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Do High-Speed Rail Networks Promote Coupling Coordination between Employment and Industry Output? A Study Based on Evidence from China

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Abstract: The sustainable development of China's economy requires better allocation of labor across regions and sectors in the face of the vanishing of demographic dividends. Based on the panel data of 276 cities from 2007 to 2019, this study explores the influence of China's high-speed rail network on the coupling coordination level between employment and output in different industries. This paper has also tested the dynamics of this effect with four different time periods. The heterogeneity of levels of city clusters is also investigated by dividing all the city samples into four groups according to the levels of city clusters, namely first tier, second tier, third tier, and non-cluster. The following conclusions are drawn. First, a high-speed rail network only positively influences the employment–output coupling coordination level of the tertiary industry while having a negative effect on the other two. Second, the higher the level of city cluster that one city has, the greater the impact of the high-speed rail. Third, the high-speed rail network's positive effect on the secondary industry tends to become negative in the longer term, while the positive impact on the tertiary industry lasts. This study provides a reference for making full use of transport infrastructures to promote the reasonable distribution of labor resources.

Keywords: high-speed rail; city cluster; employment; industry output; coupling coordination degree

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1. Introduction

The demographic dividend has been gradually disappearing in China over the past few decades. The aging population leads to relative stagnation in technological innovation, labor shortage, and decreasing consumption, which have been a significant drawback to sustainable economic growth [1]. In the face of this dilemma, reasonable allocation of labor across regions and industrial sectors is of great significance. The industrial structure can reflect the essential requirements of economic development [2], which has been playing a vital role in fulfilling economic potential as well as promoting sustainable growth. Human capital accumulation determines the differential growth among diverse industries [3], which directly influences employment structures and their evolving trends [4], thus impacting economic growth. Information asymmetry and labor market frictions have also led to a mismatch between labor and job opportunities [5]. Therefore, exploring how to motivate coupling coordination between employment and industrial structures is of practical importance for improving labor productivity and stimulating economic transformation.

The cost of labor transition is a crucial cause of labor market friction, in which migration costs significantly affect labor mobility [6,7]. High-speed rail, an emerging transportation infrastructure in China, effectively reduces spatiotemporal distances and travel costs with the accessibility gains due to its connection, thus driving labor distribution toward a Pareto optimum across regions and industries [8]. The Pareto optimum describes an ideal status of resource allocation under which there is no possibility of benefiting at least one member without damaging others [9], implying the highest efficiency for the distribution of labor across different industrial sectors in our paper. The large national territorial area and high population density in China have facilitated a relatively well-organized high-speed rail network, whose radiation effect further promotes the flow of factors, differentially impacting central and peripheral cities. Regional industrial structure and population capabilities have been reshaped accordingly. The development of high-speed railway networks has brought about more comprehensive effects on the employment–output coupling coordination level, which is worth studying.

Except for migration costs, geographical factors also have a significant influence on employment and industries. Regional specialization often implies a relatively fixed industrial structure and a stable level of employment and income [10], which is most evidently manifested in city clusters in China. By 2012, the Yangtze River Delta city cluster had become one of the world's six major city clusters, showing the optimized spatial landscape of industries and integrated development centered by Shanghai under the guidance of the integration development policy. With multiple city clusters at different developmental stages, they act as growth poles that drive regional economic growth. This study aims to explore the heterogeneity of different city clusters in the process of high-speed rail networks impacting employment–output coupling coordination according to the characteristics of city clusters at different levels.

Given the current status and the goal of sustainable development, it is of vital importance to fully understand whether the correlation between labor input and industrial output is undergoing improvement under the coverage of high-speed rail networks. Therefore, our study explores the impact of high-speed rail networks on employment–output coupling coordination with the methods of Social Network Analysis and fixed effect model, which enable us to test this effect from a more accurate perspective by abstracting the high-speed rail system into a calculable network.

Existing studies barely focus on the impact of high-speed rail on regional economies from the perspective of the interaction between human capital input and industry output. Moreover, there is little research that takes the factors of city clusters into consideration when analyzing the impact of high-speed rail as well as exploring the influence of city cluster characteristics on the role of high-speed rail. This paper will make the following contributions to the existing studies: (1) On the methodological side, we combine the employment and industrial output by expanding the coupling coordination degree model to explore the influence of high-speed rail networks on the inputs and outputs of the labor force in different industries, instead of simply focusing on the impact of high-speed rail on each system. In addition, we analyze the effects of high-speed rail on employment–output coupling coordination from the angle of the network by using Social Network Analysis, which can provide a more accurate analysis. (2) On the practical side, this paper pays attention to the heterogeneity of the impact of high-speed rail in different time periods and different types of city clusters, probing into the dynamics of the effect in different city clusters in the initial, middle, and mature stages of China's high-speed rail network construction, which recognizes the continuity and stage features of the effect of high-speed rail. The results have implied the sustaining function of optimizing the structure of employment and industrial output, which provides reliable references for future high-speed rail network planning.

This paper is organized as follows: Section 2 reviews existing studies on the correlation between high-speed rail, industry, employment, and city clusters; Section 3 introduces the concept and calculation methods of employment–output coupling coordination degree; Section 4 elaborates on data sources, variables, and model specifications; Section 5 presents empirical results, including baseline regressions, robustness tests, and heterogeneity analyses results in different time periods and city cluster levels; and Section 6 concludes the paper and puts forward related policy implications.

2. Literature Review

The economic impact of transport infrastructure has been generally acknowledged [11,12]. The improvement of accessibility and connectivity provided by transport infrastructures can break the barrier to the factor exchange between regions [13]. Cities with different hub levels tend to gain different levels of locational advantage, which can cause agglomeration of labor, as well as economic activities in those core cities [14]. The decrease in communication and carrying costs can significantly promote the productivity of local firms [15,16], thus stimulating regional economic growth. At the same time, the concentration of labor and factors can create further demands for new transport infrastructures, which can contribute to sustainable economic development in return [17]. It is also worth noting that transport infrastructures need to function together with other supplementary factors, such as regional industry structure and supporting policies [18], which partly explains why developed regions can benefit more from transport networks.

Among all the transport modes, the economic impact of high-speed rail has been under heated discussion. For example, there have been papers investigating the agglomeration and diffusion effects of high-speed rail on specific industries, revealing its significant impact on industrial structure upgrading. Taking cities along the Beijing–Shanghai high-speed rail line as an example, it shows that the effects of high-speed rail on industries' agglomeration and diffusion vary across different industry sectors. For example, the connection by high-speed rail has led to a tendency for most manufacturing industries to cluster, but with no significant effect on agriculture and mining [19]. Moreover, the construction of high-speed rail promotes the agglomeration of service industries in the regions near the high-speed rail lines. Compared to consumer services and public services sectors, the impact of high-speed rail on manufacturing services is more pronounced [20,21]. Innovation, as a crucial mechanism, can efficiently facilitate the industrial upgrading instigated by high-speed rail [22].

In addition, high-speed rail, as a passenger transport mode, deeply affects the commuting activities of residents by changing transport costs [23–25]. While the benefits of high-speed rail for commuting are relatively less significant compared to its stimulation on non-work travel, high-speed rail still provides considerable agglomeration benefits for work-related activities [26]. For example, it increases local labor's commuting frequency and wage levels [27]. Thus, the promotion of labor mobility is one of the most fundamental and intrinsic impacts of high-speed rail. Further research shows that networked high-speed rail fosters a more specialized employment landscape in the region, especially in knowledge-intensive industries [28]. Scholars have generally verified the positive contribution of high-speed rail to labor mobility, employment structure, and productivity, thereby recognizing the impact of high-speed rail on labor and employment.

Apart from China, the high-speed rail in Europe also shows a significant influence on regional economic development. The European high-speed rail system has been deeply reshaping the development landscape between regions [29]. There have also been papers showing that the introduction of high-speed rail can contribute to the convergence both between and within regions in Northwest Europe [30], which mainly stems from three aspects: related technological progress, the multiplier effects of transport investments, and the role as a crucial component of a market to carry people and goods [31]. Though high-speed rail can reshape the distribution of productivity and economic growth, it is also noticeable that the effect largely depends on the city size, industrial structure, and geography characteristics [32]. Many studies have also stressed this point that the stimulating effect and transformative function of high-speed rail need to go with other supplemented conditions to release its full potential [33], such as related policy interventions [18].

Existing studies indicate that city clusters in China have become the primary growth pole [34]. Among all the factors, the interaction between transport infrastructures and city clusters is crucial. Scholars have confirmed that the networking of transport facilities can promote the integrated development of city clusters [35]. High-speed rail is for sure an important tool for stimulating agglomeration economies. But this effect needs to function together with other complementary factors such as local resources endowment, economic development status, policy environments and so on [36–38]. Furthermore, networked high-speed rail significantly enhances internal connections within city clusters and improves the stability of their spatial structure [39]. More specifically, high-speed rail can stimulate the redistribution of economic activities within city clusters, which can strengthen the role of the core cities and thus promote consumption activities in cities without high-speed rail with a spatial spillover effect [40]. Therefore, a high-speed rail network can contribute to the integrated development of city clusters. The impact of high-speed rail on several specific industries is more obvious, such as tourism, which would affect the cluster into a spatial pattern of core–peripheral structure [41]. The existing literature mainly focuses on the impact of high-speed rail on the development of city clusters, while this study would inversely focus on exploring the influence of city cluster hierarchies on the externalities of high-speed rail network.

3. Theory and Hypothesis

Overall, the changes in the employment–output coordination level caused by high-speed rail are primarily determined by the labor flow and industry location alignment, i.e., how well labor demand and supply match.

A high-speed rail network effectively enhances the accessibility of cities, broadens the spatial range of labor mobility, and increases its flexibility, thereby improving the spatial distribution of economic activities and capital [42]. In the early stages of HSR network construction, the improved market potential from urban location advantages leads to labor force clustering in central cities [43]. The manufacturing sector, related producer services, and other agglomeration-induced services also cluster in central cities, providing labor demand for population agglomeration and enhancing the coordination of inputs and outputs in secondary and tertiary industries.

As high-speed rail construction gradually connects more regions, many less developed cities have been covered by this network as well. The agglomeration of knowledge-intensive industries and technology-intensive industries in central cities significantly elevates their hub level, thus attracting labor from less developed regions due to the network's radiating effects [44]. Consequently, small and medium-sized cities tend to take over those resource-intensive and labor-intensive industries, which mainly move from large cities seeking lower production costs. Losing the labor force and taking in those industries at the same time can cause a decline in the employment–output coordination level in secondary industries in periphery cities. However, as most enterprises in tertiary industries are not labor intensive, smaller cities' tertiary industries may not suffer from population outflow and may even see an increase in the coordination level of employment–output due to the simultaneous relocation of tertiary sector enterprises to large cities.

Based on this understanding, this paper proposes the following hypotheses H1, H2, and H3.

Hypothesis 1 (H1): *High-speed rail networks will significantly enhance the employment–output coupling coordination level in tertiary industries.*

Hypothesis 2 (H2): *In the early stages of high-speed rail network development, developed cities' secondary and tertiary industries will experience an increase in employment–output coupling coordination levels.*

Hypothesis 3 (H3): *In the longer term, the high-speed rail network may negatively affect secondary industries' employment–output coupling coordination levels in less-developed cities while positively affecting tertiary industries.*

In addition, cities with different economic development levels are likely to be covered at different periods during the process of high-speed rail network expansion, leading to sequential variations in when and how they are affected by high-speed rail [45]. Specifically, cities with higher per capita GDP and population density, such as Beijing and Shanghai, usually have the priority to build high-speed rail because of their high transport demands.

Furthermore, cities within different city clusters have diverse policy support, resource endowments, and other facilities. Thus, the market potential and locational advantages enhanced under the impact of high-speed rail tend to differ [46,47]. Therefore, the sequence and extent of the impact of the high-speed rail network would vary across cities within different city clusters.

Accordingly, the hypothesis H4 is proposed.

Hypothesis 4 (H4): *The impacts of the high-speed rail network on employment–output coupling coordination level differs across city clusters as well as time periods.*

4. Data and Methodology

4.1. Data

The panel data of 276 cities in China from 2007–2019 are adopted for the empirical analysis. The data on the socio-economic variables are collected from China City Statistical Yearbooks and the official websites of every province. To ensure the accuracy of the estimation, we eliminated the city samples that have too many missing values. Data related to the high-speed rail are gathered and organized from the 12306 website (12306.cn, accessed on 1 January 2022), which has been serving as the official rail ticket in China.

The classification standard of city clusters is based on the Outline of the 14th Five-Year Plan (2021–2025) for National Economic and Social Development and the Long-Range Objectives Through the Year 2035 of the People's Republic of China, a planning document published by China's National Development and Reform Commission. According to this document, there have been 19 main city clusters in China by the end of 2021. Among all those city clusters, there are five well-developed clusters, five middle-developed clusters, and nine less-developed clusters, which we define as first tier, second tier and third tier, respectively. All the city clusters are listed in Table 1. Figure 1 shows the location of all the first-tier and second-tier city clusters, which are mainly located in eastern and southern China.

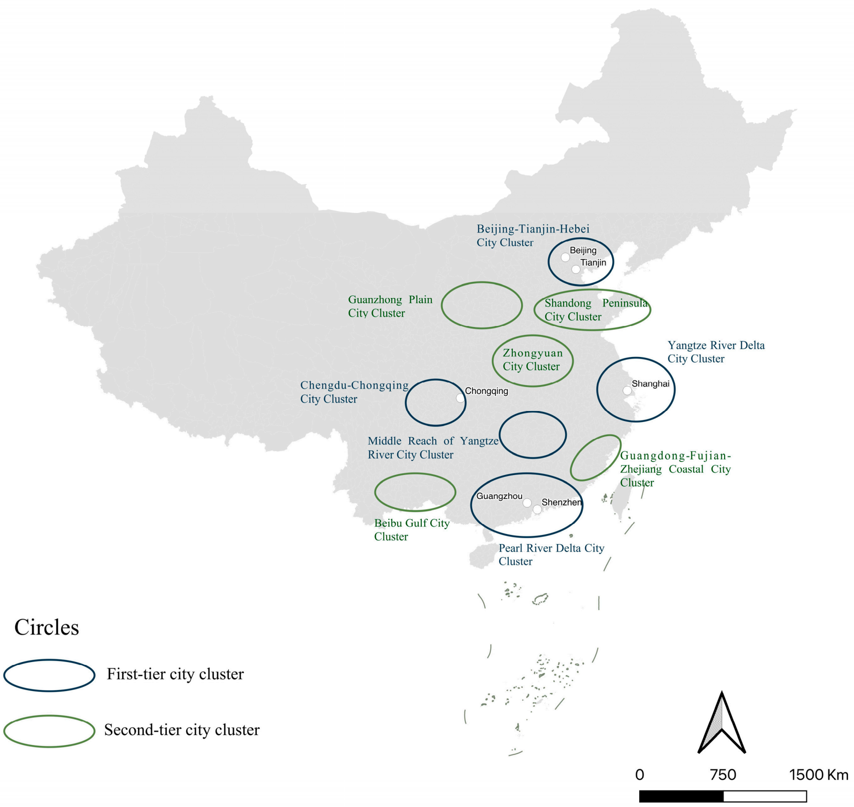

Figure 1. Location of China's first-tier and second-tier city clusters.

Table 1. Groups of China's city clusters.

Level	City Clusters in the Group
First tier	Beijing–Tianjin–Hebei City Cluster, Yangtze River Delta City Cluster, Pearl River Delta City Cluster, Chengdu–Chongqing City Cluster, Middle Reach of Yangtze River City Cluster.
Second tier	Shandong Peninsula City Cluster, Guangdong–Fujian–Zhejiang Coastal City Cluster, Zhongyuan City Cluster, Guanzhong Plain City Cluster, Beibu Gulf City Cluster.
Third tier	Harbin–Changchun City Cluster, Mid-southern Liaoning City Cluster, Central Shanxi City Cluster, Central Guizhou City Cluster, Central Yunnan City Cluster, Hohhot–Baotou–Ordos–Yulin City Cluster, Lanzhou-Xining City Cluster, Ningxia Yellow River City Cluster, Northern Slope of Mt. Tianshan City Cluster.

4.2. Methodology

4.2.1. Explained Variables

The coupling coordination degree between employment and output of primary industry, secondary industry and tertiary industry is calculated as the explained variable, measuring the correlation and matching level between human capital input and output value in different industrial sectors. The coupling coordination degree is derived from physics, reflecting how much different systems can interact with each other [47]. This index has been applied in previous related papers to measure the matching level between different objectives, such as the tourism–transportation–low carbon coupling coordination degree [48] and urban rail–land use coupling coordination degree [49]. By referring to the calculating methods of existing studies [28], we calculate the coupling coordination degree by taking employment structure and industrial structure as two targeted objects. The degree is calculated following the next steps.

$$C_n = \left\{ \frac{f_n(X) \cdot g_n(X)}{\left[\frac{f_n(X)+g_n(X)}{2} \right]^2} \right\}^K, \ i = 1,2,3 \tag{1}$$

where C_n is the coupling degree of industry n, showing the interaction between employment and industry output. $f_n(X)$ and $g_n(X)$ denote the level of employment and industry output. We use the ratio of the number of laborers in industry n to the number of nationwide laborers, and the ratio of the output value of industry n to GDP to stand for $f_n(X)$ and $g_n(X)$, respectively.

$$T_n = \alpha f_n(X) + \beta g_n(X), \ i = 1,2,3 \tag{2}$$

where T_n indicates the overall development level of these two systems, α and β are the share of contribution of them. According to existing studies, their values are both equal to 0.5 [5].

$$D_n = \sqrt{C_n \cdot T_n} \tag{3}$$

Based on Equations (1) and (2), the coupling coordination degree D_n is calculated as shown in Equation (3).

4.2.2. Explanatory Variable

To measure the structure of a high-speed rail network, the index of betweenness centrality is calculated based on the theory of Social Network Analysis (SNA), a quantitative method to analyze the structure features of networks [50]. By considering the cities with rail stations and high-speed rail lines to be hubs and links, we can abstract the high-speed rail system into a network to analyze its features. Centrality is one of the key indices in SNA to describe the importance of the hub in the network, which can be used to describe how much a city can act as a hub to connect other cities with high-speed rail [51]. There are mainly three most frequently used centrality indices, namely degree centrality, betweenness centrality, and closeness centrality. Degree centrality measures the dominance of one node merely by the number of nodes directly connected to it, closeness centrality is calculated based on the distance between one node and others [52]. In view of the meaning and computing difficulty, we choose betweenness centrality (BC_i) as the explanatory variable to denote the impact of each city on other hubs and even the whole high-speed rail network.

$$BC_i = \frac{2}{N^2 - 3N + 2} \sum_{o \neq i \neq d}^{N} \frac{a_{od}^i}{\delta_{od}}$$

where N is the number of all cities with high-speed rail stations, δ_{od} is the number of the shortest paths from city O to city D, a_{od}^i is the number of all the shortest paths that go through city i. When the value of BC_i is greater, city i would have more influence on the whole network with its hub level. Figure 2 shows the distribution of betweenness centrality and high-speed rail lines in 2019.

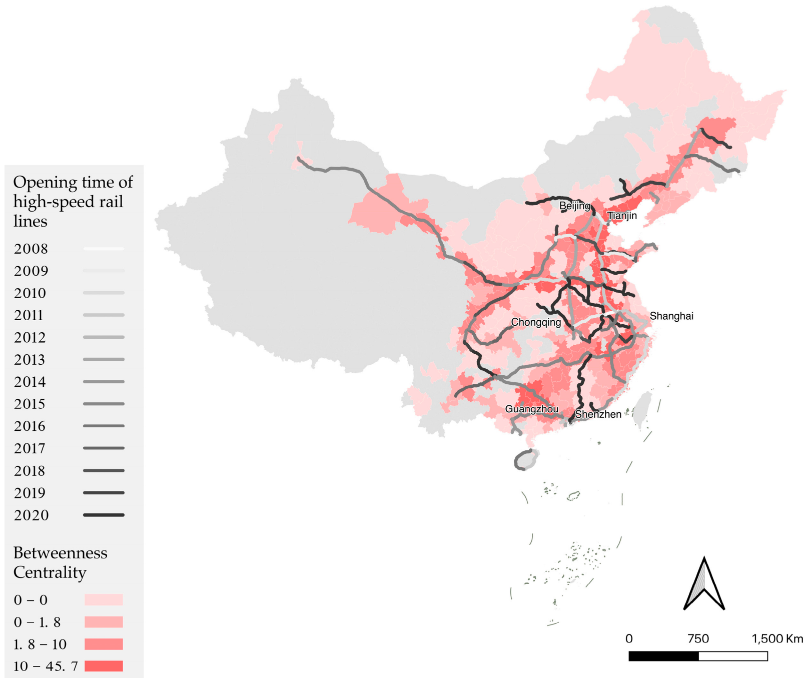

Figure 2. The spatial distribution of betweenness centrality of cities and high-speed rail network in 2019.

4.2.3. Control Variable

There are five control variables used in the empirical analysis to eliminate the influence of other factors on the explained variables. (1) Total population Pop_i, which can directly affect the number of labor force and the decision on firm locations. (2) Number of employees Em_i. (3) Regional government expenditure Gov_i, denoting regional government scale. (4) The value of gross regional domestic product GDP_i. (5) Urban population $Urban_i$, showing the level of urbanization.

All the variables are presented in Table 2.

Table 2. Descriptive analysis.

Variables		Observations	Mean	Std. Dev	Min	Max
Explained variables	D_1	3588	0.1838	0.1063	0	0.172
	D_2	3588	0.6703	0.0893	0.315	1.282
	D_3	3588	0.6714	0.0751	0.381	1.844
Explanatory variables	BC	3588	0.6596	1.5923	0	37.5

Table 2. *Cont.*

Variables		Observations	Mean	Std. Dev	Min	Max
Control variables	*Pop*	3588	445.9554	317.4186	18.14	3416
	Em	3588	641,342.4	1,014,595	42,100	10,564,600
	Gov	3588	3,137,419	5,603,669	24,375	71,081,480
	GDP	3588	21,666,110	32,394,977	618,352	381,560,000
	Urban	3588	209.4179	209.4197	10	2428.14

4.2.4. Model Specification

To estimate the impact of the high-speed rail network on the employment–output coupling coordination degree of primary industry, secondary industry, and tertiary industry, we construct the following panel model. According to related studies on the economic impact of transport [15], we choose fixed effects estimates to avoid bias due to the correlation between independent variables and individual effects [53]. The model is specified as follows.

$$D_{itn} = \alpha_1 BC_{it} + \beta_1 X_{it} + u_i + \delta_t + \varepsilon_{it},\ n = 1,2,3$$

where D_{itn} is the employment–output coupling coordination degree of industry n in city i at year t, and BC_{it} is the betweenness centrality of city i at year t. Additionally, X_{it} stands for all the control variables in every city at year t.

5. Results

5.1. Multicollinearity Test

Before conducting the regression, we first test the existence of multicollinearity between all the explanatory variables to avoid possible bias with two statistical methods, including Pearson's correlation coefficient and Variance Inflation Factor (VIF).

5.1.1. Pearson's Correlation Coefficient

Pearson's correlation coefficient is a basic method to check for the collinearity between explanatory variables. The correlation analysis in the format of a matrix is carried out, as shown in Table 3.

Table 3. Pearson's correlation coefficient matrix.

Variables	*Pop*	*Em*	*Gov*	*GDP*	*Urban*
Pop	1	0.5524	0.5277	0.5359	0.5132
Em	0.5524	1	0.6156	0.6860	0.6234
Gov	0.5277	0.6156	1	0.6939	0.6821
GDP	0.5359	0.6860	0.6939	1	0.6282
Urban	0.5132	0.6234	0.6821	0.6282	1

According to Shrestha's (2020) research on the detection of multicollinearity, collinearity is less likely to occur when the absolute value of Pearson's correlation coefficient is smaller than 0.8 [54]. The largest correlation coefficient in Table 3 is the one between *GDP* and *Gov*, with a value of 0.6939. Therefore, we may preliminarily infer that there is no multicollinearity problem in the model according to the correlation coefficient among all the independent variables.

5.1.2. Variance Inflation Factor

Secondly, we compute the Variance Inflation Factor (VIF) of all the variables, which is one of the most widely used methods to check for multicollinearity. The VIFs for *BC*, *Pop*, *Em*, *Gov*, *GDP* and *Urban* are 1.12, 1.81, 4.38, 3.56, 2.34 and 2.90, respectively. In the light of Daoud's (2017) study, when VIF is between 1 and 5, the predictors are moderately correlated, indicating there is no serious multicollinearity problem [55]. By combining both indicators of correlation coefficient and VIF, there would not be bias caused by multicollinearity in our model.

5.2. Baseline Regression

Table 4 presents the regression results for the employment–output coupling coordination level in the primary, secondary, and tertiary industries, using betweenness centrality as the key explanatory variable. Models (1)–(3) are regression results based on the full sample of 276 cities. The results indicate that the development of high-speed rail networks has a negative impact on the employment–output coupling coordination level in the primary and secondary industries. In contrast, the employment–output structure in the tertiary industry tends to become more coordinated as the network develops. The impact on the primary and secondary industries lies partly in the inconsistency of labor flows and industrial location choices, which may exist for two reasons. The first reason is that the demand for related technology and equipment for the construction of high-speed rail directly affects the location choice of manufacturing enterprises. The agglomeration of manufacturing enterprises directly affects the flow of low-skilled labor oriented to the primary and secondary industries, while the labor engaged in the primary industry tends to flow to the center areas to seek a higher income, thus resulting in the shortage of labor in the primary industry, which negatively affects the coordination level of inputs and outputs in this sector. The second reason is that central cities gain locational advantages from the high-speed rail network, which causes the clustering of talent and capital in those regions, leading to the upgrading of industrial structures and higher production costs as well. Most manufacturing enterprises tend to relocate to peripheral areas for access to cheaper land, equipment, and labor. However, the abundant resources in central cities continue to attract labor, leading to some degree of resource mismatch.

Table 4. Baseline regression results.

	All Sample			Cities Belong to City Clusters			Non-Cluster Cities		
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**
Variables	**D1**	**D2**	**D3**	**D1**	**D2**	**D3**	**D1**	**D2**	**D3**
BC_{it}	−0.00547 ***	−0.00121 ***	0.000808 ***	−0.00559 ***	−0.000856 ***	0.000692 **	−0.000716	−0.00283 ***	0.00124
	(0.00102)	(0.000318)	(0.000313)	(0.00113)	(0.000313)	(0.000329)	(0.00232)	(0.00104)	(0.000894)
Pop_{it}	0.230 ***	−0.0123	−0.0578 ***	0.273 ***	−0.0330	−0.0375 *	0.284 **	0.0548	−0.118 **
	(0.0640)	(0.0200)	(0.0197)	(0.0744)	(0.0206)	(0.0216)	(0.122)	(0.0545)	(0.0469)
Em_{it}	−0.0772 ***	0.0116 ***	−0.0128 ***	−0.0976 ***	0.0140 ***	−0.0124 ***	0.0204	0.0118	−0.0258 ***
	(0.00974)	(0.00304)	(0.00299)	(0.0113)	(0.00313)	(0.00329)	(0.0200)	(0.00894)	(0.00770)
Gov_{it}	−0.0832 ***	−0.00711 **	0.0155 ***	−0.108 ***	−0.00254	0.00908 **	−0.0360 ***	−0.0107 *	0.0255 ***
	(0.00945)	(0.00295)	(0.00291)	(0.0123)	(0.00340)	(0.00357)	(0.0138)	(0.00618)	(0.00532)
$Urban_{it}$	−0.145 ***	−0.0143	0.0492 ***	−0.0947 ***	−0.0228 **	0.0525 ***	−0.331 ***	0.0151	0.0477 **
	(0.0287)	(0.00897)	(0.00883)	(0.0333)	(0.00922)	(0.00968)	(0.0549)	(0.0246)	(0.0212)
GDP_{it}	−0.240 ***	0.00237	0.0283 ***	−0.242 ***	−0.00660	0.0357 ***	−0.215 ***	0.0131	0.0187 **
	(0.0153)	(0.00479)	(0.00471)	(0.0201)	(0.00555)	(0.00583)	(0.0218)	(0.00976)	(0.00841)
Constant	5.922 ***	4.267 ***	4.072 ***	6.034 ***	4.423 ***	3.958 ***	4.413 ***	3.682 ***	4.525 ***
	(0.363)	(0.113)	(0.112)	(0.430)	(0.119)	(0.125)	(0.649)	(0.291)	(0.250)
Observations	3588	3588	3588	2756	2756	2756	832	832	832
R-squared	0.430	0.015	0.121	0.453	0.023	0.129	0.384	0.020	0.119
Number of id	276	276	276	212	212	212	64	64	64

Note: Contents in brackets refer to P statistics, ***, ** and * denote significance under levels of 1%, 5% and 10%.

The positive impact of the high-speed rail network on the tertiary industry can also be explained by the direction of labor flow and location choices for industries. The construction of high-speed rail generates more demand for labor, land, and capital, thereby increasing the attractiveness of cities with stations. Specifically, the tertiary industries represented by tourism and services flourish in central cities [56]. Additionally, due to reduced travel costs and increased city potential, labor tends to cluster in central cities, aligning with increasingly advanced industrial structures in central cities.

The hub level of cities within the high-speed rail network reflects their network location conditions, while the city clusters they belong to can represent their economic location status. To explore the heterogeneity of high-speed rail's impact on city clusters, an initial exploration was conducted by dividing the 276 cities into two sub-samples. Models (4)–(6)

show the regression results for cities belonging to city clusters according to the National Economic and Social Development and the Long-range Objectives Through the Year 2035 of the People's Republic of China, and models (7)–(9) for non-cluster cities, which do not belong to any city clusters. Comparing the significance of the coefficients of key explanatory variables in the two sets of models, the impact of high-speed rail is more significant in cities within city clusters. This suggests that the role of high-speed rail largely depends on complementary factors including economic integration, resource sharing, and policy guidance among cities within the same region. For example, in the Yangtze River Delta city cluster, 26 cities centered around Shanghai have achieved strong regional economic growth, industry upgrading, and integrated development with policy support. These external conditions provide a solid foundation for high-speed rail to play its role effectively. Meanwhile, the direction of the BC coefficients corresponding to the primary, secondary, and tertiary industries in models (4)–(6) are consistent with the results for the full sample, indicating the reliability of the results.

Subsequent empirical research focuses on the 212 cities that belong to city clusters. Observations in models (1)–(6) also show that the direction of the regression coefficients of control variables such as government size, urbanization level, and local GDP is mostly significant. However, the impact of city population size and number of employees on the employment–output coupling coordination level in the tertiary sector is negative. This suggests that optimizing employment structure and improving labor quality are the rational paths to enhance employment–output coupling coordination level instead of simply expanding city size.

5.3. Robustness Test

To ensure the reliability of the above results, this study adopts two methods for the robustness test. The first method is to use lagged betweenness centrality as the key explanatory variable. The second method is to eliminate municipalities from the samples including Beijing, Shanghai, Chongqing, and Tianjin, as their development level substantially exceeds those of other cities.

Table 5 displays the outcomes of the robustness checks. Models (10)–(12) involve regression results using lagged betweenness centrality, while models (13)–(15) present results from the remaining 272 cities after excluding the four direct-administered municipalities. The direction of the BC coefficients is a similar tendency to the previous regression results, proving the robustness of the empirical findings of this study.

Table 5. Robustness test results.

	(10)	**(11)**	**(12)**	**(13)**	**(14)**	**(15)**
Variables	**D1**	**D2**	**D3**	**D1**	**D2**	**D3**
BC_{it}	−0.00535 ***	−0.00121 ***	0.000780 **	−0.00568 ***	−0.00121 ***	0.000815 **
	(0.00108)	(0.000335)	(0.000332)	(0.00103)	(0.000323)	(0.000320)
Pop_{it}	0.250 ***	−0.00291	−0.0646 ***	0.235 ***	−0.0110	−0.0583 ***
	(0.0680)	(0.0212)	(0.0210)	(0.0637)	(0.0200)	(0.0198)
Em_{it}	−0.0771 ***	0.0113 ***	−0.0113 ***	−0.0807 ***	0.0117 ***	−0.0128 ***
	(0.0101)	(0.00313)	(0.00310)	(0.00974)	(0.00306)	(0.00303)
Gov_{it}	−0.0862 ***	−0.00821 ***	0.0175 ***	−0.0854 ***	−0.00672 **	0.0154 ***
	(0.00986)	(0.00307)	(0.00304)	(0.00944)	(0.00296)	(0.00293)
$Urban_{it}$	−0.150 ***	−0.0185 *	0.0490 ***	−0.146 ***	−0.0116	0.0475 ***
	(0.0317)	(0.00987)	(0.00978)	(0.0288)	(0.00904)	(0.00895)
GDP_{it}	−0.247 ***	−0.00145	0.0337 ***	−0.238 ***	0.00265	0.0287 ***
	(0.0165)	(0.00513)	(0.00508)	(0.0153)	(0.00481)	(0.00477)
Constant	5.917 ***	4.276 ***	4.025 ***	5.949 ***	4.240 ***	4.082 ***
	(0.386)	(0.120)	(0.119)	(0.361)	(0.113)	(0.112)
Observations	3312	3312	3312	3536	3536	3536
R-squared	0.382	0.019	0.120	0.436	0.014	0.119
Number of id	276	276	276	272	272	272

Note: Contents in brackets refer to P statistics, ***, ** and * denote significance under levels of 1%, 5% and 10%.

5.4. Heterogeneity Analysis

High-speed rails, as a vital infrastructure for enhancing element mobility and accelerating regional economic integration, play an important role in the construction and optimization of city clusters. Estimating the heterogeneous effects of high-speed rails across different types of cities within city clusters is crucial for the rational planning of high-speed rail networks and the further policy designing related to city cluster strategies. This section classifies the cities in city clusters into three categories: 92 cities in first-tier clusters, 70 in second-tier clusters, and 50 in third-tier clusters. Moreover, this study divides the whole sample into four time periods: 2007–2009, 2010–2012, 2013–2015, and 2016–2019. The period of 2007–2009 is considered the starting stage of high-speed rail network construction, while the other three periods are regarded as the developing period of the high-speed rail network. Since the contribution rate of the primary industry in China has been decreasing year by year, and the industrial structure of most cities is dominated by the secondary and tertiary industries, the analysis in this part focuses on the impact of the high-speed rail network coverage on the secondary and tertiary industries.

Table 6 shows the results of the heterogeneity analysis. The results reveal that the secondary and tertiary industries in first-tier city clusters are affected by the high-speed rail network construction in the early stage, while third-tier city clusters only experience an effect during the developing period of the high-speed rail network, with the impact increasing over time. The employment–output coupling coordination level of second-tier city clusters does not show any significant effect from the high-speed rail networks. The reasons for this observation are mainly related to the order of high-speed rail network coverage and the labor migration patterns. On one hand, the order of high-speed rail network coverage varies across different city clusters. First-tier city clusters, such as the Yangtze River Delta and Pearl River Delta, are mostly located in the plains and hilly areas with gentle topography, which makes them the first to be covered by high-speed rail networks. Third-tier city clusters, such as central Shanxi Province, Hohhot city, Baotou city, Ordos city, and Yulin city, are generally lagging in terms of their economic development level, and the construction of high-speed railways in these cities has been delayed, which makes them fall behind the first-tier city clusters in terms of the impact of high-speed rail networks. On the other hand, the coordinated development of the employment–output coupling is largely driven by labor migration, which is mainly influenced by regional economic disparities in China. The more economically developed a region is, the more significant its economy of scale is, which generates higher labor demand and income levels. Therefore, the opening of high-speed rails has the most remarkable effect on the optimized and third-tier city clusters, which are at the two extremes of the development level.

Table 6. Heterogeneity analysis results.

Explanatory Variable	**Industry Sector**	**City Cluster Level**	**Time Periods**			
			(16)–(21) 2007–2009	**(22)–(27) 2010–2012**	**(27)–(32) 2013–2015**	**(33)–(38) 2016–2019**
BC	Secondary industry	First tier	0.0154 ** (0.00633)	−0.000781 (0.000779)	−0.00180 (0.00138)	0.000159 (0.00139)
		Second tier	−0.00792 (0.0112)	0.000212 (0.000826)	−0.000318 (0.000855)	−0.000965 (0.000957)
		Third tier	0.000562 (0.00217)	0.351 ** (0.140)	−0.00642 *** (0.00212)	−0.0153 *** (0.00519)
	Tertiary industry	First tier	0.00976 * (0.00580)	0.000641 (0.000562)	−0.00132 (0.00147)	−0.00214 (0.00119)
		Second tier	0.0151 (0.0110)	0.000256 (0.000430)	0.0000523 (0.00101)	0.000715 (0.000955)
		Third tier	−0.00431 (0.00270)	−0.310 *** (0.0938)	0.00673 *** (0.00205)	0.0297 *** (0.00737)

Note: Contents in brackets refer to P statistics, ***, ** and * denote significance under levels of 1%, 5% and 10%.

With respect to the direction and value of the regression coefficients, for first-tier city clusters, both the employment–output coupling coordination levels of second and tertiary industries experience a positive impact in the starting period of high-speed rail network formation. This effect is partly attributed to the clustering of manufacturing enterprises related to the high-speed rail construction in cities with stations to provide technical and equipment support and the influx of labor from the planning period of the high-speed rail in the central cities to meet the needs of these enterprises. In the longer term, as transportation costs drop and the city's attractiveness increases, high-skilled labor and quality technology resources cluster in central cities, and the industrial structure is constantly upgraded and optimized. High-quality human resources meet the demand of the tertiary industry, leading to an increasingly coordinated development of employment–output structure in the tertiary industry. For third-tier city clusters, the effect of high-speed rail networks on the employment–output coupling coordination in the second industry becomes increasingly negative over time. This is partly because the network status of third-tier city clusters would gradually rise in the longer term. The manufacturing enterprises tend to relocate to non-cluster cities for lower production costs, thereby reducing the concentration of the manufacturing industry within third-tier city clusters. Simultaneously, high-speed rail networks in third-tier city clusters lead to a gradual increase in the level of the employment–output coupling coordination in the tertiary industry, aligning with the cities' improved hub level in the longer time periods.

6. Discussion and Conclusions

As the demographic dividend gradually diminishes in China, how to stimulate another round of economic growth has become the focus of China's government. Our study intends to investigate whether high-speed rail would contribute to reasonable labor allocation across different industries, thus promoting sustainable economic growth. Based on panel data from 276 prefecture-level cities in China spanning from 2007 to 2019, this study investigates the impact of high-speed rail network development on the employment–output coupling coordination across cities. This study also examines the heterogeneity of this impact across different tiers of city clusters and time periods. The main findings are as follows.

Overall, the development of the high-speed rail network has a negative impact on the employment–output coupling coordination in the primary and secondary industries, while it facilitates the enhancement of this coordination in the tertiary industry. There were also related studies showing similar trends when studying the concentration trend or output level of different industries under the influence of high-speed rail. Chang and Diao (2021) discovered that high-speed rail can cause agglomeration in the service sector, while leading to the decentralization of agriculture and manufacturing sectors in China's Great Bay Area [44]. Shao and Tian (2017) have also found that service industries tend to concentrate in regions with high-speed rail service in the Yangtze River Delta Area [20]. Our study further explains this effect from the coupling coordination perspective of labor distribution, which provides a new angle to better understand the role of China's high-speed rail.

In addition, this effect shows a significant heterogeneity across different types of cities. First, the above impact is predominantly observed in cities that belong to main city clusters in China, while non-cluster cities do not exhibit this influence. Second, the impact of high-speed rail networks on employment–output coupling coordination is most obvious in third-tier city clusters, followed by first-tier city clusters, while second-tier city clusters show no significant trends. Thirdly, high-speed rail enhances the level of employment–output coupling coordination in the secondary and tertiary industries of first-tier city clusters, but this effect is only evident in the starting stages of high-speed rail network formation. The level of employment–output coupling coordination in the secondary and tertiary industries in third-tier city clusters experiences an increasingly intensified effect in the developing period of high-speed rail network construction. Specifically, the level of employment–output coupling coordination in the secondary industry decreases over time, while that of the tertiary industry increases with the optimization of the high-speed rail networks. Though the heterogeneity of the impact of high-speed rail on industries across different sectors has been largely discussed, such as more positive influence on service industries in cities with more population density [57], there have been few studies taking the dynamics in different time periods into consideration. Our results further emphasize the importance of paying attention to the change of the effects in different stages of the development of high-speed rail construction.

Those results indicate that the high-speed rail development leads to a shortage of human capital in the secondary industry within non-cluster regions and third-tier city clusters. It is worth noting that China has been facing an aging population and thus labor shortage as the demographic dividend gradually eliminates, which would severely restrict further development of manufacturing industries. The improvement in overall education level also leads to more and more labor shifting from secondary industries to tertiary industries, which would intensify the labor shortage in manufacturing sectors [58]. Therefore, China's governments should play an effective guiding role in protecting labor rights, organizing training programs, and improving assessment systems to enhance the educational levels of both local and migrant workers. Moreover, active efforts should be made to attract labor-intensive industries that move out of central cities, thereby creating more employment opportunities for the labor force. Within the secondary industry, enterprises should consider raising wages and improving working conditions to increase their appeal to the workers.

In addition, cities without high-speed rail should plan proactively for its construction and rely on these high-speed rail networks to form more effective city clusters with better accessibility, especially under the dilemma that many of China's city clusters have been facing significant spatial disparity, such as Beijing–Tianjin–Hebei City Cluster with the over-concentration of resources towards Beijing. This would improve the coordination of labor inputs and outputs in the tertiary industry, thereby stimulating the upgrading of industrial structures. Moreover, considering the less significant effects observed in first-tier and second-tier city clusters in the later stages of high-speed rail network development, there should be a focus on improving the service quality and frequency in the developing period of high-speed rail network construction in these city clusters. This could further leverage the role of the high-speed rail network in promoting labor mobility, thereby enhancing the level of employment–output coupling coordination.

Apart from China, the high-speed rail construction in other countries also shows problems of imbalance and inefficiency. For example, some stations in the Korean high-speed rail system perform poorly in attracting passengers and realizing the agglomeration of economic activities, which are mainly located in periphery areas [38]. For this kind of countries with high population density, the agglomeration and diffusion effect of high-speed rail would become more significant. Therefore, it is necessary to avoid negative impacts due to a siphonic effect, which usually happens in less developed regions to suffer from losing population. Reasonable allocation of industries matching with high-speed rail lines would be an efficient method to promote better distribution of labor and capital.

Moreover, it should be noted that the correlation between two objects is almost impossible to maintain a constant value or direction in all time periods, especially for a system that is emerging or quickly evolving, like high-speed rail. Our study implies the necessity of considering the dynamics during this process.

In this study, the classification of industrial sectors is not detailed enough due to the data accessibility. Additionally, the heterogeneity of the effect of high-speed rail on employment and industries can be further explored with more group standards. For future research, the impact of high-speed rail on the subdivided industrial sectors deserves more exploration. Meanwhile, the samples can be classified by GDP level, population scale, and other meaningful group standards to do more heterogeneity investigation.

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