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Research article

High-speed rail construction and market access of cities: Empirical evidence from China

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Abstract: After decades of rapid development, economic level has undergone qualitative changes in both aggregate and structural terms in China. This paper introduces the concept of market access, which argues that there are externalities to the opening of high-speed railways (HSRs) and that the accessibility of cities without high-speed railways is similarly affected by the opening of high-speed railways in other cities and investigates the impact of the opening of high-speed railways on the market access of cities. By drawing on Herzog's estimation framework, general equilibrium conditions for trade are estimated and a derived simplified model is used to determine a method for measuring cities' ability to enter the market. A systematic study of the *market access* indicator methodology for assessing transport infrastructure improvements is conducted to examine the spatial and temporal evolution of high-speed rail construction in China, measure the changes in market access due to high-speed rail and conduct a characteristic factual analysis based on the results obtained. The paper finds that the average inter-city travel time in China fell by 2.27 hours, i.e., 15.67%, from 2015 to 2019, with the marginal contribution to the decline in travel time coming mainly from the opening of HSRs. Over the 10 years from 2010 to 2019, the logarithm of access to market capacity for Chinese cities increased by around 50%, with the construction of high-speed railways leading to a substantial increase in access to market capacity. Overall, this paper focuses on the scientific method of measurement to provide a better objective understanding of the impact and evolution of high-speed rail construction on the market access of cities in China.

Keywords: market access; urban development; high-speed rail; trade; general equilibrium

1. Introduction

Among the many factors that influence the variability of the output of factors of production, transport plays an important role, as changes in accessibility can alter not only the human factor but also the physical factor. The well-known concept of "to get rich, build roads" vividly illustrates the relationship between transport and income. The diffusion effect of transport infrastructure has many positive effects on local development. On the one hand, the network properties of transport can strengthen the links between regions and promote regional integration, and the strong diffusion effect of central cities can also lead to the development of peripheral regions [1]. The improvement of transport conditions facilitates the movement of people and goods, optimizes the matching of labor and production materials and increases efficiency, thus creating more wealth within a certain period. On the other hand, improved transport conditions can also greatly facilitate inter-regional exchanges. This flow of information can bring advanced management experience and technology, especially after the opening of high-speed railways. Due to the increased convenience, high-technology personnel can travel conveniently to and from different cities and the management and innovation capacity of local enterprises will be greatly enhanced. Finally, the increased accessibility improves the local location advantage and enhances the investment and financing environment.

Transportation fixed asset investment grew at an average annual rate of 18.17% from 1978 to 2018 in China, a rate much higher than the average annual GDP growth rate of 9.5% over the same period. The massive investment in transport infrastructure has driven the breakthrough growth in the mileage of highways and railways in operation in China. By the end of 2019, China had 149,600 km of motorways and 139,000 km of railways in operation, including 35,000 km of high-speed railways (Figure 1), ranking first in the world for all three. The high intensity of transport infrastructure construction has effectively lowered the time and space barriers between regions and enhanced the vitality of economic development and the National Comprehensive Three-Dimensional Transport Network Planning Outline released in February 2021 draws a grand blueprint for a strong transport nation, which is expected to be completed by 2035 with a modern and high-quality national three-dimensional transport network involving railways, highways, water transport, civil aviation and postal express. Transport infrastructure construction has entered a new stage of development. In particular in China, the mileage of high-speed railways will double compared to today, reaching 70,000 km. It is foreseeable that the high-speed railway, the world's largest high-speed railway network, will play an even more important role in economic and social development in China and will have a profound impact on everything from people's lives to regional economic development pattern of China.

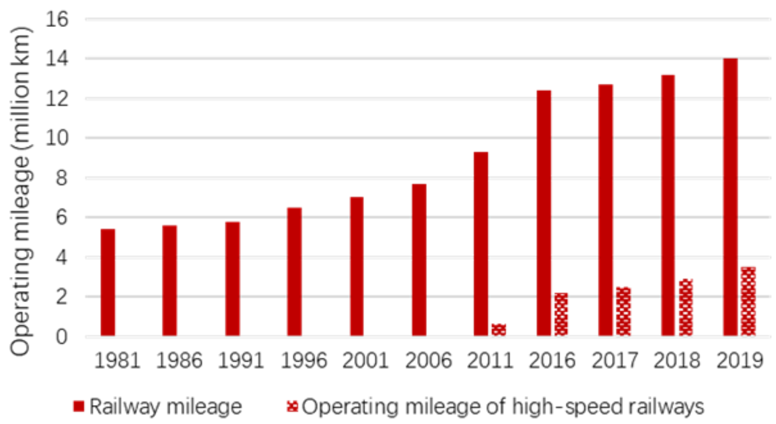

Figure 1. Changes in the operating mileage of railways and high-speed railways in China. Data source: China Railway Yearbook (2019) and China Research Data Service Platform (CNRDS).

At present, some scholars have studied the impact of high-speed rail construction on urban spatial structure and believe that high-speed rail has a strong positive effect on expanding urban space [2–4]. Countries and regions such as Japan and Europe started early in the construction of high-speed rail and there are relatively rich studies on the impact of high-speed rail on urban accessibility. From 1975 to 1988, due to the improvement in accessibility after the completion of the Japanese Shinkansen, the population growth of station cities was significantly higher than that of non-station cities [4,5]. After the completion of the French high-speed train (TGV) main line, the economic growth of cities with high-speed rail stations was significantly higher than that of cities without station [3]. In countries such as Germany and Italy, the research results of the growth effect of high-speed rail were similar [6]. The construction of high-speed rail in China started relatively late and the research of relevant scholars mainly focused on urban space expansion [7], land use change [3] and income distribution [8] and the characteristics of spatial evolution around high-speed rail [9], etc. There is a lack of relevant research on the impact of high-speed rail opening on urban accessibility in China. This paper makes incremental contributions in the following aspects: First, introduce the market access approach, use the minimum spanning tree idea, use the spatial analyst tool in ArcGIS software to construct a spatial transit time pair matrix, and study the impact of the opening of high-speed rail on urban access. Second, it expands the relevant literature on high-speed rail research of China and based on the consistency of methods, it makes Chinese issues and international issues horizontally comparable.

2. Methods and data sources

2.1. Research methodology

The market access approach, a method proposed by Donaldson and Hornbeck to estimate the total impact of railways, argues that in a multi-regional model, changes in market access capacity reflect the direct or indirect impact of changes in the rail network on each region [10]. It is a parsimonious form derived from general equilibrium trade theory, in which the market access of the place of measurement increases when the cost of trade between the place of measurement and the target place decreases, especially when the target place has a larger population and the cost of trade with the rest of the region is higher. Donaldson and Hornbeck use this as a proxy variable for the fixed cost of trade that Lin used this approach to measure the impact of HSR network expansion on the market access of cities and estimated the impact of changes in market access on urban transport, employment, and overall economic development [11]. Tang et al. use this method to assess the change in fixed trade costs due to the opening of HSR [12]. Specifically, for any city *k* the market access is defined as follows:

$$MA_k = \sum_{j=1}^{N} \tau_{kj}^{-\theta} X_j T_j$$

where τ_{kj} represents the cost of transportation from city k to city j, X_j represents the cost that city j obtain labor from other cities where labor is assumed to be the only factor of production and T_j represents the technical parameters of production of city j.

2.2. Data sources

The data related to the opening of high-speed rail lines used in this study are obtained from the China Research Data Service Platform (CNRDS). In the specific study, special treatment is also given to the year of opening of high-speed rail lines. If the high-speed rail line opens in the first half of the year, the opening time is taken as the current year and the opening time of the high-speed rail line is in the second half of the year, the opening time is postponed by one year. In particular, because of the concentration of HSR openings in China, some HSR lines were chosen to open on July 1 of the year. The opening of HSR lines that opened on July 1 is also recorded in this paper as the current year. The rest of the city-level data is obtained from the China Economic and Social Development Statistics Database and the China City Statistical Yearbook. The geographic base map data in this paper is obtained from the China Geographic Information Resources Catalogue Service System, based on which ArcGIS software is used to spatially process the relevant traffic data.

3. Basis for building market access

3.1. Trade and market access model

The concept of market access in transport research was first introduced by Donaldson and Hornbeck, which is derived from general equilibrium trade theory to estimate the additive effect of changes in inter-regional trade costs with the construction of transport infrastructure [10]. To assess the change in transport costs associated with transport infrastructure improvements, this paper introduces the indicator of *market access*. The framework for estimating market access draws on Herzog, who constructs a trade county model based on Eaton and Kortum, Donaldson and Hornbeck and others and derives a specific form of market access [10,13,14].

An economy is assumed to consist of N inter-trading areas in a single production sector, where city *i* is the trade origin city and city *n* is the city of destination for trade. The total population is $\bar{L}$ and each household inelastically supplies one unit of homogeneous labor and receives w_n wage income. The land is an input to the production of traded goods and housing, the supply of land for housing is fixed everywhere, rents increase with total income and households weigh housing costs against wages to choose where to live. Drawing on the concepts of Duranton and Turner's road commuting welfare model, households are assumed to derive positive utility from the convenience and comfort of roads [15].

3.1.1. Family

Households have Cobb-Douglas preferences with a utility function of $U_n = \frac{A_n}{\tau_n} C_n^{\mu} H_n^{1-\mu}$, where A_n is the local public good, τ_n is the negative utility of the typical commuter, H_n is housing and C_n is a range of traded goods. Preferences of households imply that the elasticity of substitution of traded goods is constant so that the ideal price index P_n contains a mix of trade costs between cities. Households also pay ρ_n for each unit of housing.

It is assumed that local roads reduce commuting time. So, the speed is set to $\widetilde{\tau^S} \left(\frac{L_n}{R_n}\right)^{\widetilde{\delta^S}}$, where L_n is the total number of jobs in the county and R_n is the local road mileage. The negative utility of commuting is assumed to be a constant elasticity function of travel time and is extracted from the distance difference $\tau_n = \tau \left(\frac{L_n}{R_n}\right)^{\delta}$, where δ contains the preference for shorter commute times and the marginal effect of roads on commute times.

Therefore, the level of utility achieved by the residents of city n,

$$u_n = \tau \mu^{\mu} (1-\mu)^{(1-\mu)} A_n \left(\frac{R_n}{L_n}\right)^{\delta} \frac{w_n}{P_n^{\mu} \rho_n^{1-\mu}} \quad (1)$$

Families will choose to live and work where the level of utility is highest.

