sustainability

MDPI

Article

Does Transportation Infrastructure Construction Enhance Enterprise Innovation Resilience in China?

Enji Li [1,2,*] and Ziwei An [1]

[1] School of Business Administration, Hebei University of Economics and Business, Shijiazhuang 050061, China; anziwei2021@stu.hueb.edu.cn
[2] Hebei Collaborative Innovation Center for Urban-rural Integrated Development, Shijiazhuang 050061, China
* Correspondence: lienji@ucass.edu.cn; Tel.: +86-185-1313-3976

Abstract: With increasing uncertainty and ambiguity in the external business environment, the risks and challenges faced by enterprises also increase accordingly; resilience has become a necessary characteristic for the evolution and upgrading of enterprise innovation systems, and improving enterprise innovation resilience becomes the key for enterprises to establish sustainable competitive advantages and achieve sustainable development. Based on the panel data of Chinese listed companies and cities, we employ the common factor method to measure enterprise innovation resilience and explore the impact of transportation infrastructure construction on enterprise innovation resilience. The results reveal that, firstly, enterprise innovation resilience shows an overall upward trend, but there is a certain degree of temporal–spatial and industrial disparity. Secondly, transportation infrastructure construction, represented by HSR opening, can significantly improve enterprise innovation resilience. However, this effect performs the following heterogeneity: (1) Regionally, the promotion effect is more obvious in eastern regions, central cities, and non-central cities within 107 km and 764 km away from the central city. (2) For enterprises, compared to state-owned enterprises and non-high-tech industries, transportation infrastructure construction has a greater effect in non-state-owned enterprises and high-tech industries. (3) The higher the degree of centrality and closeness centrality, the more obvious the promotion effect of transportation infrastructure construction. Finally, mechanism tests show that enterprise resource acquisition and resource allocation abilities are important channels for transportation infrastructure construction, to enhance enterprise innovation resilience.

Keywords: transportation infrastructure construction; enterprise innovation resilience; high-speed rail; resource basis; the common factor model

check for updates

Citation: Li, E.; An, Z. Does Transportation Infrastructure Construction Enhance Enterprise Innovation Resilience in China? *Sustainability* **2024**, *16*, 2931. https://doi.org/10.3390/su16072931

Academic Editor: Andrew Thomas

Received: 31 January 2024
Revised: 23 March 2024
Accepted: 25 March 2024
Published: 1 April 2024

1. Introduction

In recent years, with the frequent occurrence of uncertainty in events such as the trade disputes between China and the United States, and the Russia–Ukraine conflict in 2022, "VUCA" (standing for Volatility, Uncertainty, Complexity, and Ambiguity) is synonymous with current environmental characteristics, which make higher demands on the innovation system, and resilience has become an essential trait for innovation systems to overcome crises. Innovation system refers to the overall structure within an organization consisting of various elements, mechanisms, and interactive relationships collectively driving and supporting innovation activities. As the main body of the innovation system, enterprise innovation resilience is essential for the steady far-reaching of national innovation systems. Only if micro-enterprises can quickly adjust and push the enterprise innovation system to a higher level in adversity will the innovation outcomes continue to be created and the sustainable impetus for the evolution of innovative systems be provided. Therefore, it is urgent to explore influencing factors of enterprise innovation resilience and its improvement path, which is of practical significance for enterprise sustainable development in the "VUCA" era.

The resource base provides a competitive advantage for enterprises engaging in innovation activities and fostering sustainable development. According to the production process of innovation, enterprise innovation ability not only depends on its own innovation resources and conditions, but it is also affected by the inflow of external production factors [1,2]. As an important carrier for the spatial flow of production factors, transportation infrastructure can quickly shorten the temporal–spatial distance and facilitate the dissemination and exchange of knowledge and technology between regions, which is conducive to promoting mutual exchange and learning among regions and enhancing enterprise innovation ability [3–5]. The Report to the 20th National Congress of the Communist Party of China once again emphasized building a modern comprehensive transportation system that is safe, convenient, efficient, green, and economical; and building a transportation system that satisfies the people, provides strong guarantees, and is at the forefront of the world. Then, against the backdrop of frequent external shocks, will transportation infrastructure construction still play an important role in enhancing enterprise innovation resilience? If yes, what are the mechanisms? The answers to these questions not only help to reveal the formation mechanism of enterprise innovation resilience, but also provide direction for enterprise innovation activities and enterprise sustainable development in the VUCA era.

The academic circle has conducted valuable explorations of the connotations, measurement, and influencing factors of innovation resilience. Resilience is derived from physics and refers to the ability of the system to recover its original state. Innovation system refers to the innovation network formed by the interaction between relevant departments within an organization. As an expansion of the concept of resilience in the field of innovation, scholars generally agree that enterprise innovation resilience refers to the adaptive adjustment ability of enterprise innovation systems under external shocks [6,7]. For the measurement of innovation resilience, there are two methods in existing research. One is—according to the characteristics of resilience—to construct an index evaluation system from the perspective of diversity, liquidity, buffering, etc. [7,8]; and the other is to analyze the differences between variables in practice and counterfactual conditions using counterfactual analysis [9,10], referring to the measurement of economic resilience. For driving factors of innovation resilience, existing studies have found that diverse talents and industries, innovation input, technical resources, government support, etc., have a positive effect on innovation resilience [7,9]; while administrative monopoly and pollution caused by gas emissions inhibit innovation resilience. Based on the structural equation modeling analysis, Lisdiono et al. (2022) [11] revealed that leadership capabilities play a significant role in improving enterprise resilience. Putritamara et al. (2023) [12] found that dynamic capabilities can enhance MSMEs' resilience through improving digital transformation.

The studies mentioned above have provided valuable insights for us, but there are still areas for improvement. Based on the research perspective, although improving innovation resilience has become a key issue in practice, research on the origin of innovation resilience is obviously lagging and most research mainly conducts empirical research on innovation resilience from the macro perspective, while few studies focus on enterprise innovation resilience, and even fewer focus on the perspective of transportation infrastructure construction. External business uncertainty requires enterprises to have sufficient resource support, and timely access to external resources is crucial for enterprise survival and sustainable development. Through promoting factor mobility, transportation infrastructure can broaden channels for enterprise resource acquisition, but this effect may be constrained by factors such as urban resource endowment and enterprise characteristics. For example, if a city faces a shortage of financial resources and is close to a nearby HSR station, the government's blind construction of HSR may worsen the regional business environment and have a negative impact on enterprise production and operation. Moreover, as the number of HSR lines increases, the disparity between cities opening or not opening HSR is gradually diminishing, leading to an expansion of distance between cities that have opened HSR. Therefore, a deeper analysis of the direction and extent of the impact of transportation infrastructure on enterprise innovation resilience is necessary, especially in the context of intensified competition among cities for HSR construction.

From the perspective of research method, the index evaluation system method easily confuses causality [13], does not easily portray the adjustment process under the shock, and implicitly assumes that the external shock is fixed and the response of different innovation systems to external shocks is homogeneous, which is even more inconsistent with the actual situation. The counterfactual approach needs to subjectively set “resistance periods” and “recovery periods”, and focuses on a single shock. A more reasonable way is to abide by the connotation of resilience (“external shock” and “adaptive adjustment”) to measure innovation resilience. Unfortunately, the existing literature on the measurement of innovation resilience is limited.

In this paper, we match the data of listed companies and the construction of HSR in China, employ the common factor model to calculate enterprise innovation resilience, and explore the causal effect of transportation infrastructure construction on enterprise innovation resilience. This study contributes to the literature in four aspects. **Firstly, we provide a new research perspective for understanding enterprise innovation resilience.** From the perspective of the flow of production factors, we explore the impact of transportation infrastructure construction on enterprise innovation resilience, providing new empirical evidence for understanding enterprise innovation resilience and offering a quantitative reference for the construction of innovation resilience theory.

Secondly, we expand the measurement of enterprise innovation resilience. In contrast with previous studies, we adopt the common factor model to estimate the response coefficient of the enterprise innovation system to different external shocks, making up for the limitation that the “index system method” and the “counterfactual analysis method” do not easily reflect the core connotation of resilience.

Thirdly, we provide new empirical evidence for clarifying the formation mechanism of enterprise innovation resilience. Previous studies have mostly revealed the mechanism of system resilience from the perspective of case studies or empirical induction and proposed that redundant resources are the core of system resilience construction [14–16]. Large-sample empirical research is relatively rare, especially in innovation system resilience. From the perspective of enterprise resource acquisition and resource allocation, we have revealed the impact mechanism of transport infrastructure construction on enterprise innovation resilience, which helps to open the “black box” of the generation of enterprise innovation resilience.

Fourthly, we carry on a systematical test for the resilience effect of HSR. The study of “high-speed rail economics” usually only focuses on the impact of whether cities open HSR and ignores the heterogeneity characteristics of the construction of urban HSR [17]. We comprehensively identify the causal effect of HSR construction on enterprise innovation resilience from three dimensions: the opening of HSR, the optimal radius of the HSR effect, and the HSR network; enriching the research on the economic effect of HSR.

2. Theoretical Analysis and Research Hypothesis

The resource base is key to the ability of enterprises to establish a lasting competitive advantage and achieve sustainable development, especially in an environment where external shocks are frequent [13]. In the face of external shocks, it is necessary for enterprises to find a solution to quickly recover their original state or find a new development path after being shocked. The more resources the enterprise has, the stronger its resistance to shocks. Gittell et al. (2006) [14], Lengnick-Hall and Beck (2011) [15], and Ortiz-de-Mandojana and Bansal (2016) [16] found that enterprises’ human resources and the training of daily human resources, redundant funding, and sufficient cash flow can improve organizational resilience. Transportation infrastructure construction contributes to promoting the speed and scale of factor flow, changing the internal composition and external connection of enterprise innovation systems, and enriching enterprises’ resources; which is bound to affect enterprises’ reactions and responses to external shocks. According to the resource-based theory, we will reveal the impact mechanism of the transportation infrastructure construction on enterprise innovation resilience from two perspectives of, resource acquisition and resource allocation.

2.1. Resource Acquisition

2.1.1. Enterprise Human Capital

Due to the advantages of fast, safe, comfortable, and punctual transport services, vehicles represented by HSR are gradually becoming the preferred travel method for enterprise talents, especially high-quality talents with higher time sensitivity [18–20]. Therefore, the impact of the transportation infrastructure construction on enterprise innovation resilience is first reflected in enterprise human capital. Firstly, transportation infrastructure construction can reduce high-quality talents' mobility costs [21,22]. The rapid development of transportation infrastructure construction has increased accessibility for individuals to search for work, thereby reducing the mobility cost of high-skilled talents to cities along the line and attracting high-quality talents to work in enterprises located on the line [23,24]. Secondly, transportation infrastructure construction can improve the quality of talents. The face-to-face communication of high-quality talents caused by the opening of HSR is conducive to stimulating the knowledge spillover effect [25] and promoting cross-regional cooperation between talents in different regions [26,27], thereby improving enterprise human capital and laying a solid foundation for enterprises' sustainable development. At the same time, the continuous deepening of transportation infrastructure construction can enable highly educated talents to have a more comprehensive understanding of industry dynamics and market changes, and improve their professional knowledge and technical capabilities in a timely manner.

As the most important production factor of enterprises, enterprise human capital level directly affects enterprise R&D, technical level, and market competitiveness; thereby affecting enterprise innovation resilience. Firstly, it is well known that enterprises with higher human resources can improve enterprises' innovation ability [28,29]. A higher level of human capital means that enterprises have more highly qualified employees with excellent skills and knowledge who can adapt and react quickly to market changes and competitive environments, and then drive enterprises' sustainable development in innovative ways. Secondly, the enrichment of enterprise human capital can also strengthen enterprise knowledge management. Enterprises with high-quality human capital can enable enterprises to better transform knowledge into enterprise value. Abundant human capital can promote knowledge flow and exchange [1], and improve enterprise knowledge management ability, thereby enhancing enterprise risk identification and risk perception capabilities. Thirdly, a higher level of human capital can enhance enterprises' adaptability and resistance [16,30]. In the face of complex environmental changes, the diversity and flexibility of human capital can make enterprises more resilient and transformative, as well as able to predict future environmental changes, thereby promoting the sustainable and healthy development of enterprise innovation systems.

2.1.2. Enterprise Financing Constraints

Transportation infrastructure construction provides the possibility for enterprises to ease financing constraints. Firstly, transportation infrastructure construction can shorten the distances between regions and reduce transportation costs [17]. Research shows that after the opening of HSR, the geographical division between investors and enterprises is broken, and the speed and quality of information exchange and communication are improved [17,31]; therefore, the rising transaction costs will be alleviated. This is conducive to the needs of enterprise research and development, market expansion, production, sales, and other aspects, and relieves the pressure of enterprise financing. Secondly, transportation infrastructure construction can attract more external investment, further expand the market scale, and increase the level of enterprise income. Studies have shown that enterprises located far from central cities receive less external financing [32]. HSR facilitates the flow of "soft information" among enterprises, weakens investors' "local preference", and makes it easier to raise funds through private investment, trust plans, and other ways [33], which can broaden enterprise financing channels and ease enterprise financing constraints. Thirdly, transportation infrastructure construction can improve bank competition level, thereby reducing enterprise financing constraints. For instance, taking A-share listed companies from 2009 to 2016 as a sample, Wu et al. (2021) [34] showed that the opening of HSR improves the level of bank competition in the place where it is opened, thereby reducing the cost of enterprise debt financing.

Capital reserve plays a crucial role in enterprises' response to the crisis [35]. Firstly, financing constraints affect enterprise investment in innovation. Studies have shown that financing constraints have a negative impact on enterprise innovation investment, and the greater the relaxation degree of enterprise financing constraints, the higher the enterprise innovation investment [36]. Because financing difficulties will lead to a shortage of funds, which will reduce enterprise support for R&D and innovation investment, and ultimately lead to the reduction of enterprise innovation resilience. Secondly, enterprise financing constraints will also affect enterprises' market competitiveness. Some studies have shown that the competitiveness of enterprises with financing constraints in the market is weaker, and the greater the threat of financing constraints, the lower the enterprise market competitiveness [37]. Enterprises without financing constraints can make full use of external funds and market opportunities so that enterprises can expand their scale in time, consolidate their market position, and improve their sustainable development and innovation resilience. Overall, enterprises with abundant funds can not only establish a risk prevention system in advance to help them cope with the "unknown in the known", but also offer trial and error space for enterprise innovation systems to cope with external shocks and this contributes to enterprises recovering, improving, and finding new development paths after suffering external shocks.

2.2. Resource Allocation

The essence of enterprise competition is the competition of resource allocation efficiency, and the establishment of enterprise innovation resilience is a process of optimizing resource allocation. Transportation infrastructure has played a decisive role in promoting the integration and coordinated development of regional resources and improving enterprise resource allocation efficiency. Firstly, the continuous optimization of transportation infrastructure can weaken market segmentation, correct resource misallocation, and accelerate the transfer of resource elements from inefficient to highly efficient enterprises [18,38,39]. Secondly, transportation infrastructure construction promotes the optimization and upgrading of the industrial structure in different regions [40], creates an external environment for benign interaction among enterprises, and provides an impetus for enterprises' high-quality development. Thirdly, the upgrading of transportation infrastructure attracts more high-quality labor and capital, and provides more channels to obtain higher-quality products at lower prices [41], which will promote the improvement of enterprise core competitiveness and resource allocation efficiency.

The improvement of production efficiency means that enterprises have more resources to deal with external shocks, which can help to reinforce the bearing capacity of enterprises against external shocks and consolidate enterprise resilience resources in the face of new adversities and crises. Firstly, the improvement of resource allocation can bring about technological progress and innovation ability [42]. That is, it can facilitate the enterprise's ability to conduct technological research, new product development, and innovation. These innovative measures can enable enterprises to better adapt to market changes and improve industrial competitiveness, while also achieving sustainable development and breakthroughs, and increasing enterprise innovation resilience. Secondly, the improvement of total factor productivity can also enable enterprises to better adapt to changes in culture, organization, and management [43], so as to meet the challenges of innovation and increase enterprise innovation resilience. Thirdly, enterprises with higher resource allocation efficiency are more likely to establish new business models and can obtain more opportunities to develop new markets, so that enterprises can find new growth paths quickly after suffering external shocks.

Based on the above analysis, the research hypothesis of this paper can be proposed as follows:

H1. *Transportation infrastructure construction can enhance enterprise innovation resilience.*

H1a. *Transportation infrastructure construction can enhance enterprise innovation resilience by improving enterprise human capital, alleviating enterprise financing constraints, and optimizing enterprise resource allocation efficiency.*

3. Research Design

3.1. Sample Selection and Data Sources

This paper selects the listed companies and urban panel data from 2007 to 2021 as the initial sample. Based on the research of Li et al. (2022) [44], we process the data as follows: (1) exclude the listed companies with ST and ST* in the sample period; (2) eliminate the sample of enterprises in the year of IPO; (3) eliminate observations with serious missing values, such as enterprise innovation investment and patent applications; (4) eliminate abnormal observations, such as negative total assets, total assets that are less than current or intangible assets, and negative liabilities. In addition, to eliminate the influence of outliers, the continuous variables are winsorized at levels of 1% and 99%. The final sample consists of 9186 enterprises. (Since it is necessary to use balanced panel data for the common factor model, the final sample consists of 9186 enterprises after removing samples with missing values and matching the data of enterprise innovation resilience, enterprise finance, and urban transportation).

The micro-level data on companies are from the China Stock Market and Accounting Research (CSMAR) database. The HSR data are from the China Railway Yearbook, the National Railway Passenger Train Timetable, and the official website of the China Ministry of Railways (https://www.nra.gov.cn/) accessed on 1 March 2024. The urban data used in this paper are from China City Statistical Yearbook, and the data related to the geographical environment come from the National Platform for Common Geospatial Information Services.

3.2. Model Setting

Firstly, taking the urban opening HSR as a quasi-natural experiment, this paper employs the difference-in-differences (DID) model to identify the causal effect of the opening of HSR on enterprise innovation resilience. The following model is constructed:

$$Resilience_{ict} = \alpha_0 + \alpha_1 HSR_{ct} + \alpha_2 X + \mu_i + \lambda_t + \xi_{ict} \quad (1)$$

where the subscripts i, c, and t refer to the enterprise, city, and year, respectively. The explained variable *Resilience* is enterprise innovation resilience, which is measured by the common factor model. The explanatory variable *HSR* represents whether the city where the enterprise located has opened HSR and the opening time of the HSR; namely, the interaction term of HSR opening and time dummy variable. X is a set of control variables. μ_i represents enterprise fixed effect, λ_t represents year fixed effect, and ξ_{ict} is random error.

Secondly, with the continuous construction and improvement of HSR, the functional orientation of different cities in the HSR network is gradually different, and cities' factor agglomeration and radiation capacity may be difficult to be portrayed by simply opening HSR and not opening HSR. Referring to Li and Luo (2022) [17], the degree centrality and closeness centrality are introduced to the model to effectively investigate the differential treatment effect of the construction of HSR on enterprise innovation resilience. The specific model is as follows:

$$Resilience_{ict} = \beta_0 + \beta_1 DC_{ct} + \beta X + \mu_i + \lambda_t + \xi_{ict} \quad (2)$$

$$Resilience_{ict} = \theta_0 + \theta_1 CC_{ct} + \theta X + \mu_i + \lambda_t + \xi_{ict} \quad (3)$$

Among them, explanatory variables DC_{ct} and CC_{ct} indicate the city c's degree centrality and closeness centrality in year t. In addition, the meaning of other variables is the same as Equation (1).

3.3. Variables

3.3.1. Enterprise Innovation Resilience (Resilience)

Based on the existing literature, we argue that enterprise innovation resilience is the adaptability of the enterprise innovation system under external shocks. Resilient enterprises do not necessarily have the ability to withstand all external shocks. The resilient system can make adaptive adjustments according to the change in the external environment, expand the positive impact, and reduce the negative effects of external shocks [45]. When the system is subjected to external shocks, it will temporarily deviate from the original operation trajectory [46], providing an opportunity to observe the innovation system's adaptability by using the response of enterprise innovation systems to external shocks. Following this, we construct the following model to reflect enterprise innovation ability:

$$Y_{it} = \beta_0 + \beta Z_{it} + \mu_i + \lambda_t + \xi_{it} \quad (4)$$

In Equation (4), Y_{it} represents enterprise innovation level, Z_{it} is a set of observable variables that affect enterprise innovation level, including enterprise leverage ratio (*Lev*), enterprise size (*Size*), enterprise age (*Age*), the shareholding ratio of the top 10 shareholders (*Top10*), management shareholding ratio (*MS*), and board size (*Board,* measured as the natural logarithm of the number of board members). The meaning of other variables is the same as Equation (1).

In order to capture the response degree of enterprise innovation systems to external shocks, we introduce external shocks and enterprise heterogeneity on the basis of Equation (4), decompose the unobservable factors affecting enterprise innovation level, and construct the following common factor model:

$$Y_{it} = \beta_0 + \beta Z_{it} + \mu_i + \lambda_t + v_{it} + \xi_{it} \quad (5)$$

where v_{it} denotes the direction and degree of the system's deviation under external shocks. Referring to Bai (2009) [47], v_{it} can be further decomposed into $\sum_{t=1}^{d} \lambda_{il} f_{lt}$. f_{lt} represents the lth external shock faced by the system in the t period and only changes with time, reflecting the intensity and direction of the external shock. λ_{il} indicates the response of enterprise i to the lth external shock and does not change with time, reflecting enterprise heterogeneity. The product of λ_{il} and f_{lt} captures the changes and reactions of different enterprises to external shocks at different times. The larger the v_{it}, the stronger the ability of the enterprise to adapt and adjust under external shocks; that is, the greater the innovation resilience. Since external shocks are not observable, the estimation of Equation (4) cannot be explored directly, for which we refer to the practice of Bai (2009) [47] (Firstly, the corresponding coefficients are estimated based on the traditional two-way fixed-effect model. Then, the residuals are factorized to obtain several common factors (f_{lt}). Finally, introduce the common factor into the two-way fixed-effects model to re-estimate the corresponding coefficient and factor load, (λ_{il}), and continue the factor decomposition of the residuals. Repeat the above steps until convergence).

3.3.2. HSR Construction

(1) Whether the City Has Opened HSR (*HSR*)

HSR_{ct} is the core explanatory variable, measured by $Treat_i \times Post_{it}$. Referring to Feng et al. (2023) [22], if the city has opened HSR, the value of $Treat_i$ is 1; otherwise, the value of $Treat_i$ is 0. The value of $Post_{it}$ is 1 for the year of HSR opening and subsequent years; otherwise, the value of $Post_{it}$ is 1. The opening year of urban HSR is defined as the time when the first HSR station was opened in the city. If the value of HSR is 1, the sample belongs to treatment group, otherwise, the sample belongs to control group. The coefficient α_1 reflects the causal effect of the opening of HSR on enterprise innovation resilience, which is expected to be significantly positive according to the analysis above.

(2) The Location of the City in the HSR Network

Referring to Li et al. (2022) [17], and Li and Luo (2020) [48], we use the SNA method to calculate the degree centrality and closeness centrality of the city in the HSR network. The measurement formulas are as follows:

$$DC_{ct} = \frac{k_{ct}}{n-1} \tag{6}$$

$$CC_{ct} = \frac{1}{d_{ct}} = \frac{n}{\sum_{j=1}^{n} d_{cjt}} \tag{7}$$

Among them, K_{ct} denotes the number of cities directly connected to city c in year t, and n − 1 represents the maximum degree centrality of a node city in the HSR network with n-node cities. DC reflects the number of other node cities connected to the node city. The more cities connected by the node city, the higher the degree centrality, the more important the node city is in the HSR network, and the more developed the transportation of the node city. In Equation (7), CC indicates the reciprocal of the average distance between the node city and other node cities; d_{ct} is the average distance of node city c to the rest of the node cities in year t; d_{cjt} represents the average distance from node city c to node city j in year t. The larger the d_{ct}, the farther the average distance between the city and other node cities, and the lower the closeness centrality of the city in the HSR network.

3.3.3. Control Variables

Referring to [49,50], in this paper, the following variables are selected as control variables to control the influence of other factors on enterprise innovation resilience, including Tobin Q; enterprise growth (Growth), measured by enterprise sustainable growth rate; enterprise size (Size), measured by the natural logarithm of the enterprise assets; enterprise profitability, expressed by return on assets (ROA); enterprise debt-to-asset ratio (Lev), measured by the ratio of the enterprise total liabilities to the total assets. Table 1 shows the meaning of key variables and their descriptive statistics.

Table 1. The descriptive statistics of main variables.

Variable Meaning	Meaning	Obs.	Mean	Std.	Min	Max
Resilience	Using the common factor model to estimate the response of enterprise innovation activities to external shocks	9186	0.402	3.620	−28.200	18.610
HSR	The opening of HSR	9186	0.747	0.435	0	1.000
DC	Degree centrality	9186	0.010	0.012	0	0.052
CC	Closeness centrality	9186	0.010	0.013	0	0.067
Tobin Q	Tobin Q	9186	2.261	1.634	0.864	12.16
Growth	Sustainable growth rate	9186	0.049	0.138	−0.720	0.441
ROA	Return on asset	9186	0.037	0.063	−0.270	0.235
Lev	Asset-liability ratio	9186	0.494	0.201	0.049	0.974
Size	The natural logarithm of enterprise assets	9186	22.340	1.357	19.290	25.930
Manager	The rate of managerial ownership	9186	0.026	0.085	0	0.697

4. Characteristics of Enterprise Innovation Resilience

4.1. The Temporal–Spatial Characteristics of Enterprise Innovation Resilience

Table 2 reports the regional characteristics of enterprise innovation resilience in China, which is estimated by the common factor model. During the sample period, the mean of enterprise innovation resilience is −0.113 and the standard deviation is 3.317, indicating that there are large fluctuations. According to the division criteria of the National Bureau of Statistics, we divide the sample into the eastern region, the central region, and the western region. The results show that the means of enterprise innovation resilience in eastern regions and non-eastern regions are 0.810 and −0.243, respectively, indicating that the innovation resilience of enterprises in eastern regions is higher than that of enterprises in non-eastern regions. Compared with non-eastern regions, eastern regions have a higher level of transportation infrastructure, more production factors, and higher market accessibility, resulting in significantly higher scientific and technological innovation capabilities and factor agglomeration ability in eastern than those in non-eastern regions [4]. The standard deviations of enterprise innovation resilience in eastern regions and non-eastern regions are 2.258 and 4.212, respectively, reflecting that there are large differences in enterprise innovation resilience within the region, among which the gap of enterprise innovation resilience within eastern regions is more obvious.

Table 2. Enterprise innovation resilience in various regions of China.

	Obs.	Mean	Std.	Min	Max
Eastern regions	5626	0.810	4.212	−25.049	18.608
Non-eastern regions	3560	−0.243	2.258	−28.201	4.715
Central cities	3795	0.572	3.014	−28.201	15.362
Non-central cities	5391	0.422	3.993	−25.049	18.608
Full sample	9186	−0.113	3.317	−28.573	17.874

Next, we divided the sample into central cities and non-central cities. During the same period, the means of enterprise innovation resilience in central cities and non-central cities are 0.572 and 0.422, respectively, showing that enterprise innovation resilience in central cities is higher than that of non-central cities. In China, central cities have a siphon effect on high-quality talents and various innovative resources in surrounding cities, and are easier to carry out technical exchanges and cooperative innovation. The standard deviations of enterprise innovation resilience in central cities and non-central cities are 3.014 and 3.993, respectively, indicating that there are large gaps in enterprise innovation resilience, among which the gap of enterprise innovation resilience in non-central cities is more obvious. Looking at the whole sample, regional differences in enterprise innovation resilience are basically the same as China's regional innovation landscape.

4.2. Operating Characteristics of Enterprises with Different Resilience

According to the mean of enterprise innovation resilience, we divide the sample into two groups: the low innovation resilience group and the high innovation resilience group; the comparison results of the two groups are shown in Table 3. The enterprise size, enterprise leverage ratio, shareholding ratio of the top five shareholders, the number of highly educated employees, enterprise financing constraints, and enterprise total factor productivity of the high innovation resilience group are significantly higher than those of the low innovation resilience group. Looking at enterprise property rights, the proportion of SOEs in the high resilience group is obviously higher than that in the low resilience group. (In this paper, enterprise human capital (*Human*) is measured by the proportion of talents with a college degree or above, enterprise financing constraints (*SA*) is measured by the SA index, and enterprise total factor productivity (*TFP*) is measured by the LP method. *Dum_state* is a dummy variable, if the enterprise is the state-owned enterprise, the value is 1; otherwise, the value is 0).

Table 3. Business characteristics of enterprises with different resilience.

Group	Size	Lev	ROA	Top5	Human	SA	TFP	Dum_state
Low-innovation resilience	22.260	0.427	0.042	0.521	0.279	−3.743	8.073	0.334
High-innovation resilience	22.322	0.438	0.043	0.534	0.327	−3.733	8.218	0.357
Differences	−0.062 ***	−0.012 ***	0.000	−0.013 ***	−0.047 ***	−0.010 **	−0.145 ***	−0.023 ***

Notes: In this paper, *** and ** represent the significance levels of 1%, and 5%, respectively.

5. The Impact of Transportation Infrastructure Construction on Enterprise Innovation Resilience

5.1. The Causal Effect of the Opening of HSR

5.1.1. Benchmark Regression

Table 4 reports the benchmark results of the impact of the opening of HSR on enterprise innovation resilience. Whether control variables are added or not, the coefficient of *HSR* is significantly positive at the 1% level, indicating that the opening of HSR can obviously enhance enterprise innovation resilience, confirming H1. It can be seen from Column (3) that, compared with cities without HSR and which have not had HSR before, enterprise innovation resilience increased by about 0.163 after the opening of HSR. Compared with the mean of enterprise innovation resilience (0.157), the impact cannot be ignored. Theoretically, transportation infrastructure construction has attracted more elements to the city, and these elements constitute the core strength of enterprises to resist and recover from external shocks and achieve sustainable development. The mechanism of transportation infrastructure construction on enterprise innovation resilience will be examined in Chapter 6.

Table 4. Benchmark regression results.

Variable	(1)	(2)	(3)
HSR	0.230 ***	0.177 ***	0.163 ***
	(0.032)	(0.033)	(0.033)
Tobin Q		−0.084 ***	−0.085 ***
		(0.008)	(0.008)
Growth		0.114	0.097
		(0.114)	(0.115)
ROA		0.552 *	0.577 **
		(0.292)	(0.294)
Lev		−0.382 ***	−0.383 ***
		(0.090)	(0.091)
Size		0.173 ***	0.178 ***
		(0.020)	(0.020)
Manager		−0.547 **	−0.526 **
		(0.232)	(0.234)
Constant	7.211 ***	1.187 ***	1.138 ***
	(0.043)	(0.066)	(0.052)
Individual FE	Yes	No	Yes
Year FE	Yes	No	Yes
N	9186	9186	9186
Adjusted R^2	0.262	0.314	0.351

Notes: In this paper, ***, **, and * represent the significance levels of 1%, 5%, and 10%, respectively. We report the standard errors for city-level clustering in parentheses. The dependent variable is enterprise innovation resilience.

5.1.2. The Robustness Test and Endogeneity Discussion

(1) The Parallel Test

The use of the DID model in the benchmark regression needs to meet parallel trends, that is, the variation in enterprise innovation resilience between cities with and without HSR must have a similar change trend over time. Only when this condition is met can the change difference in enterprise innovation resilience between the treatment and control groups be attributed to the opening of HSR. In order to ensure the reliability of the research conclusions, referring to the research method of Li et al. (2016) [51], we take the year of HSR opening as the base period. In this paper, two sets of variables are constructed from 1 to 10 years before and after the opening of HSR, as shown in Figure 1. The estimated coefficients from 1 to 10 years before the opening of the HSR are almost not significantly different from zero, indicating that enterprise innovation resilience did not have a significant upward trend before the opening of HSR. It is not until the opening of HSR that the development trend of enterprise innovation resilience in the treatment group and control group began to diverge. That is, the model conforms to the parallel trend assumption. In the meantime, from the estimated coefficients of each year after the opening of HSR, there is a long-term dynamic impact of the opening of HSR on enterprise innovation resilience, which further verifies the previous conclusion.

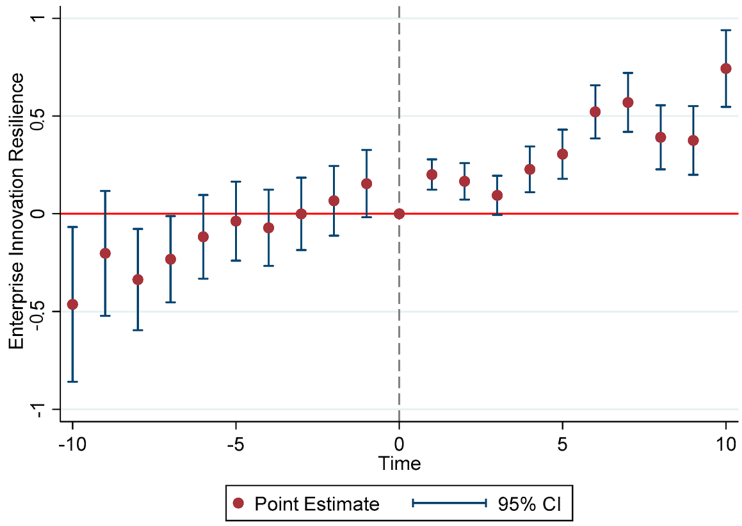

Figure 1. The parallel test.

(2) Use the Instrumental Variable Method for Estimation

Although the behavior of a single enterprise cannot affect HSR construction, the overall performance of enterprises in the jurisdiction is an important basis for the government's decision-making, so the model may have reverse causality. In addition, there may be some unobservable factors, which simultaneously affect the opening of HSR and enterprise innovation resilience. Therefore, it is necessary to use the instrumental variable (IV) method to re-estimate. In the existing literature, the historical planning of the city's transportation lines, the city's geographic conditions, and the province's transportation infrastructure construction are mostly used as the instrument variable for the opening of HSR. In light of this, we also adopt a similar method, selecting the product of the city's geographical slope and the number of cities with HSR as the instrument variable and using the two-stage least squares (2SLS) method to re-estimate. The results are shown in Column (1) of Table 5. The results of the Kleibergen–Paap rm LM statistic and Kleibergen–Paap Wald F statistic show that the instrumental variable selected in this paper is reasonable. According to the results of Column (1) in Table 5, compared with cities without HSR and which have not had HSR before, enterprise innovation resilience has increased by about 0.399 after the opening of HSR. The H1 is verified again.

Table 5. The regression results of the robustness test and endogeneity discussion.

	(1) IV-2SLS	(2) The Debiased Machine Learning	(3) Control the Impact of Highways	(4) Replacing the Measurement of Enterprise Innovation Resilience
HSR	0.399 ***	0.259 *	0.231 ***	0.102 **
	(0.130)	(0.152)	(0.039)	(0.045)
Highways			0.194 ***	
			(0.050)	
N	7388	7890	6785	8900
Adjusted R2			0.309	0.269
Individual FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Kleibergen–Paap rk LM statistic	243.291 [0.000]			
Kleibergen–Paap rk Wald F statistic	149.323			
Wald chi^2(1)		39.80 [0.000]		

Notes: In this paper, ***, **, and * represent the significance levels of 1%, 5%, and 10%, respectively. We report the standard errors for city-level clustering in parentheses and the p values in brackets.

(3) Adopt the Debiased Machine Learning Method

The model misspecification would also affect the parameter estimation results. The benchmark regression is a linear model that ignores the nonlinear effect of the explanatory variable on the dependent variable, making it susceptible to the influence of data noise. To alleviate the linear assumption of benchmark estimation, we relax the linear model assumption and use the debiased machine learning method proposed by Chernozhukov et al. (2018) [52] to re-estimate the impact of the opening of HSR on enterprise innovation resilience. The estimated results are shown in Column (2) of Table 5. It can be seen that the positive effect of the opening of HSR on improving enterprise innovation resilience is still very obvious, which is consistent with the benchmark conclusion.

(4) Control the Impact of Highways

As an important part of transport infrastructure in China, the rapid development of the highway also plays a crucial role in promoting the improvement of enterprises' innovation activities and sustainable development [53,54]. At the same time, there are crossings and overlaps in highway and HSR construction. In order to rule out the influence of highways, we add urban highway construction as a major control variable to re-examine. Column (3) of Table 5 reports the regression results of controlling the impact of highways. The coefficient of *HSR* is still obviously positive, which once again verifies the previous discussion.

(5) Replace the Measurement of Enterprise Innovation Resilience

The measurement of enterprise innovation resilience may also have an important influence on the results, so we adopt the number of patent applications to re-measure enterprise innovation resilience in the robustness test. The estimated results are reported in Column (4) of Table 5. The estimated coefficients of *HSR* are 0.102, and are significant at the 5% level, indicating that the opening of HSR can improve enterprises' abilities in the face of external shocks. Namely, transportation infrastructure construction is conducive to the improvement of enterprise innovation resilience.

5.1.3. Heterogeneity Test

According to the results of enterprise innovation resilience, there are great differences in the innovation resilience of enterprises in the eastern, central, and western regions; and in central cities and non-central cities. At the same time, a large number of studies have shown that the economic effects of the opening of HSR are heterogeneous at the regional and enterprise levels. Next, we will further capture the heterogeneous treatment effects of HSR construction from the region and enterprise levels.

(1) Regional Heterogeneity

Based on the estimation results of enterprise innovation resilience in Chapter 4, this paper will conduct heterogeneity tests from two perspectives: between eastern and non-eastern regions, and between central and non-central cities. Firstly, we divide the sample into eastern regions and non-eastern regions for estimation. The regression results of Columns (1) to (2) in Table 6 show that the opening of HSR on enterprise innovation resilience is significant in eastern regions, but not in non-eastern regions. The reason may be that eastern regions possess a greater level of economic development and market mechanism, and are more attractive to labor, capital, and other factors. The construction of HSR has broken geographical restrictions, optimized resource allocation efficiency, and accelerated the inflow of production factors from underdeveloped regions to developed regions, resulting in a greater impact on enterprise innovation resilience. Similarly, the sample is divided into central cities and non-central cities, and the regression results are shown in Columns (3) and (4) of Table 6. It can be seen that the impact of the opening of HSR on central cities is more significant in economics and statistics. In China, the administrative level has an important impact on the city's economic development and infrastructure construction. Most central cities are municipalities directly under the central government, provincial capitals, cities with separate planning status, and other cities at or above the sub-provincial level; these enjoy more economic resources and policy advantages, and economic factors are more inclined to flow into these areas. Therefore, the opening of HSR has a stronger effect on the innovation resilience of enterprises located in central cities, which is consistent with the logic that HSR has a greater effect on the innovation resilience of enterprises in central regions.

Table 6. Regional heterogeneity of the opening of HSR on enterprise innovation resilience.

Variable	(1) Eastern Regions	(2) Non-Eastern Regions	(3) Central Cities	(4) Non-Central Cities	(5) Non-Central Cities
HSR	0.271 ***	0.072	0.306 ***	0.082 *	
	(0.047)	(0.047)	(0.054)	(0.044)	
$HSR \times Dum_1$					0.255 **
					(0.107)
$HSR \times Dum_2$					−0.037
					(0.089)
$HSR \times Dum_3$					−0.052
					(0.076)
$HSR \times Dum_4$					−0.131
					(0.092)
$HSR \times Dum_5$					0.285 ***
					(0.069)
Constant	4.259 ***	3.135 ***	4.498 ***	3.406 ***	2.542 ***
	(0.065)	(0.087)	(0.084)	(0.067)	(0.063)
Individual FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
N	5626	3560	3795	5391	5391
Adjusted R^2	0.285	0.295	0.310	0.268	0.272
Suest test chi^2	4.57 **		5.09 **		

Notes: In this paper, ***, **, and * represent the significance levels of 1%, 5%, and 10%, respectively. We report the standard errors for city-level clustering in parentheses.

Furthermore, in order to capture the optimal radius of the HSR opening, we generate 5 dummy variables (dum_1~dum_5) according to the quantiles of 20%, 40%, 60%, and 80% of the geographical distance from the non-central city to the central city. Replace the explanatory variable in Equation (1) with $HSR \times Dum_{1\_5}$ and the regression results are shown in Columns (5) of Table 6. It can be found that there are large differences in estimation coefficients of $HSR \times Dum_{1\_5}$ and only the coefficients of $HSR \times Dum_1$ and $HSR \times Dum_5$ are significant, indicating that the promotion effect is more obvious in non-central cities that are less than 20% (107 km) and beyond 80% quantiles (764 km) from the central city.

(2) Enterprise Heterogeneity

Firstly, state-owned enterprises (SOEs) and non-state-owned enterprises (non-SOEs) differ significantly in terms of business nature, ownership structure, and management mechanisms, which may have different impacts on enterprise innovation resilience. By comparing these two types of enterprises, we can better understand the adaptive capacity of different types of enterprises in response to external shocks, thereby providing a basis for formulating targeted policies. Therefore, we divide the sample into SOEs and non-SOEs, and the regression results are shown in Columns (1) to (2) of Table 7. The estimated coefficient of *HSR* is significantly positive at the 10% level, indicating that the opening of HSR can enhance enterprise innovation resilience, whether for SOEs or non-SOEs. The Suest test results show that compared with the SOEs, the opening of HSR has a more obvious impact on non-SOEs' innovation resilience. In China, non-SOEs face greater resource constraints and institutional costs than SOEs, which restricts enterprise operation and development [44]. One the one hand, transport infrastructure construction has promoted the flow of factors over a wider scale and brought a more efficient and open market environment for enterprise, which can reduce the cost of non-SOEs in dealing with the local government; as a result, the impact of transportation infrastructure construction on non-SOEs' innovation resilience is more prominent. On the other hand, SOEs have a close relationship with the government, have a certain government background and resource advantages, can receive government support to a certain extent, and can more easily obtain preferential funds and resources provided by the government. These advantages can make SOEs have stronger risk resistance capability. Therefore, compared to non-SOEs, transportation infrastructure construction has a greater effect on SOEs' innovation resilience.

Table 7. Enterprise heterogeneity of HSR opening on enterprise innovation resilience.

	(1) Non-SOE	(2) SOE	(3) High-Tech Industry	(4) Non-High-Tech Industry
HSR	0.501 ***	0.433 ***	0.386 ***	0.204 ***
	(0.045)	(0.067)	(0.078)	(0.045)
Individual FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	6187	2999	2602	6584
Adjusted R2	0.228	0.233	0.339	0.331
Suest test chi2	3.21 *		5.03 **	

Notes: In this paper, ***, **, and * represent the significance levels of 1%, 5%, and 10%, respectively. We report the standard errors for city-level clustering in parentheses.

Secondly, compared to traditional low-tech industries, high-tech industries possess innate innovation genes, and higher levels of knowledge and technological intensity, as well as stronger adaptability. Therefore, we divide the sample into high-tech industries and non-high-tech industries and perform sub-sample regression, and the results are shown in Columns (3) to (4) in Table 7. In the high-tech industry, the estimated coefficient of *HSR* is 0.386, which is significant at the 1% level, but in the non-high-tech industry, the estimated coefficient of *HSR* is 0.204 and significant at the 1% level, indicating that the opening of HSR has a stronger role in the high-tech industry. The reason behind this is that the factors of high-tech industries are more intensive, enterprises are more sensitive to factor flows, especially high-end production factors, and high-tech industries themselves are more likely to obtain capital favor. Compared to non-high-tech industries, high-tech enterprises rely more on the rapid dissemination of information and the interaction and cooperation of talents. The opening of HSR can improve personnel flow efficiency, promote technological exchange, accelerate the gathering and sharing of innovation resources, and therefore have a more significant impact on high-tech enterprises' innovation resilience. Our findings are consistent with the research results of Fan et al. (2022) [55], who found that the improvement of the business environment has a more positive impact on production activities in high-tech industries.

5.2. The Impact of the HSR Network on Enterprise Innovation Resilience

With the continuous construction and improvement of HSR, the functional orientation of different cities in the HSR network gradually changes, and cities' factor agglomeration and radiation capacity may be difficult to be portrayed by simply opening HSR and not opening HSR. Therefore, we examine the impact of HSR network on enterprise innovation resilience and the results are shown in Table 8. Column (1) shows the estimated results with *DC* as the explanatory variable and Column (2) shows the estimated results using *CC* as the explanatory variable. The regression coefficients of *DC* and *CC* are significant at the level of 1%, reflecting that the higher the city's degree centrality and closeness centrality in the HSR network, the more obvious the effect of HSR construction on enterprise innovation resilience. Degree centrality and closeness centrality reflect the city's position in the HSR network. Compared with cities with lower degree centrality, cities with a higher degree centrality can attract factor resources inflow and expand resource reserves through HSR, thereby improving the ability of enterprise innovation systems to withstand external shocks or move to a higher level. Compared with cities with lower closeness centrality, cities with higher closeness centrality have shorter geographical distances and lower transportation and time costs. So, cities with a higher degree centrality and closeness centrality are relatively more attractive to capital, talents, technology, and other factors to inflow, and the effect on enterprise innovation resilience is more obvious.

Table 8. The regression results of the HSR network on enterprise innovation resilience.

	(1)	**(2)**
DC	27.801 ***	
	(2.791)	
CC		20.154 ***
		(4.230)
Individual FE	Yes	Yes
Year FE	Yes	Yes
N	4790	4790
Adjusted R^2	0.375	0.290

Notes: In this paper, *** represents the significance level of 1%. We report the standard errors for city-level clustering in parentheses.

6. The Mechanisms of Transportation Infrastructure Construction on Enterprise Innovation Resilience

As mentioned above, transportation infrastructure construction can quickly shorten the temporal–spatial distance of exchanges between regions in a short period of time, enabling factors to break through distance restrictions and achieve cross-regional flow, thereby improving enterprise resilience. Next, we will examine how transportation infrastructure construction affects enterprise innovation resilience from resource acquisition and resource allocation. The mechanism test is shown as follows:

$$Mech_{ict} = \beta_0 + \beta_1 HSR_{ct} / DC_{ct} / CC_{ct} + \beta X + \mu_i + \lambda_t + \xi_{ct} \quad (8)$$

Next, we test the influence of mechanism variables on enterprise innovation resilience.

$$Resilience_{ict} = \delta_0 + \delta_1 Mech_{ict} + \delta X + \mu_i + \lambda_t + \xi_{ict} \quad (9)$$

where *Mech* represents enterprise human capital (measured by the proportion of talents with a college degree or above), enterprise financing constraints (measured by the SA index), and enterprise total factor productivity (measured by the LP method).

6.1. Resource Acquisition

6.1.1. Enterprise Human Capital

Table 9 reports the regression results using enterprise human capital as the mechanism variable. The coefficient of *HSR, DC,* and *CC* are 0.012, 0.235, and 0.198, respectively, and are significant at least at the 5% level. This result shows that the construction of HSR accelerates the cross-regional flow of highly educated talents, thereby strengthening R&D investment, technical cooperation, and independent innovation in cities along the route. This result is consistent with the conclusions of Du et al. (2017) [56]. The estimated coefficient of enterprise human capital on enterprise innovation resilience is 0.167 and is significant at the 10% level, indicating that the enhancement of human capital is conducive to improve enterprise innovation resilience. In a stable environment, the importance of human capital to enterprise sustainable development has been widely recognized. In the era of VUCA, on the one hand, human capital is the core strength of enterprise innovation and sustainable development, indicating that human capital can help enterprises perceive and identify risks in advance, and quickly adapt when enterprises encounter external shocks. On the other hand, the enhancement of enterprise human capital means employees possess a wealth of knowledge, skills, and experience, along with stronger creative thinking, cooperation, and learning adaptability. These factors enable the enterprise to better adapt to market changes, swiftly address challenges, and consistently propose new innovative solutions, thereby enhancing enterprise innovation resilience.

Table 9. Mechanism test: enterprise human capital.

	(1) Human	(2) Human	(3) Human	(5) Resilience
HSR	0.012 *** (0.004)			
DC		0.235 ** (0.094)		
CC			0.198 ** (0.073)	
Human				0.167 * (0.096)
Individual FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	7905	7905	7905	7905
Adjusted R^2	0.347	0.343	0.259	0.401

Notes: In this paper, ***, **, and * represent the significance levels of 1%, 5%, and 10%, respectively. We report the standard errors for city-level clustering in parentheses.

6.1.2. Enterprise Financing Constraints

Table 10 reports the regression results using enterprise financing constraints as the mechanism variable. It can be seen from Columns (1) to (3) that the regression coefficients of *HSR*, *DC*, and *CC* are −0.109, −7.251, and −4.770, respectively; all of which are significant at the level of 1%. The results show that the construction of HSR can reduce enterprise financing constraints, and with the increase of degree centrality and closeness centrality, the less the inhibiting effect of the HSR network on enterprise financing constraints. From Column (4) of Table 10, it is observed that the coefficient of enterprise financing constraints on enterprise innovation resilience is −0.812 and passes the 1% significance level test. Financing ability is crucial to enterprise production and operation activities. The temporal–spatial compression brought by the HSR network reduces the asymmetry of long-distance investment and alleviates the financing constraints of enterprises along the route. The alleviation of financing constraints or sufficient financial resources is conducive to the rational allocation of enterprise production factors, which helps to improve the ability of the enterprise innovation system to cope with uncertainty and also provides more opportunities for enterprise innovation systems to cope with external shocks, so as to maintain the enterprise innovation system's stable state or reach a higher stable state. In addition, abundant cash flow offers trial and error space for enterprise innovation system to cope with external shocks, contributing to enterprises to recovering, improving, and finding new development paths after suffering external shocks.

Table 10. Mechanism test: enterprise financing constraints.

	(1) SA	(2) SA	(3) SA	(4) Resilience
HSR	−0.109 *** (0.003)			
DC		−7.251 *** (0.203)		
CC			−4.770 *** (0.301)	
SA				−0.812 *** (0.207)
Individual FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	No
Observations	7905	7905	7905	7905
Adjusted R^2	0.491	0.354	0.409	0.355

Notes: In this paper, *** represents the significance level of 1%. We report the standard errors for city-level clustering in parentheses.

6.2. Resource Allocation

Table 11 reports the regression results using enterprise total factor productivity as the mechanism variable. In Columns (1) to (3), the regression coefficients of *HSR*, *DC*, and *CC* are 0.041, 2.031, and 1.701, respectively, and pass the significance level test of 1%. The results indicate that the construction of HSR can increase enterprise total factor productivity by 0.041 units, and the more obvious the role of the city in the HSR network, the greater the promotion effect on enterprise total factor productivity. Column (4) reflects that enterprise total factor productivity plays a positive role in promoting the adaptability of the enterprise innovation system. This conclusion is consistent with the research conclusion of Zhang et al. (2018) [57]. Enterprises with higher total factor productivity can improve enterprise resource allocation ability and facilitate enterprise technological innovation, thereby reducing the risk faced by the enterprise innovation system and increasing the adaptability of the enterprise innovation system. Additionally, the improvement of enterprise total factor productivity signifies its ability to utilize resources more efficiently, enhance production efficiency and competitiveness, thus releasing more resources for innovation activities and strengthening enterprise adjustment adaptability and sustainability. To this extent, H1a has been confirmed.

Table 11. Mechanism test: total factor productivity.

	(1) TFP_LP	(2)	(3)	(4) Resilience
HSR	0.041 *			
	(0.023)			
DC		2.031 ***		
		(0.674)		
CC			1.701 ***	
			(0.453)	
TFP_LP				0.091 **
				(0.043)
Individual FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	No
Observations	7905	7905	7905	7905
Adjusted R^2	0.605	0.497	0.481	0.209

Notes: In this paper, ***, **, and * represent the significance levels of 1%, 5%, and 10%, respectively. We report the standard errors for city-level clustering in parentheses.

7. Conclusions

Taking the panel data of listed companies and cities in China from 2007 to 2021 as the research sample, based on the quasi-natural experiment of the opening of HSR, we empirically explore the impact of transportation infrastructure construction on enterprise innovation resilience. The results show that firstly, enterprise innovation resilience shows an overall upward trend, and the innovation resilience of enterprises in eastern and central regions is higher than that in non-eastern and non-central regions. Secondly, Benchmark regression results show that transportation infrastructure construction, represented by HSR, is conducive to enterprise innovation resilience and the conclusions are very stable after a series of robustness tests. Thirdly, the promotion effect of transportation infrastructure construction on enterprise innovation resilience varies across different regions, enterprises, and HSR networks. (1) At the regional level, the promotion effect is more obvious in eastern regions, central cities, and non-central cities within 107 km and 764 km away from the central city. (2) At the enterprise level, compared to state-owned enterprises and non-high-tech industries, transportation infrastructure construction has a greater effect in non-state-owned enterprises and high-tech industries. (3) With the continuous construction of the HSR network, the higher the degree centrality and closeness centrality, the more obvious the role of HSR construction in enhancing enterprise innovation resilience. Fourthly, transportation infrastructure construction will promote enterprise innovation resilience by promoting the gathering of highly educated talents, alleviating enterprises' financing constraints, and improving enterprises' total factor productivity. Based on the above conclusions, we put forward the following policy recommendations.

First of all, on the whole, governments at all levels should use a combination of HSR construction and heterogeneous policies to improve enterprise innovation resilience. For cities that have opened HSR, local governments should formulate a talent introduction policy based on the characteristics of local industries, absorb more productive and creative high-quality talents into the enterprise, and fully release the allocation optimization effect and technological progress effect of HSR to improve the level of enterprise innovation resilience. For cities that do not have HSR, local governments should continue to promote and deepen cooperation between cities and improve accessibility by improving transportation infrastructure. At the same time, the central government should accelerate the layout of the "eight horizontal and eight vertical" HSR network, so that these cities that have not opened HSR can narrow the innovation resilience gap with other cities.

Secondly, attention should be paid to the heterogeneous impact of urban HSR on enterprise innovation resilience, so as to narrow the gap between different cities in enterprise innovation resilience. For central cities, eastern regions, non-SOEs, and high-tech industries, the opening of HSR has an obvious promoting effect on the innovation resilience of enterprises along the route. To this end, it is necessary for cities that open HSR to seize the opportunities brought by the opening of HSR, and tap the advantages of local resources; thereby improving enterprise technological innovation capabilities, reinforcing the talent foundation for enterprise sustainable development, and strengthening enterprise ability to adapt, adjust, and innovate to external shocks. China's deepening of the layout of the HSR network should also focus on the coverage density of the HSR in non-eastern regions, non-central cities, SOEs, and non-high-tech industries, and increase the HSR lines in the above areas as much as possible.

Thirdly, there should be an increase in the accessibility of HSR, thereby enhancing enterprise innovation resilience. Local governments should strive to seize the opportunity of market accessibility brought by the construction of transportation infrastructure, provide a good environment to attract the inflow of capital, technology, and talent, and then provide a guarantee for enterprises to respond to external uncertainties. For example, connecting more HSR cities in terms of breadth, or shortening the transportation distance between cities should accelerate the flow speed and upgrading of production factors in cities along the route, and ensure the silent operation of the innovation entities in the crisis.

The limitations of this paper are mainly reflected in two aspects. Firstly, transportation infrastructure includes many aspects, and HSR is just one representative of them. In this paper, we mainly explored the impact of transportation infrastructure construction on enterprise innovation resilience from the perspective HSR construction, ignoring the economic benefits of other infrastructure construction, and future research could explore how emerging technologies (e.g., 5G, IoT) might interplay with transportation infrastructure to influence innovation resilience. Secondly, this paper mainly analyzes the mechanism of transportation infrastructure construction on enterprise innovation resilience from the perspective of resource basis, including resource acquisition and resource allocation; and future research could explore the mechanisms from other aspects.

Author Contributions: Conceptualization, E.L. and Z.A.; methodology, E.L.; software, Z.A.; validation, E.L. and Z.A.; formal analysis, E.L.; investigation, E.L. and Z.A.; resources, E.L.; data curation, E.L.; writing—original draft preparation, E.L. and Z.A.; writing—review and editing, E.L. and Z.A.; visualization, E.L.; supervision, E.L.; project administration, E.L.; funding acquisition, E.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by a general project for the National Social Science Fund: A Study on the Bidirectional Embedding Mechanism and Optimization Path for the Stability of Migrant Workers Returning Home for Entrepreneurship, grant number 20BRK010; Key projects for scientific research and development program of Hebei University of Economics and Business, grant number 2023ZD02.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The dataset generated and analyzed in this study is not publicly available. The dataset is available from the corresponding author on reasonable request.

Acknowledgments: The authors would like to acknowledge the professionals who collaborate during this study and would also like to thank the editor and the anonymous referees at the journal for their insightful comments.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Liao, J.Q.; Wu, X.F. The Impact of High-speed Rail on the Quality of Enterprises' Patents: Evidence from Listed Companies. *Contemp. Financ. Econ.* **2021**, *3*, 3–14. [CrossRef]
2. Wang, Y.L.; Yuan, W.P. Metro Opening, Knowledge Spillovers and Urban Innovation: Evidence from 289 Prefecture-level Cities in China. *Econ. Sci.* **2022**, *2*, 82–95.
3. Wu, Q.; Pan, A.L.; Qiu, J.L. High-speed Rails, Inter-regional Trust and Inter-regional Capital Flow: From the Perspective of Trans-regional Business M&As. *Contemp. Financ. Econ.* **2020**, *10*, 75–86. [CrossRef]

4. Bian, Y.C.; Wu, L.H.; Bai, J.H. Does High-speed Rail Improve Regional Innovation in China? *J. Financ. Res.* **2019**, *6*, 132–149.
5. Li, Y.; Yang, J.; Zhang, W.; Zhou, Z.; Cong, J. Does High-Speed Railway Promote High-Quality Development of Enterprises? Evidence from China's Listed Companies. *Sustainability* **2022**, *14*, 11330. [CrossRef]
6. Lv, W.D.; Tian, D.; Wei, Y. Innovation Resilience: A New Approach for Managing Uncertainties Concerned with Sustainable Innovation. *Sustainability* **2018**, *10*, 3641. [CrossRef]
7. Liang, L.; Zhao, Y.B.; Liu, B. Research on Monitoring and Early Warning of the Resilience of the Innovation Ecosystem in the China's National New Districts. *China Soft Sci.* **2020**, *7*, 92–111.
8. Yang, W.; Lao, X.Y.; Zhou, Q.; Zhang, L. The Governance Niche Configurations for the Resilience of Regional Digital Innovation Ecosystem. *Stud. Sci. Sci.* **2022**, *40*, 534–544.
9. Wei, J.Z.; Ren, T. Innovation Diversification, Economic Structure and Innovation Resilience. *Sci. Technol. Manag. Res.* **2022**, *42*, 39–48.
10. Hu, J.B.; Yu, L.P. Research on the Influence Mechanism and Characteristics of Innovation Resilience on High-tech Industry Innovation. *Sci. Technol. Prog. Policy* **2022**, *39*, 49–59.
11. Lisdiono, P.; Said, J.; Yusoff, H.; Hermawan, A.A. Examining Leadership Capabilities, Risk Management Practices, and Organizational Resilience: The Case of State-Owned Enterprises in Indonesia. *Sustainability* **2022**, *14*, 6268. [CrossRef]
12. Putritamara, J.A.; Hartono, B.; Toiba, H. Do Dynamic Capabilities and Digital Transformation Improve Business Resilience during the COVID-19 Pandemic? Insights from Beekeeping MSMEs in Indonesia. *Sustainability* **2023**, *15*, 1760. [CrossRef]
13. Wang, P.; Zhong, M. Research on the Evolution and Improvement Path of Industrial Clusters' Resilience Under the Impact of Crisis. *Comp. Econ. Soc. Syst.* **2021**, *6*, 76–88.
14. Gittell, J.H.; Cameron, K.; Lim, S.; Rivas, V. Relationships, Layoffs, and Organizational Resilience Airline Industry Responses to September 11. *J. Appl. Behav. Sci.* **2006**, *42*, 300–329. [CrossRef]
15. Lengnick-Hall, C.A.; Beck, T.E.; Lengnick-Hall, M.L. Developing a Capacity for Organizational Resilience through Strategic Human Resource Management. *Hum. Resour. Manag. Rev.* **2011**, *21*, 243–255. [CrossRef]
16. Ortiz-de-Mandojana, N.; Bansal, P. The Long-term Benefits of Organizational Resilience through Sustainable Business Practices. *Strateg. Manag. J.* **2016**, *37*, 1615–1631. [CrossRef]
17. Li, H.; Lu, J.; Guo, F. High Speed Rail and Corporate Social Responsibility Performance: Analysis of Intra-regional Location and Inter-regional Spillover. *Transp. Policy* **2022**, *128*, 65–75. [CrossRef]
18. Xu, F.; Liu, Q.; Zheng, X.D.; Cao, L.Q.; Yang, M. Research on the Impact of China's High-speed Rail Opening on Enterprise Market power: Based on the Perspective of Market Segmentation. *Transp. Policy* **2022**, *128*, 121–137. [CrossRef]
19. Li, Y.; Chen, Z.H.; Wang, P. Impact of High-speed Rail on Urban Economic Efficiency in China. *Transp. Policy* **2020**, *97*, 220–231. [CrossRef]
20. Cheng, J.; Chen, Z. Impact of High-speed Rail on the Operational Capacity of Conventional Rail in China. *Transp. Policy* **2021**, *110*, 354–367. [CrossRef]
21. Guirao, B.; Lara-Galera, A.; Campa, J.L. High Speed Rail Commuting Impacts on Labour Migration: The Case of the Concentration of Metropolis in the Madrid functional area. *Land Use Policy* **2017**, *66*, 131–140. [CrossRef]
22. Feng, Q.Y.; Chen, Z.H.; Cheng, C.C.; Chang, H.Q. Impact of high-speed rail on high-skilled labor mobility in China. *Transp. Policy* **2023**, *133*, 64–74. [CrossRef]
23. Ji, B.; Yang, Q. Can the High-speed Rail Service Promote Enterprise Innovation? A Study Based on Quasi-natural Experiments. *J. World Econ.* **2020**, *43*, 147–166.
24. Sun, W.H.; Zhang, J. Can the High-speed Rail Network Promote High-quality Innovation in Manufacturing Enterprises? *J. World Econ.* **2020**, *43*, 151–175.
25. Claudel, M.; Massaro, E.; Santi, P.; Murray, F.; Ratti, C. An exploration of Collaborative Scientific Production at MIT through Spatial Organization and Institutional Affiliation. *PLoS ONE* **2017**, *12*, e0179334. [CrossRef]
26. Wang, Y.M.; Cao, G.H.; Yan, Y.L.; Wang, J.J. Does high-speed rail stimulate cross-city technological innovation collaboration? Evidence from China. *Transp. Policy* **2022**, *116*, 119–131. [CrossRef]
27. Dong, Y.M.; Zhu, Y.M. Study on the Employment Effect of the Construction of High-speed Railway-Evidence from 285 Cities of China Based on PSM-DID Method. *Bus. Manag. J.* **2016**, *38*, 26–44.
28. Ahlfeldt, G.M.; Feddersen, A. From Periphery to Core: Measuring Agglomeration Effects Using High-speed Rail. *J. Econ. Geogr.* **2018**, *18*, 355–390. [CrossRef]
29. Xiao, T.S.; Wu, Y.S.; Qi, W.T. Does Digital Transformation Help High-quality Development of Enterprises? Evidence from Corporate Innovation. *Bus. Manag. J.* **2022**, *44*, 41–62.
30. Williams, T.A.; Gruber, D.A.; Sutcliffe, K.M.; Shepherd, D.A.; Zhao, E.Y. Organizational Response to Adversity: Fusing Crisis Management and Resilience Research Stream. *Acad. Manag. Ann.* **2017**, *11*, 733–769. [CrossRef]
31. Agarwal, S.; Hauswald, R. Distance and Private Information in Lending. *Rev. Financ. Stud.* **2010**, *23*, 2757–2788. [CrossRef]
32. Loughran, T.; Schultz, P. Liquidity: Urban Versus Rural firms. *J. Financ. Econ.* **2005**, *78*, 341–374. [CrossRef]
33. Hauswald, R.; Marquez, R. Competition and Strategic Information Acquisition in Credit Markets. *Rev. Financ. Stud.* **2006**, *19*, 967–1000. [CrossRef]
34. Wu, Y.; Zhang, Y.; Li, G.Z. High-speed Railway Opening, Bank Competition and Corporate Debt Financing Cost. *Financ. Forum* **2021**, *26*, 27–36.

35. Martin, R.; Sunley, P. On the Notion of Regional Economic Resilience: Conceptualization and Explanation. *J. Econ. Geogr.* **2015**, *1*, 1–42. [CrossRef]
36. Duan, H.Y.; Yang, X.L.; Dong, F. Digital Transformation, Financing Constraints, and Enterprise Innovation. *Stat. Decis.* **2023**, *39*, 164–168.
37. Zhu, Y.J.; Zhong, H.L. Financial Constraint and Product Market Performance of Export Firms-From the Perspective of Exchange Rate Reform Shock. *China J. Econ.* **2020**, *7*, 35–60.
38. Zheng, S.; Kahn, M.E. China's bullet trains facilitate market integration and mitigate the cost of megacity growth. *Proc. Natl. Acad. Sci. USA* **2013**, *110*, l24–l253. [CrossRef]
39. Wang, Y.; Sun, X. Mark-up, Industry Structure and R&D Investment: A Reexamination of the Relationship between Market Power and Technological Innovation. *R D Res. Manag.* **2018**, *39*, 144–152.
40. Givoni, M. Development and Impact of the Modern High-speed Train: A review. *Transp. Rev.* **2006**, *26*, 593–611. [CrossRef]
41. Bernard, A.B.; Moxnes, A.; Saito, Y.U. Production Networks, Geography and Firm Performance. *J. Political Econ.* **2019**, *127*, 639–688. [CrossRef]
42. Khuong, V.; Hartley, K. Sources of Transport Sector Labor Productivity Performance in Industrialized Countries: Insights from a Decomposition Analysis. *Transp. Policy* **2022**, *129*, 204–218.
43. Long, J.H. Dual Path and Related Mechanism of Innovation-driven Development—An Empirical Finding Based on TFP. *Sci. Technol. Manag. Res.* **2017**, *37*, 27–34.
44. Li, E.J.; An, Z.W.; Zhang, C.; Li, H. