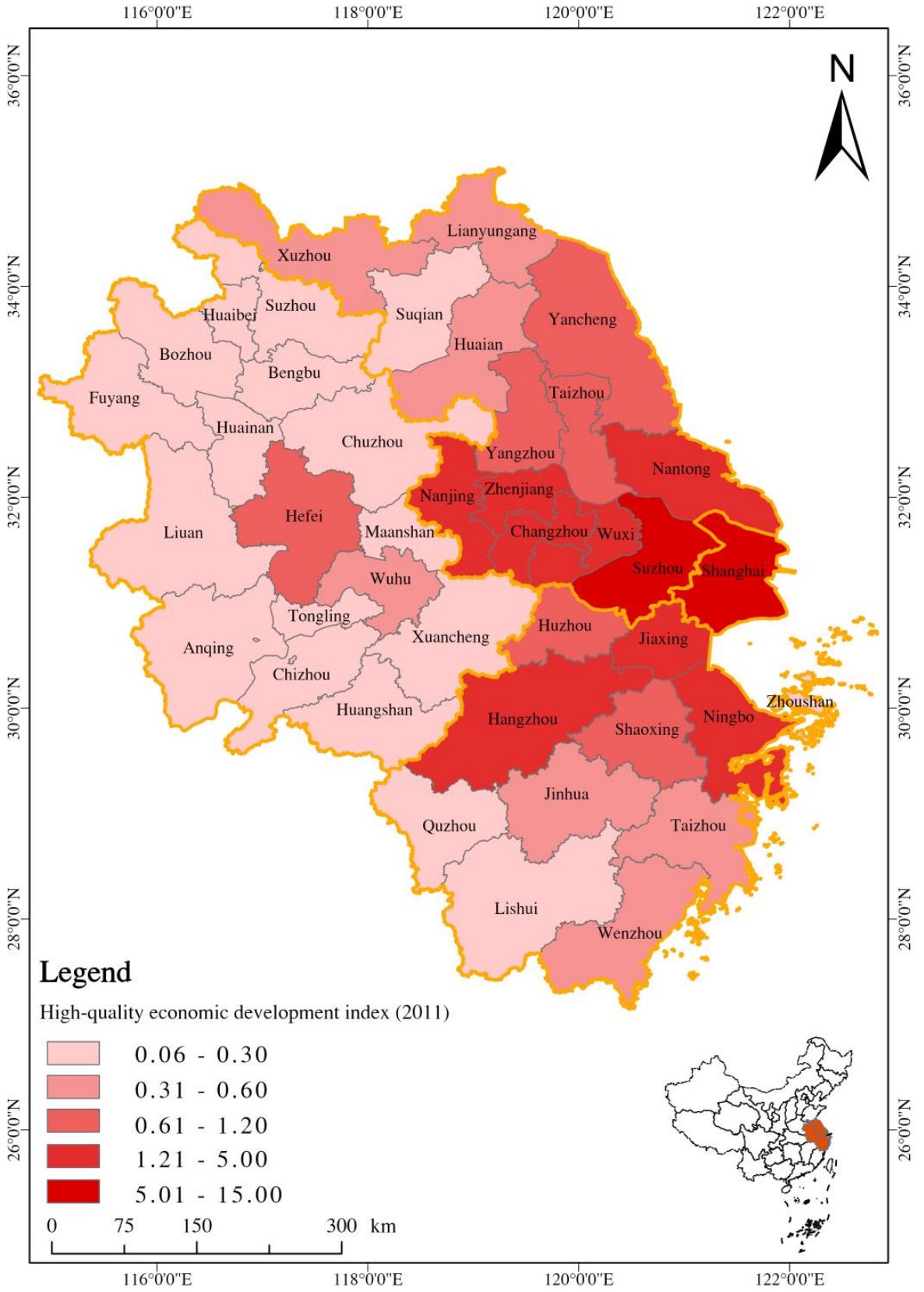

Figure 3. Distribution of the HQED index in the YRD (2011).

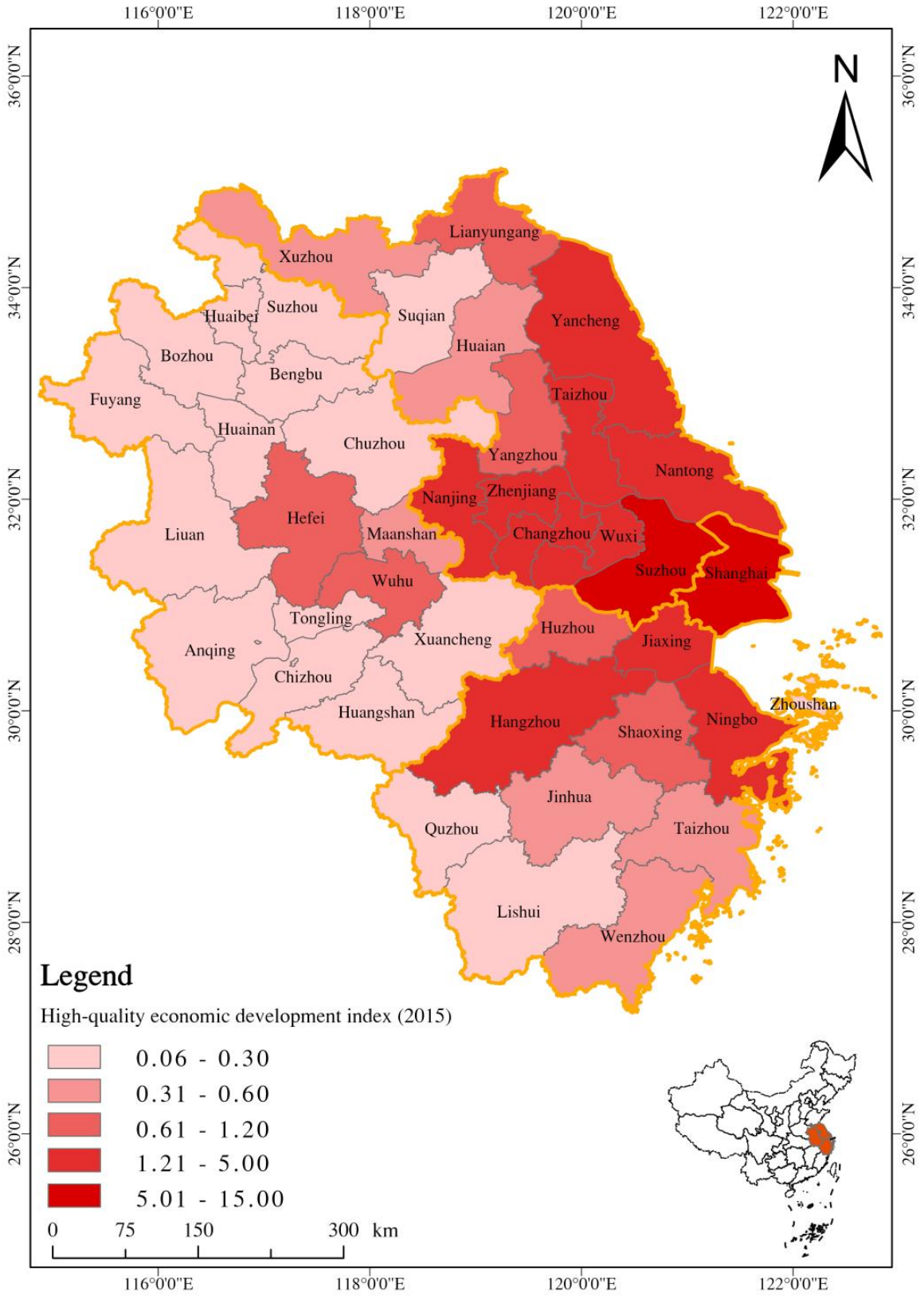

Figure 4. Distribution of the HQED index in the YRD (2015).