3.1.2. Production, trade and labor demand

For each city i, a series of perfectly competitive firms, using labor, land, and free-flowing capital, produce goods (denoted as v) according to the Cobb-Douglas production function, total factor productivity is $\widetilde{T_i} z_i(v)$. Thus, the marginal cost of each variety of product is $\frac{q_i^{\gamma} w_i^{\alpha} r^{1-\alpha-\gamma}}{\widetilde{T_i} z_i(v)}$. r is a fixed rent of capital. w_i and q_i is the price paid by the firm for labor and land respectively.

Drawing on Eaton and Kortum, the productivity of the firm is $z_i(v)$ that follows a cumulative density function of Fréchet distribution $F(z) = exp(-z^{-\theta})$ [14]. $\theta > 1$ is the change in productivity or comparative advantage. Firms enjoy agglomeration spillovers and therefore $\widetilde{T_i} = T_i L_i^{\zeta}$. Finally, goods transported from place i to n requires the payment of iceberg trade costs $\tau_{in} > 1$. Therefore, the cost p_{in} of n brings p_{in}/τ_{in} net benefit for i.

This means that, in a zero-profit equilibrium, the price of the good transported from the producer at place i to the consumer at place n is

$$p_{in}(v) = \alpha^{\alpha} \gamma^{\gamma} \frac{q_i^{\gamma} w_i^{\alpha} r^{1-\alpha-\gamma}}{L_i^{\zeta} T_i z_i(v)}$$

Eaton and Kortum argue that this equilibrium price implies the price index of the place *n* is $P_n = \kappa_1 CMA_n^{-\frac{1}{\theta}}$, where $CMA_n = \sum_j \left[\frac{q_j^{\gamma} w_j^{\alpha}}{L_i^{\zeta} T_j} \tau_{jn}\right]^{-\theta}$ denotes access to low-cost producers in each locality, often referred to as consumers' ability to enter the market, or market access [14]. In addition, the value of commodity sold at place *i* to *n* is

$$X_{in} = \left[\frac{q_i^{\gamma} w_i^{\alpha}}{L_i^{\zeta} T_i}\right]^{-\theta} \frac{\tau_{in}^{-\theta}}{CMA_n} Y_n \tag{2}$$

where the Y_n is the total output of place *n*. Sum the above equation for all trading partners at place *i* and assume trade equilibrium. Then, the total income satisfies $Y_i = \left[\frac{q_i^{\gamma} w_i^{\alpha}}{L_i^{\zeta} T_i}\right]^{-\theta} \sum_n \frac{Y_n \tau_{in}^{-\theta}}{CMA_n}$, where $\sum_n \frac{Y_n \tau_{in}^{-\theta}}{CMA_n}$ represents the opportunity for enterprises to enter large export markets, often referred to as the market access of enterprises. As noted by Donaldson and Hornbeck, the symmetry of trade costs implies that firms and consumers have equal market access [10]. Thus, structural market access is defined as:

$$MA_i \equiv CMA_i = \sum_n \frac{Y_n \tau_{in}^{-\theta}}{CMA_n} \tag{3}$$

Under a single market access condition and a Cobb-Douglas production function, the region's total revenue decreases to $Y_i^{1+\theta(\alpha+\gamma)} = T_i^{\theta} L_i^{\theta(\zeta+\alpha)} S_i^{\theta\gamma} MA_i$, where S_i is the resource endowment of a region's productive land. Bringing in $Y_i = \frac{w_i L_i}{\gamma}$ yields that the local labour supply is a constant elasticity function concerning wages, productivity, land area and market access,

$$L_i = \kappa_2 T_i^{\frac{\theta}{1+\theta(\gamma-\zeta)}} S_i^{\frac{\gamma\theta}{1+\theta(\gamma-\zeta)}} MA_i^{\frac{1}{1+\theta(\gamma-\zeta)}} w_i^{-\frac{\theta(\alpha+\gamma)+1}{1+\theta(\gamma-\zeta)}} \tag{4}$$

The expanding ability to enter markets moves local labour demand upwards, an effect that is stronger when land is a small part of total costs or when comparative advantage is significant.

3.1.3. Housing

Considering housing as a commodity, endogenous housing production costs are identified by constructing a housing supply model. Competitive housing suppliers will use two factors of production, land and capital, based on the Cobb-Douglas production function, with marginal cost pricing to obtain the cost of housing $\rho_i = (q_i^R)^{\eta} r^{1-\eta}$, where η is the share of land in housing production and q_i^R is the residential land rent. For simplicity, assume that developers use different land than producers of traded goods and pay proportionate rents $q_i^R = \phi q_i$ and that $q_i^R = \phi q_i = \phi\gamma \frac{Y_i}{S_i} = \phi \frac{\gamma w_i L_i}{\alpha S_i}$. Thus, the housing supply function is

$$\rho_i = \left(\phi \frac{\gamma w_i L_i}{\alpha S_i}\right)^{\eta} r^{1-\eta} \tag{5}$$

In equilibrium, land rents are related to capital rents. Landlords live on the land they own, receive income in proportion to the output of their area and spend all income on the consumption of traded goods. This simplification addresses the challenge of the lack of data on rents and makes housing costs an explanation for the regional congestion externalities mentioned by Allen and Arkolakis [16].

3.1.4. Labour supply

When the commodity and housing markets are in equilibrium, $P_i = \kappa_1 MA_i^{-\frac{1}{\theta}}$ and $\rho_i = \phi\left(\frac{\gamma w_i L_i}{\alpha S_i}\right)^{\eta} r^{1-\eta}$ are substituted into Eq 1 to obtain local utilities in terms of market access and population. In the spatial equilibrium, mobile households arbitrage differences in utility across regions such that $\bar{u} = u_i \forall i$, the local labor supply is

$$w_i = (\bar{u}\kappa_3)^{\frac{1}{1-\eta(1-\mu)}} A_i^{-\frac{1}{1-\eta(1-\mu)}} S_i^{-\frac{\eta}{1-\eta(1-\mu)}} R_i^{-\frac{\delta}{1-\eta(1-\mu)}} MA_i^{-\frac{\mu}{\theta}\frac{1}{1-\eta(1-\mu)}} L_i^{\frac{\eta(1-\mu)+\delta}{1-\eta(1-\mu)}} \tag{6}$$

As an increase in market access brings down the price index, it likewise brings down the equilibrium wage level.

3.1.5. Balance

Equilibrium wages and employment levels are obtained from labor demand (Eq 4) and supply (Eq 6), both of which are log-linear functions of infrastructure, roads and market access.

$$ln\, w_i = ln\, \kappa^w + \delta_u^w\, ln\, \bar{u} + \beta^w\, ln\, M\, A_i + \delta_R^w\, ln\, R_i + ln\, \chi_i^w \tag{7}$$

$$ln\, L_i = ln\, \kappa^L + \delta_u^L\, ln\, \bar{u} + \beta^L\, ln\, M\, A_i + \delta_R^L\, ln\, R_i + ln\, \chi_i^L \tag{8}$$

$$MA_i = \frac{1}{\alpha}\sum_j \frac{w_j L_j \tau_{ij}^{-\theta}}{MA_j} \tag{9}$$

$$\bar{L} = \sum_i L_i \tag{10}$$

where, the χ_i^w and χ_i^L are functions of exogenous local productivity, amenities and land endowment; κ^w and κ^L depends on interest rates; the elasticities β^w, β^L, δ_u^L, δ_u^w, δ_R^w and δ_R^L are functions of the exogenous parameters. Given the parameters $\{\alpha, \gamma, \mu, \zeta, \eta, \delta, \theta\}$, capital interest rate$(r)$, total employment in China$(\bar{L})$, local fundamentals(χ_i^w, χ_i^L) and bilateral trade costs(τ_{in}), regional employment, wages, market access and local utility$(\bar{u})$ at equilibrium make Eqs 7–10 valid. Bartelme argues that as long as $\beta^w + \beta^L \leq 2$, there is a particular equilibrium. Most importantly, market access confirms the effect of intercity transport on equilibrium wages and employment [17].

3.2. Measurement of market access

According to Donaldson & Hornbeck, "a simplified treatment that does not overly rely on the model is applied to approximate a first-order approximation of entry capacity", market access is measured by omits the recursion term and the economic centrality of each region is regarded as the sum of the income of other regions with respect to discounted travel time [10]. Transaction costs are assumed to be a fixed elasticity function of travel time $\tau_{ijt} = \tau_0 time_{ijt}^{\tau_1}$. Then, market access of place *i* in *t* year is

$$MA_{it} = \tilde{\tau} \sum_{j \neq i} w_{jt} L_{jt} \, time_{ijt}^{-\tilde{\theta}} \quad (11)$$

Where, $w_{jt}L_{jt}$ is the total wages of place j, the$\tilde{\theta} = \tau_1\theta$, and $\tilde{\tau} = \frac{\tau_0^{-\theta}}{\alpha}$ is the scale parameter, which is normalised to 1, because it does not affect the growth rate. Specifically, Eq 2 can be written as,

$$lnX_{ij} = \alpha_i + \alpha_j - \theta\tau_{ij} = \alpha_i + \alpha_j - \theta\tau_1 \, ln\, time_{ij} + \varepsilon_{ij}$$

Where, X_{ij} is value transferred from the region i to region j, α_i and α_j are the fixed effects of source and destination and ε_{ij} is the residual term.

4. Empirical study

4.1. Evolution of the Chinatown time pass time

market access is one of the main explanatory variables in this study and is dependent on inter-city travel times. This paper identifies the variation in market access by estimating the variation in travel time for *city pairs* across years and assumes that inter-city travel is symmetrical, i.e., from *i* to *j* and from *j* to *i*. The paper identifies changes in market access by estimating the change in travel time for *city pairs* across years and assumes symmetry in inter-city travel, i.e., traffic conditions from place to place and from place to place are identical.

This paper calculates the inter-city travel time matrix in 2000, 2015 and 2019 respectively. Before 2000, the railways implemented three speed increases in China, namely in 1997, 1998 and 2000. Although the overall average speed increase was limited and the average speed was less than 70 km/h, based on the following three considerations, we assume that in 2000 the railway speed is 80 km/h, the highway speed is 65 km/h and the national road speed is 45 km/h. In 2015 and 2019, the railway speed will be increased to 100 km/h and the average speed of high-speed rail will be set at 200 km/h. First, this paper calculates the shortest travel time between cities without considering station stays and assumes that in order to save travel time, there is no limit to the number of times to change the travel mode. For example, the average speed of railway travel is the fastest, from A to D to D The railway goes through B and C, but C is a detour, there is a road connection from B to A and the travel time is shorter than that via C to D. At this time, you will choose to transfer to road traffic at B. D (Figure 2), borrowed from the measurement idea of the minimum spanning tree method, in which the weight is the transit time, which measures the shortest transit time between cities. Second, railway carried out the third major speed increase in China in 2000, the average speed of railway traffic exceeded 60 km/h and the maximum design speed was 200 km/h. At that time, the minimum speed of expressway traffic was 60 km/h. Taking into account the average traffic efficiency of the three types of traffic modes, the above setting is made in order to distinguish the traffic speed of railways, expressways and national highways. Third, after 2000, railways have experienced four major speed increases in China, namely in 2001, 2004 and 2007, and opened the EMU in 2007, based on the development of railways. In this paper, the category of *high-speed rail* was added in 2015 and 2019 and the above-mentioned driving speed setting was made.

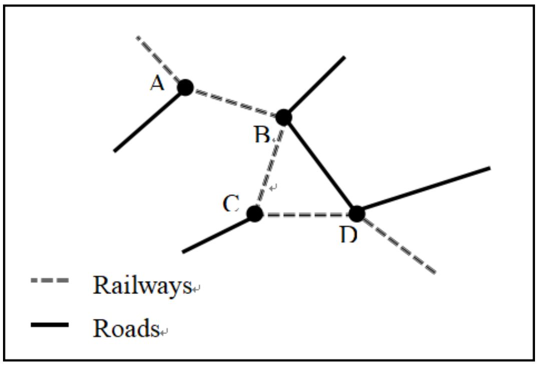

Figure 2. Schematic representation of optimal access path selection.

In the selection of geographic data, the road network data in 2000 was obtained from the China Geographic Information Resources Catalogue Service, the general railway, motorway and national road network data in 2015 and 2019 were obtained from the open street map (OSM) database and the high-speed railway network data in 2015 and 2019 were manually drawn from the information of the opening of high-speed railways in China in previous years. Figure 3 shows the spatial distribution of road network in 2000 and 2019 in China. Due to density constraints, only some national roads are shown in the figure. In the last 20 years, transport construction has progressed by leaps and bounds in China, with significant increases in road network density in parts of the eastern, central and western regions, where high-speed railways have gradually replaced ordinary railways as the main arteries for inter-city passenger transport.

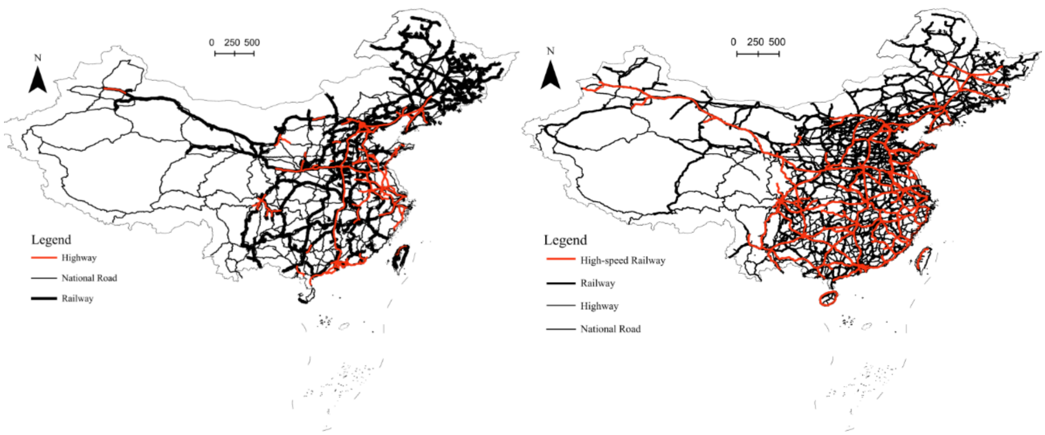

Figure 3. Main traffic routes in China in 2000 (left) and 2019 (right). Note: The above map is based on the standard map of the China Geographic Information Resources Catalogue Service (review number: GS (2016) 2556), with no modifications to the base map. The base map used in the subsequent text is the same.

In this paper, with the help of the spatial analyst tool in ArcGIS 10.2 software, the OD cost matrix of approximately 314 inter-city travel times was measured for each year using relevant road network data, and the descriptive statistics of inter-city travel times are shown in Table 1. From 2000 to 2019, the average inter-city travel time in China decreased from 31.23 hours to 12.22 hours, which is a decrease of over 60%. Of these, the decline from 2015 to 2019 was 2.27 hours or 15.67%. According to the base map used in the measurement, all the cities involved were connected to highways in 2015. Therefore, the marginal contribution to the decline in travel time in these five years comes mainly from the opening of high-speed rail.

Table 1. Descriptive statistics for inter-city travel time data.

Indicators	2000	2015	2019
Average value (hours)	31.23	14.49	12.22
Median (hours)	27.67	12.79	10.78
Standard deviation (hours)	18.79	8.66	7.32
Kurtosis	1.58	0.86	1.14
Skewness	1.15	1.00	1.09
Region	123.53	45.50	39.01
Min. value (hours)	0.25	0.24	0.22
Maximum value (hours)	123.78	45.74	39.23
Sample size	98280	98280	98280

4.2. Spatial evolution of high-speed rail construction in China

In this paper, I focus on the impact of the opening of high-speed rail on the market access capabilities of Chinese cities. By the end of 2020, China has the world's longest and busiest high-speed rail transport network, with an operational mileage of nearly 40,000 km[1]. 2003 can be seen as the first year of high-speed rail in China, when the Qin-Shen Passenger Dedicated Line was opened to traffic, covering about 400 km from Qinhuangdao to Shenyang, with a line design speed of 250 km/h. In 2008, China's National Development and Reform Commission approved the medium-term and long-term railway network plan, which proposed the construction of a high-speed railway network with a spatial pattern of four vertical and four horizontal and the speed of high-speed railway construction accelerated. Figure 4 shows the total mileage of new high-speed railways opened each year from 2003 to 2020, with an average of over 3,000 km of new high-speed railways opened each year after 2008. Only the newly opened mileage every year exceeds the total operating mileage of most countries in the world. By 2020, the total mileage of high-speed rail in China accounts for more than two-thirds of the total mileage of high-speed rail in the world.

[1] Includes high-speed railways with design speeds of 300–350 km/h, passenger lines of 250 km/h, passenger and freight railways of 200 km/h, and intercity railways that do not include the metro system.

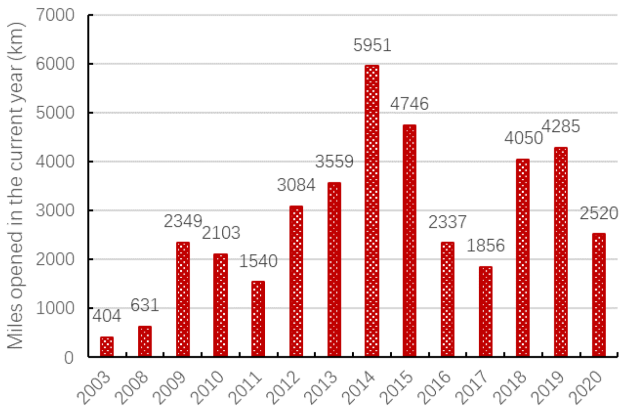

Figure 4. New mileage of high-speed rail in China over the years.

The location of railway stations takes into account the level of economic development, the distribution of population and resources, and even the national security, environment, and stability of each region. China's high-speed railway network aims to connect provincial capitals with the majority of major prefecture-level cities in a more convenient and faster transportation network. By 2020, all of China's provincial capitals, except Lhasa in Tibet, will be connected by high-speed rail, which has greatly reduced the distance between major cities in terms of time and space and reshaped China's economic geography. From 2008 to the present, the number of high-speed rail passengers has grown from 128 million to 2.29 billion in 2019, accounting for 9% to 63% of China's railway passenger traffic (Figure 5). In addition, the share of road passenger traffic in total passenger traffic has been declining year on year, evidence that the traditional modes of transport of ordinary railways and roads are being fiercely competed with by high-speed rail transport. High-speed rail is playing an increasingly important role in economic and social development.

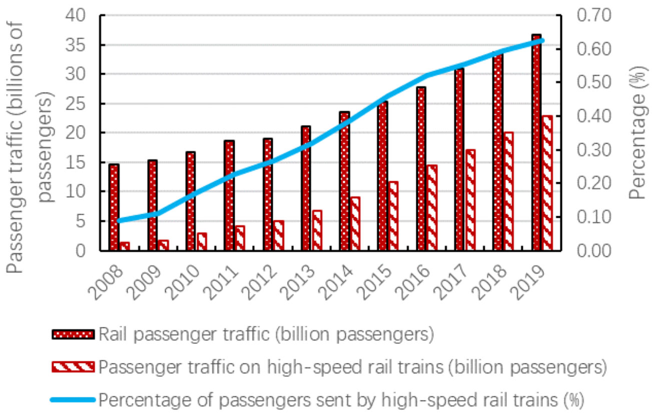

Figure 5. Passengers sent by high-speed rail and railways in China 2008–2019.

Figure 6 is a hand-drawn spatial distribution map of the mileage of China's high-speed rail from 2010 to 2020 based on the operation of China's high-speed rail over the years. In 2010, high-speed rail was mainly used to connect major cities in China, such as Beijing, Shanghai, Guangzhou, Shenzhen and Wuhan. The construction of high-speed rail was mainly distributed in the eastern region and some central regions. At this time, the network structure of high-speed rail was far from being formed. In 2012, new first-tier cities such as Zhengzhou opened high-speed rail one after another and major cities in the eastern and central regions were connected. 2014 was the year with the largest number of high-speed rail lines opened. Western regions such as Xinjiang, Gansu, Guangxi and other provinces also opened high-speed rail lines one after another. High-speed rail began to appear on a large scale in the western region of China. From 2014 to 2020 is a critical period for China's high-speed railway weaving a network. A large number of cities have opened high-speed railways during this period. The formation of high-speed railway networks has greatly improved travel efficiency and is also known as the new engine of China's economic growth.

After 2010, China's national roads and expressways have been well developed and almost all prefecture-level cities have been connected, and the increase in their density has not greatly improved the inter-city traffic. Therefore, in the following measurement of the changes in the market access capacity caused by the opening of the high-speed rail, we regard the national road or expressway as the basic traffic endowment of each city and assume that its overall situation is constant because we only consider the shortest. Therefore, after ordinary railways and expressways have been fully opened in China's prefecture-level cities, the basic traffic endowments formed by these two types of traffic methods will not affect the city's ability to enter the market in the next two years. Marginal impact, the annual changes in the market access capabilities of all cities are jointly determined by the changes in marginal commuting time caused by the opening of high-speed rail and the changes in wage levels in prefecture-level city.

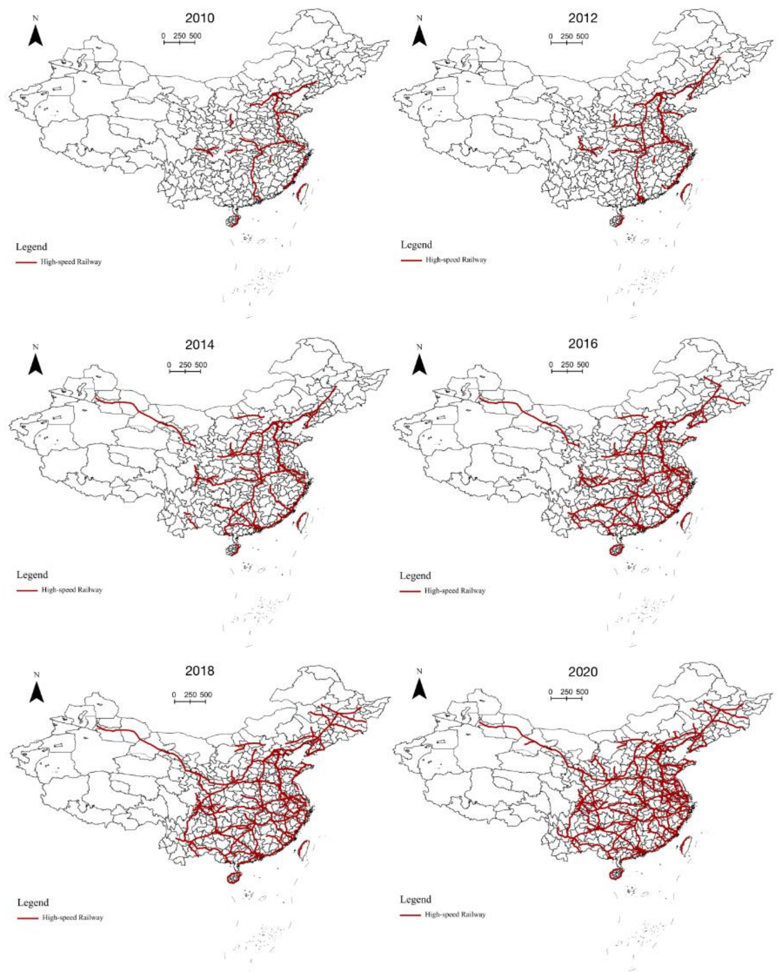

Figure 6. Spatial evolution of high-speed rail construction in China.

5. Results

In the measure of market access, the following form was eventually used:

$$MA_{it} = \sum_{j \neq i} w_{jt} L_{jt}\, time_{ijt}^{-\tilde{\theta}}$$

The estimation of parameters $\tilde{\theta}$ is key to the measurement of market access. In the existing literature, some of which measuring market access of nation, on the parameters $\tilde{\theta}$, Eaton and Kortum using OECD internal trade data for 1995, measured the values of $\tilde{\theta}$ were 8.28, 3.6 and 12.86 [14]. Some scholars have obtained values between 4.5 and 6.5 using OECD data [18,19]. Others are estimation of parameters $\tilde{\theta}$ in the calculation of measuring domestic market access, mainly found in relevant foreign studies. Among them, Bernard et al. used the firm-level productivity distribution in the US and estimated $\tilde{\theta} = 3.6$ [20]. Donaldson and Hornbeck used interregional trade data for India and estimated $\tilde{\theta} = 3.6$ [10]. There is no literature to date on parameter $\tilde{\theta}$ estimation in China so far, mainly due to the lack of data on inter-city trade flows within the country. In previous studies on transport-induced changes in market access, Tombe and Zhu set a value of 4 based on a literature review [21]. Lin refers to Donaldson and Hornbeck's study and sets the value of $\tilde{\theta}$ to 3.6 [10,11], and Xu based on Simonovska and Waugh's estimation results sets the value of $\tilde{\theta}$ to 4 [19,22]. In the study of the impact of HSR on trade costs and productivity, Chinese scholars also refer to previous literature and sets the value of $\tilde{\theta}$ to 3.6 [12,23]. Considering the existing studies, we set $\tilde{\theta} = 3.6$ and to increase the robustness of the results, additionally selects $\tilde{\theta} = 4$ and $\tilde{\theta} = 8.28$ to measure the market access of Chinese cities. The descriptive statistics of the city's market access values by year, which I measured using the above method, are reported in Table 2.

Specifically, in the measurement, the travel time matrix between prefecture-level cities in China was measured using the China Road Network Data and the income data was selected from the GDP data of each city and deflated using 2000 as the base period. When the parameter is chosen as $\theta = 3.6$, the logarithm of market access increased from 5.69 to 8.26 from 2010 to 2019, an increase of nearly 45% over the decade. When the parameter is chosen as $\theta = 4.0$, this ratio is 50%. When the parameter is chosen as $\theta = 8.2$, the logarithm of market access has increased by 128% over the decade. In conclusion, the market access of Chinese cities has increased substantially in the last decade due to the massive construction of transport infrastructure, particularly the expansion of the high-speed rail network.

Table 2. Descriptive statistics for market access measured under different parameters, 2010–2019.

Year	Average	Standard deviation	Minimum value	Maximum value	Sample size
Logarithmic value of Market Access (θ = 3.6)					
2010	5.69	2.07	0.07	11.35	226
2011	5.93	2.12	0.20	11.58	226
2012	6.37	2.19	0.39	11.73	226
2013	6.79	2.16	0.70	11.84	226
2014	7.07	2.08	0.94	12.91	226
2015	7.34	2.07	1.08	13.00	226
2016	7.57	2.00	1.87	13.11	226
2017	7.79	1.96	1.97	13.22	226
2018	8.02	1.82	3.27	13.28	226
2019	8.26	1.73	3.51	13.42	226
Logarithmic value of Market Access (θ = 4.0)					
2010	5.43	2.34	−0.91	11.78	226
2011	5.67	2.39	−0.78	12.00	226
2012	6.13	2.47	−0.60	12.15	226
2013	6.56	2.46	−0.31	12.26	226
2014	6.87	2.37	−0.08	13.43	226
2015	7.16	2.36	0.06	13.52	226
2016	7.41	2.29	0.83	13.63	226
2017	7.63	2.25	0.93	13.74	226
2018	7.89	2.09	2.42	13.80	226
2019	8.15	1.98	2.68	13.94	226
Logarithmic value of Market Access (θ = 8.2)					
2010	3.50	5.02	−9.83	16.61	226
2011	3.84	5.11	−9.70	16.75	226
2012	4.53	5.32	−9.53	16.90	226
2013	5.12	5.36	−9.23	17.01	226
2014	5.73	5.26	−9.09	18.98	226
2015	6.21	5.26	−8.94	19.07	226
2016	6.60	5.20	−8.63	19.20	226
2017	6.99	5.15	−8.56	19.34	226
2018	7.50	4.79	−6.22	19.36	226
2019	7.98	4.50	−6.08	19.52	226

6. Conclusion

With decades of rapid development, China's transportation infrastructure has advanced by leaps and bounds, and remarkable achievements have been made in everything from graded roads and expressways to railways and high-speed railways. A three-dimensional transportation network closely connects various cities in China and clears the traffic barriers between cities. Whether it is the flow of population or other production factors, qualitative changes have occurred after the rapid development of transportation. High-speed railways make the space-time distance between cities and regions smaller, promote the exchanges and coordinated development between cities and regions, and profoundly affect the spatial pattern of China's urban economic and social development.

This paper draws on the estimation framework of Herzog to estimate the general equilibrium condition of trade and uses the derived simplified model to determine the method to measure the market access ability of cities [13]. Based on the current situation of China's transportation infrastructure construction and since ordinary railways and expressways have already reached all sample prefecture-level cities, we believe that after 2010, the marginal change in the improvement of inter-city traffic efficiency is mainly contributed by the opening of high-speed railways. Due to the large-scale construction of a new type of transportation infrastructure such as high-speed rail, the traffic efficiency between Chinese city pairs has been improved and the connection has become closer, reshaping the spatial pattern of Chinese cities. Specifically, by constructing an 11-year inter-city travel time matrix in 2000 and 2010–2019, we found that from 2000 to 2019, the average inter-city travel time in China dropped from 31.23 hours to 12.22 hours, a drop of more than 60%. Among them, from 2015 to 2019, it decreased by 2.27 hours, a decrease of 15.67%. According to the base map I used for the measurement, all the cities involved can be connected by expressways, because we mainly focus on the shortest passage time, therefore, the connectivity situation of the transportation modes other than the high-speed rail has not changed in the past five years and the marginal impact on the transit time is zero, that is, the marginal contribution of the decline in the transit time in the past five years mainly comes from the opening of the high-speed rail. In terms of market entry capabilities, our measurement results show that during the 10 years from 2010 to 2019, due to the opening of the high-speed rail, the logarithmic value of the market entry capabilities of Chinese cities has increased significantly. From the measurement results of the three parameters we selected, the average has increased by more than about 50%. Therefore, we believe that the construction of high-speed railways has led to a substantial increase in the ability to enter the market. In the past decade, in terms of transportation infrastructure, the construction of high-speed railways has played a huge role in changing the accessibility of cities and promoting the improvement of cities' ability to enter the market.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

Conflict of interest

The authors declare no conflict of interest.

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