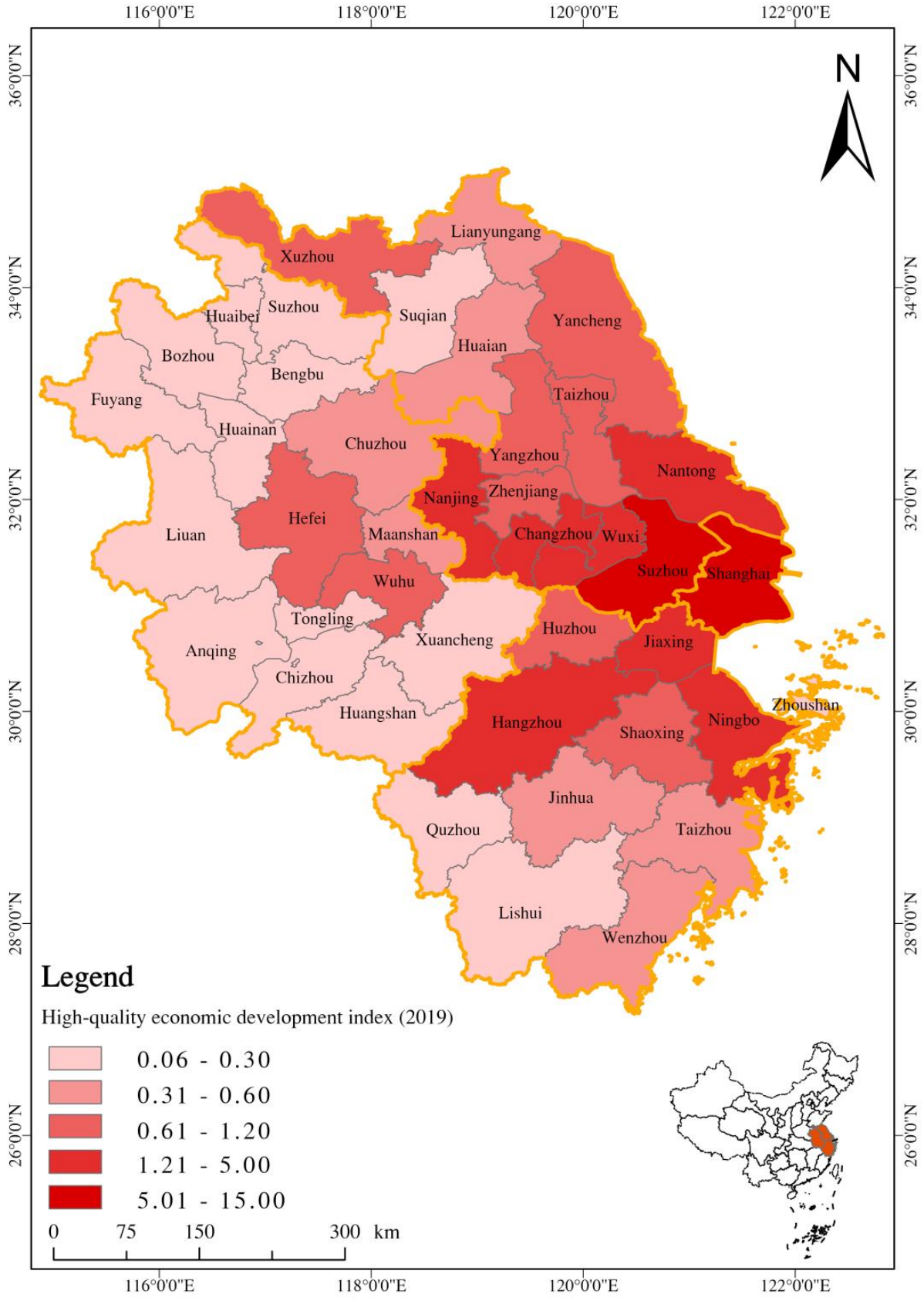

Figure 5. Distribution of the HQED index in the YRD (2019).

As shown in Figures 3–5, the HQED index for the cities in the YRD are much higher than that of the central and western regions, but the regional differences within the YRD are obvious. From 2011 to 2019, there is a significant trend of radiating down to the north, west, and south, with Shanghai and Suzhou at the centre. The two cities are always the first tier, and the second and third tiers are mainly concentrated in the areas close to Shanghai and Suzhou, in southern Jiangsu province and in eastern and northern Zhejiang province and Hefei in Anhui province. Except for Xuzhou, the cities in the peripheral areas of the YRD are in the fourth and fifth tiers. From 2011 to 2019, the HQED index for cities in Anhui province significantly improved because these cities are close to Nanjing in Jiangsu province. They are Wuhu, jumping from the fourth to the third tier, and Chuzhou and Maanshan, jumping from the fifth to the fourth tier. The rate of quality improvement in these cities is significantly higher than some similar cities in Jiangsu and Zhejiang province that are closer to Shanghai. All the other cities in the YRD basically maintained their original positions. This indicates that Shanghai has successfully driven quality improvement in the surrounding regions, which, in turn, has further driven quality improvement in the surrounding areas, showing a clear principle of distance decay. This distance attenuation law also presents a wave-like feature.

The other control variables in this study are also derived from the aforementioned databases, and the descriptive statistics for all the data are shown in Table 2.

Table 2. Descriptive statistics for the variables.

Variable	Observation Number	Mean	Standard Deviation	Minimum	Maximum
Hq	369	1.407	2.759	0.034	13.901
treat	369	0.629	0.484	0	1
lrgdp	369	1.763	0.604	0.009	2.991
lfin	369	1.31	1.111	−0.831	4.815
lforeign	369	2.165	1.226	−0.814	5.25
ind	369	6.668	0.311	5.863	7.488
lwage	369	1.815	0.297	1.011	2.774
linn	369	3.759	1.272	0.572	6.541

5. Empirical Results

5.1. Regression Results

Table 3 shows the regression results for Equation (1). Column (1) presents the regression result without adding the control variables; the coefficient of variable *treat* is 0.104 and it is significant. Columns (2) to (7) are the regression results adding in order the six control variables, namely the economic development level, openness, financial level, industrial advancement, living standard, and innovation.

The results show that the coefficients of the variable *treat* are statistically significant, with coefficient values between 0.092 and 0.123. The results indicate that the opening of a HSR has a significant positive contribution to HQED in cities in the YRD, which has led to an increase in the HQED in cities with a HSR station from 0.092 to 0.123. Comparing the regression results in columns (2)–(7), it is found that the coefficient of influence tends to be first upwards and then downwards, which indicates that it is necessary to include the control variables in Equation (1). The coefficients of the control variables are significantly positive except for *lwage and linn*, which means that the level of economic development, openness, the financial level, and industrial advancement are also conducive of HQED; this result matches with our expectations and the mechanism explained earlier. Thus, Hypothesis 1 is confirmed. It is consistent with the mainstream view [13,44] that the opening of HSR stimulates economic vitality and promotes the urban economy.

Table 3. Empirical results on the impact of HSR opening on HQED in the YRD.

	(1) FE1	(2) FE2	(3) FE3	(4) FE4	(5) FE5	(6) FE6	(7) FE7
treat	0.104 **	0.121 ***	0.120 ***	0.123 ***	0.100 **	0.100 **	0.092 **
	(4.552)	(4.475)	(4.451)	(4.395)	(4.505)	(4.488)	(4.535)
lrgdp		0.414 ***	0.416 ***	0.339 ***	0.243 **	0.280 **	0.267 **
		(10.67)	(10.61)	(10.77)	(11.64)	(11.76)	(11.79)
lforeign			0.023 **	0.020 *	0.021 **	0.025 **	0.024 **
			(1.080)	(1.070)	(1.065)	(1.079)	(1.080)
lfin				0.482 ***	0.393 **	0.373 **	0.327 **
				(15.73)	(16.20)	(16.17)	(16.57)
ind					0.451 **	0.485 **	0.458 **
					(21.40)	(21.39)	(21.48)
lwage						−0.418 *	−0.442 *
						(22.57)	(22.63)
linn							0.0629
							(5.000)
_cons	1.358 ***	0.761 ***	0.709 ***	0.420 **	−2.299 *	−1.957	−1.869
	(3.923)	(15.86)	(15.97)	(18.38)	(130.2)	(131.0)	(131.0)
N	369	369	369	369	369	369	369
R^2	0.083	0.124	0.137	0.161	0.173	0.182	0.186

Notes: *, **, *** indicate statistical significance at the 10%, 5%, and 1% levels; the values in parentheses are robust standard deviations.

The HSR opening drives the concentration of human and material capital in cities, promotes the optimal allocation of production factors, and indirectly promotes the HQED in cities by leading consumption and creating jobs. The level of innovation is expected to have a positive effect on high-quality development, but the results are not significant. This may be due to the relatively singular way of measuring the innovation level or the existence of differences in the innovation levels across cities, which may smooth out the influence of innovation on the HQED in the regression. Considering that innovation is indeed an indispensable factor affecting HQED, it is retained in the model.

Following this, we further explored the impact of the opening of HSR on the five dimensions of HQED in the YRD individually. Taking innovative, coordinated, openness, green, and shared development as dependent variables, we conducted regression analysis using Equation (1). The results are shown in Table 4. It was found that the opening of HSR have a significant positive effect on innovation and openness development in the YRD, with impact coefficients of 0.022 and 0.057, respectively. The impact coefficients on coordinated, green, and shared development are relatively small, while still positive. The results indicate that the opening of HSR greatly accelerates the level of R&D innovation and external openness in the YRD, and improves the coordinated, green, and shared development of cities to some extent, too.

5.2. Robustness Tests

5.2.1. Parallel Trend Test

Assessing the effects of policy implementation by using DID is subject to the basic assumption of parallel trends. The DID estimation results are considered credible if the experimental and control groups exhibit a similar trend prior to the commencement of the HSR and exhibit no significant differences, that is, the regression coefficient of *treat* before the opening time of the HSR is not significant, while the coefficient of *treat* after the opening time of the HSR is significantly different from zero. Therefore, the study defined dummy variables for 9 years to re-estimate the coefficients, namely *Pre-4*, *Pre-3*, *Pre-2*, *Current*, *Post-1*, *Post-2*, *Post-3*, *Post-4*, and *Post-5*, denoting the period spanning from four years prior to five years subsequent to the opening of the HSR.

Table 4. Empirical results on the impact of HSR opening on five dimensions of HQED in the YRD.

	(1) Innovative Development	(2) Coordinated Development	(3) Green Development	(4) Open Development	(5) Shared Development
treat	0.022 **	0.005 **	0.001 **	0.057 **	0.006 **
	(0.011)	(0.002)	(0.001)	(0.028)	(0.003)
lrgdp	0.065 **	0.013 **	0.004 **	0.167 **	0.018 **
	(0.029)	(0.006)	(0.002)	(0.074)	(0.008)
lforeign	0.006 **	0.001 **	0.0003 **	0.015 **	0.002 **
	(0.003)	(0.001)	(0.0001)	(0.007)	(0.001)
lfin	0.079 **	0.016 **	0.004 **	0.205 **	0.022 **
	(0.040)	(0.008)	(0.002)	(0.104)	(0.011)
ind	0.111 **	0.023 **	0.006 **	0.287 **	0.031 **
	(0.052)	(0.011)	(0.002)	(0.134)	(0.015)
lwage	−0.107 *	−0.022 *	−0.006 *	−0.277 *	−0.030 *
	(0.055)	(0.011)	(0.003)	(0.142)	(0.016)
linn	0.015	0.003	0.001	0.039	0.004
	(0.012)	(0.002)	(0.001)	(0.031)	(0.003)
_cons	−0.453	−0.093	−0.025	−1.171	−0.128
	(0.318)	(0.065)	(0.017)	(0.821)	(0.090)
N	369	369	369	369	369
R^2	0.186	0.186	0.186	0.186	0.186

Notes: *, ** indicate statistical significance at the 10%, 5% levels.

As seen in Figure 6, the coefficients of the dummy variables in the four periods before the policy shock are not significantly different from zero, indicating that the control and treatment groups have similar development trends; the coefficients are significantly higher than zero after the policy shock occurs, and they perform particularly obviously in the first to fourth periods. The test results confirm that the model in this study can reasonably reflect the policy effects.

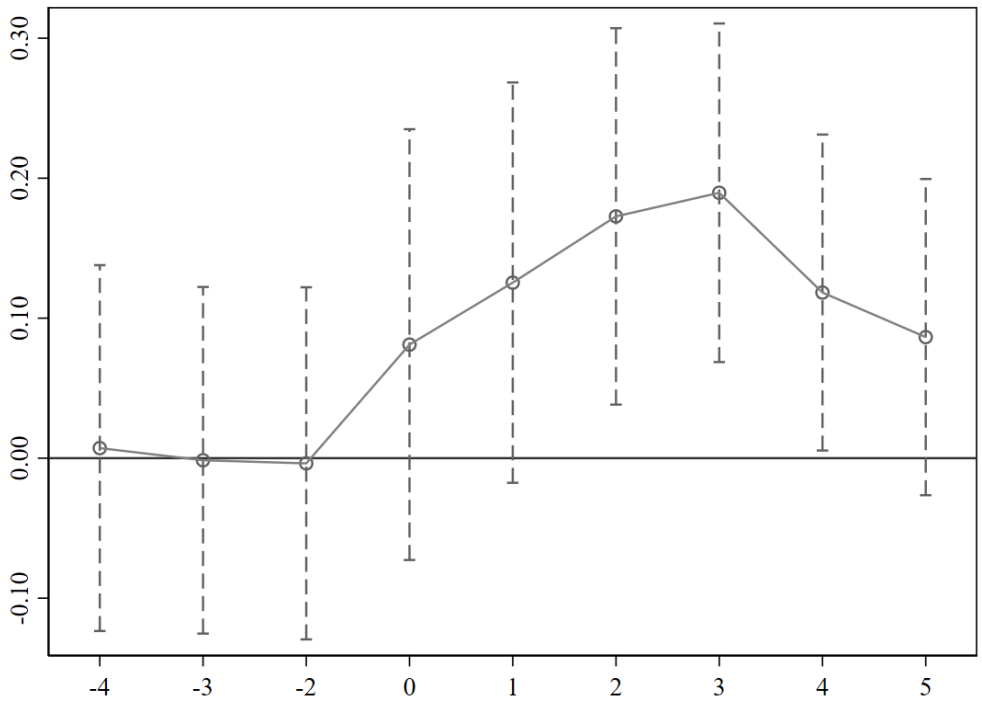

Figure 6. Parallel trend test.

5.2.2. Placebo Test

If the HQED in the city is caused by factors other than the HSR, then assume that the city does not have a HSR in the year of its opening, and the opening of the HSR will also bring about significant results. Otherwise, it can be assumed that the improvement in HQED comes from the effect of HSR shocks. For this reason, this study used a counterfactual approach to conduct placebo tests for both the region and time, that is, a random sample period was selected for each sample subject as its policy time. In the multi-period DID, each of the 41 cities in the YRD was randomly selected from 2011 to 2019 as the time when the policy was implemented, which was used as the basis for the grouping and staging of the 'experiment' of HSR opening. The evaluation of the robustness of the benchmark regression was judged by the significance and distribution of the double difference term estimates.

The red curve in Figure 7 is the kernel density distribution of the estimated coefficients, and the orange dots are the p-values corresponding to the estimated coefficients. It is evident from Figure 7 that the coefficients of the randomised DID terms are concentrated around zero, and most of the *p*-values are higher than 0.1. Randomly advancing the opening time of the HSR in each city leads to a significant weakening of the driving effect of the HSR opening on the HQED in terms of the significance and strength of the effect. This also confirms from the counterfactual perspective that the HSR does improve the HQED in the city, and Hypothesis 1 is further confirmed.

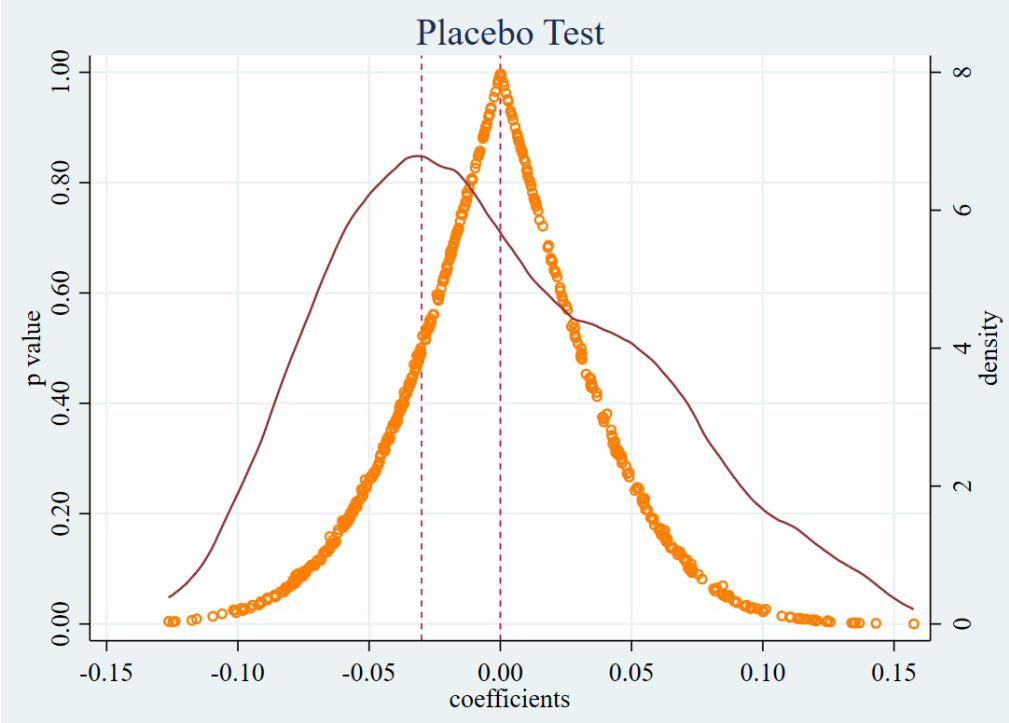

Figure 7. Placebo test.

5.2.3. Robust Test

In order to check whether the conclusion still has stable explanatory power when the conditions change, this paper conducts a robustness test by means of the Winsorise treatment, adjusting the sample period, dynamic regression, and IV, respectively. Table 5 reports the results. The impact of the HSR opening on the HQED is significantly positive in all the columns. Therefore, it is verified that the basic hypothesis, that the opening of a HSR can promote HQED in the YRD, is stable.

Table 5. Robust test results.

	(1) Winsorise	(2) 2012–2018	(3) Dynamic	(4) IV: Slope
treat	0.086 *	0.083 *	0.453 *	0.446 *
	(4.417)	(5.002)	(24.088)	(1.836)
lrgdp	0.226 **	0.257 **	0.180	0.460 **
	(11.49)	(12.74)	(16.116)	(2.277)
lforeign	0.024 **	0.023 *	0.019	0.028 ***
	(1.052)	(1.199)	(4.458)	(2.724)
lfin	0.338 **	0.327 *	0.760	0.118
	(16.14)	(19.78)	(84.671)	(0.950)
ind	0.467**	0.586**	1.278	−0.152
	(20.92)	(22.88)	(96.403)	(−0.513)
lwage	−0.423 *	−0.587 **	0.507	−1.031 ***
	(22.04)	(26.35)	(130.825)	(−3.666)
linn	0.066	0.042	−0.010	0.066
	(4.870)	(6.067)	(15.150)	(1.356)
L.hq			0.006 ***	1.625
			(0.112)	(0.867)
_cons	−1.915	−2.408 *		1.624
	(127.6)	(140.7)		(0.867)
N	369	328	287	369
R^2	0.187	0.189		0.994

Notes: *, **, *** indicate statistical significance at the 10%, 5%, and 1% levels.

Specifically, considering the large gap between the HQED in some cities and the existence of extreme value cases, this study first tries to test the extreme value treatment at the 1% and 99% quantile of *hq*. The results show that the coefficient of the impact of the opening of a HSR on HQED is 0.086, which is reduced compared with the coefficient estimate of the benchmark regression. Second, since some cities have opened a HSR before 2011, the sample period is adjusted to 2012–2019, and the results in column (2) indicate that the effect of a HSR opening on HQED after 2012 is still positive. Third, the city's development in the previous year may influence the current period's HQED index, this study lags the explanatory variables by one period to establish a dynamic panel data model, and the results are shown in column (3). The regression results for *treat* and L.hq are both significantly positive, and the coefficient of *treat* is higher when compared to the static regression results.

In order to overcome the possible endogeneity problem, this study refers to Ji and Yang [86] and selects an interaction term for the slope and year dummy variables as the instrumental variable, since the slope can affect the difficulty of HSR construction, and the slope is an exogenous geographic variable, which does not have a direct effect on the HQED index. The regression results in column (4) are still positive after correcting for potential endogeneity issues (Table 5).

5.3. Endogeneity Test

The selection of high-speed rail stations is usually considered to be non-random and biased towards cities with better economic development. There may be endogeneity issues in the model. In view of the close relationship between the opening of the post station and urban traffic, the opening of the post station is not related to the current situation. Therefore, the dummy variable (*ifyz*) for the opening of the Ming Dynasty post station can be used as an instrumental variable for the opening of the HSR (*treat*), referring to Li et al. [87].

After using the treatment effect model and MLE method, it can be seen that *ifyz* is significantly positive in the first step of the regression, which shows that the choice of an instrumental variable is effective. In the second step of the regression, the core explanatory variable treat is significantly positive, which is shown as *1.treat* in column (2), indicating that the sample with the treat value of 1 has a higher level of HQED by 0.266 units. This is

about three times the benchmark regression result of 0.092, which shows that the influence of *treat* on *hq* is underestimated without considering the self-selection bias (Table 6). After MLE processing of the models with self-selection bias, the estimation bias was alleviated. The results prove that the opening of a HSR still has an important role in promoting the HQED in the YRD.

Table 6. Endogeneity test results.

	(1) Treat	(2) Hq
lrgdp	−0.715	0.363 ***
	(0.359)	(0.064)
lforeign	−0.107 **	0.026 ***
	(0.042)	(0.010)
lfin	1.036	0.053
	(0.232)	(0.106)
ind	0.755 ***	0.192 ***
	(0.036)	(0.018)
lwage	1.627	−0.420
	(0.231)	(0.231)
linn	−0.435 ***	0.098 **
	(0.075)	(0.043)
ifyz	0.374 *	
	(0.213)	
1.treat		0.266 ***
		(0.048)
_cons	−5.971	−1.182
	(4.286)	(1.776)

Notes: *, **, *** indicate statistical significance at the 10%, 5%, and 1% levels.

5.4. Heterogeneity Analysis

The previous parts of this study mainly examined the overall effect of HSR opening on HQED. Since the initial endowment of the transportation facilities and economic characteristics of cities vary greatly in the YRD region, it is helpful to further examine the heterogeneous performance of diverse types of cities after the opening of a HSR in order to test in-depth the differential impact of HSR on HQED. Specifically, this study groups the 41 cities according to geographic distance, referred to by Gao et al. [88], and city size. Geographic distance is measured by the distance between each city and the capital city of the province in which it is located. Within a boundary of 150,000 m, it divides the sample (excluding Shanghai, Nanjing, Hangzhou, and Hefei) into 18 cities close to the provincial capital city and 19 cities far from the provincial capital city. In addition, in terms of city size, according to the national urban scale classification standards, 41 cities in the YRD are classified into three categories based on the permanent population size at the end of 2019: 1–5 million people, 5–10 million people, and more than 10 million people. The results from the sub-sample regression are shown in Table 7.

As for the impact in cities in different locations, the result shows that the opening of HSR have a significantly stronger promotional effect for the areas farther away from the provincial capital city, while the promotional effect for the areas closer to the provincial capital city is smaller and not significant. This result may be due to the siphon effect. The provincial capital cities are the political, economic, and cultural centres of the provinces in the YRD, and they are still in the stage of agglomeration development and have comparative advantages in regard to resource allocation. Due to the drainage effect caused by the opening of a HSR, provincial capital cities have an overtaking effect on neighbouring cities, which relatively reduces the HQED level of nearby cities. But in cities 150,000 m away, this effect basically disappears, and those cities are more likely to receive the combined impact of the HSR and further improve their HQED level.

Table 7. Heterogeneity analysis results.

Dependent	**Distance**		**Population**		
	(1)	(2)	(3)	(4)	(5)
Variable	close	far	1–5 million	5–10 million	10 million +
treat	0.016	0.164 ***	0.023	0.110 **	0.092 **
	(6.042)	(5.921)	(0.084)	(0.049)	(0.045)
lrgdp	0.312 ***	0.312 ***	0.272 **	0.272 **	0.267 **
	(11.99)	(11.99)	(0.118)	(0.118)	(0.118)
lforeign	0.025 **	0.025 **	0.025 **	0.025 **	0.024 **
	(1.077)	(1.077)	(0.011)	(0.011)	(0.011)
lfin	0.358 **	0.358 **	0.304 *	0.304 *	0.327 **
	(16.58)	(16.58)	(0.167)	(0.167)	(0.166)
ind	0.466 **	0.466 **	0.471 **	0.471 **	0.458 **
	(21.39)	(21.39)	(0.215)	(0.215)	(0.215)
lwage	−0.394 *	−0.394 *	−0.439 *	−0.439 *	−0.442 *
	(22.68)	(22.68)	(0.226)	(0.226)	(0.226)
linn	0.053	0.053	0.066	0.066	0.063
	(5.006)	(5.006)	(0.050)	(0.050)	(0.050)
_cons	−2.046	−2.060	−1.936	−1.943	−1.869
	(130.8)	(130.9)	(1.312)	(1.313)	(1.310)
N	369	369	369	369	369
R^2	0.195	0.195	0.189	0.189	0.186

Notes: *, **, *** indicate statistical significance at the 10%, 5%, and 1% levels; the values in parentheses are robust standard deviations. "10 million +" in column (5) represents a resident population of more than 10 million people.

As for the impact of different sized cities, the *treat* coefficient for cities with a population size exceeding 10 million is equal to the estimated coefficient of 0.092 in the basic regression, and the *treat* coefficient for cities with a population size of 5–10 million is greater than 0.092. This indicates that the HSR enhances the hub position of cities with a population over 5 million as growth poles in regional development, and the convenient HSR network brings more capital, human resources, and information to these mega cities, making positive contributions to the HQED in these cities. Meanwhile, the coefficient of treat in column (3) is 0.023, but fails to pass the significance test, indicating that the opening of the HSR has not yet brought about a significant positive impact effect on the HQED in cities with a population of 1–5 million in the YRD, which is possibly because provincial capitals and other mega cities themselves are more attractive than surrounding cities, and human and physical capital flow to big cities because of the opening of a HSR. Thus, Hypothesis 2 is verified.

The coefficients of the control variables in the heterogeneity tests are significantly positive except for *linn*, which means that the level of economic development, openness, the financial level, industrial advancement, and living standard are also conducive of HQED in the YRD region.

6. Discussion

6.1. Theoretical Value and Practical Value

Based on the five dimensions of the new development concepts, sustainable development goals, and the characteristics of HSR, this study defines the connotations of HQED and builds a comprehensive theoretical framework that includes five interacting aspects of the influence mechanism. It then sets up an evaluation system for HQED, including both input and output indexes in the first level, six dimensions in the second level, and 19 detailed indicators in third level. Compared to the present evaluation system and mechanism analysis, the mechanism framework and the evaluation system are more holistic, more comprehensive, and more practical. Subsequent empirical study confirms that HSR have a significant impact on HQED in the YRD and the robustness tests confirm the results.

The results support previous studies [13,20,30,44,84] in that the introduction of HSR have improved the HQED in the cities along the railway lines.

The heterogeneity test based on city location and size indicates that the impact of a HSR on HQED in the YRD has obvious regional differences. HSR have a stronger impact on cities far away from the provincial capital city and positively improves HQED in cities with a population more than 5 million. However, for those smaller cities, especially for those cities with population less than 5 million and close to the provincial capital city, the impact of a HSR is not significant. The heterogeneity results partly confirm the present studies, while also present inconsistent result. Some researchers find that major cities benefit more from HSR than smaller cities, and eastern cities benefit more than central and western cities [44,47]. Research on HSR in Europe indicates that the impact of a HSR on a region is complex, bringing about positive impacts on the core areas of central cities, especially those around the stations, but possibly posing a threat to the status of peripheral cities, with an impact on the renewal of edge cities as well [46]. Our study indicates that although HSR can theoretically improve the local transportation situation and bring more development opportunities to cities, the cities with a smaller population may lose their resources and production factors to large cities with higher economic agglomeration and advanced industrial structures. The loss of factors, to some extent, offsets the positive impact. But for large cities far away from the provincial capital city, such as Xuzhou city in northeast of Jiangsu province, and Ningbo city in southeast Zhejiang province, HQED benefits from the HSR.

In addition, we also found that the control variables, including the level of economic development, openness, financial level, and industry advancement contribute to the HQED in the YRD. The study not only extends the research on the economic effect of HSR and the factors affecting regional HQED, especially on the impact of HSR on HQED, but also introduces the case of the Yangtze River Delta, which is also valuable for sustainable and regional HQED in other regions and countries.

6.2. Policy Enlightenment

As the fastest and most technologically advanced ground transportation infrastructure, HSR set up inter-provincial and inter-city links and play an important role in economic development, regional integration, and urban cluster construction [89]. Against the background of the completion of the "eight vertical and eight horizontal" network, and in the context of the new economic norm that emphasises the needs of the people and solving the contradictions and problems of unbalanced and insufficient development, this study offers three policy enlightenments based on the empirical findings.

Firstly, HSR play a crucial role in facilitating regional HQED, which fits the needs of the contemporary era and the objectives of national strategic development; thus, the planning, construction, and investment in HSR networks should be further improved so as to amplify the effect of the HSR and promote HQED and sustainable development in cities along the routes, making the HSR network a more important part of the new economic circulation system. Except for HSR, a variety of factors contribute to HQED, therefore, when promoting regional HQED, other factors should be considered jointly to promote HQED in the future.

Secondly, the heterogeneity test results indicate that flexible supporting policies should be made and make full use of the dividends brought by the HSR according to local context. The influence of a HSR opening on HQED in cities with different locations and sizes varies significantly. Therefore, different countermeasures should be conducted, taking specific problems, various comparative advantages, various composition structures, various degrees of development, and accurate positioning into consideration. As the HSR comes into operation, large cities should still make full use of the high-quality resources and industrial agglomeration effect, reasonably formulate active industrial planning, and cultivate the development opportunities of high value-added industries. Meanwhile, cities with a population of less than 5 million should make full use of the dividends of HSR, and vigorously

develop secondary and tertiary industries, such as tourism and transportation logistics. At the same time, they could actively utilise the spillover effects of large cities according to their own advantages, and continuously and effectively improve HQED.

Thirdly, there is still much room to enhance the function of HSR operation in promoting innovation, openness, green, coordinated, and sharing development. The supporting infrastructure around HSR stations should be synchronously constructed to build a green transportation system with 'zero-distance interchange and seamless connection' and fully release the effects of HSR. In addition, the systemic constraints and fetters should be further broken down to achieve the potential of HSR in resource sharing. The flow and sharing of intellectual resources should be accelerated to furnish human resources and technical support for HQED.

7. Conclusions

7.1. Main Conclusions

In this study, we established the influence framework of HSR on regional HQED, built the system of indicators for measuring HQED, and then measured and analysed the temporal and spatial variation in the HQED index in the YRD. A DID model and robustness tests were then constructed to analyse whether the opening of a HSR promotes regional HQED, based on panel data from 41 cities in the YRD from 2011 to 2019. Mechanism analysis shows that HSR can improve the level of economic quality development by improving inter-city accessibility, accelerating factor flow, reducing environmental pollution, promoting industrial agglomeration, optimising income distribution, and promoting consumption. Meanwhile, the impact of HSR on the five dimensions of HQED is mutually reinforcing and interrelated.

The empirical study finds that a HSR opening made significant contributions to the HQED in the YRD cities and had significant heterogeneity in view of the location and cite size. The findings remain reliable after parallel trend tests, multiple robustness tests, placebo tests, and endogeneity tests. In addition, the level of economic development, openness, the financial level, and industry advancement contribute together to the HQED in the YRD. Secondly, there are notable differences in the contribution of HSR on the HQED in cities of different scales and locations in the YRD. The impact is significant in cities with a population greater than 5 million, while the contribution to cities with a population lower than 5 million is not obvious. At the same time, the opening of a HSR has a significant stronger promotional effect on the cities farther away from the provincial capital city.

7.2. Limitations and Future Directions

This study has the following limitations. First, due to data limitations, this empirical study is conducted on the prefecture level and only adopts the opening of a HSR as the introduction of the HSR instead of service frequency and total travel time of the HSR. If county-level data and detailed data on HSR can be obtained, the research conclusions will be more targeted and will comprehensively reflect regional differences on multiple levels. Second, although this study finds that the spatial distribution of HQED presents obvious spatial differences, and the impact of HSR on HQED is very divergent within different cities in the YRD, it has not yet explored the spatial spillover effects. In the future, the spatial spillover effects from HSR on HQED can be explored in further studies.

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Data Availability Statement: The publicly available sources for the data used in this study have been described in 4.4.2 of the article. The original data are from the China City Statistical Yearbook, the China Statistical Yearbook, the yearbooks of each province, and the website of the National Bureau of Statistics. The opening information on HSR comes from the State Railway Administration and the Special Issue on Railway Passenger and Freight Transportation. The slope used in 5.2.3 is from https://mp.weixin.qq.com/s/9qZMImMyMbQIgwI7HB7EUg. The Ming Dynasty post station used in 5.3 is from https://mp.weixin.qq.com/s/CqCEexVbYrz6V6JIFEiSvg. The data used in this paper are available on request from the corresponding author.

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Notes

[1] The concept of 'space–time compression' was first proposed by American sociologist R.D. McKenzic in his book Urban Community in 1933. It is a theory on temporal and spatial changes in human interaction caused by advances in transportation and communication technology. According to the theory, the time and distance required for human interaction within a given geographical area have been reduced by improvements in transportation and communication technology.

[2] Data resource: Wang Li. The Yangtze River Delta plans to invest more than 90 billion yuan in railway construction this year and add 2500 km of HSR in the next three years [N]. Jiefang Daily, 12th, Feb, 2023.

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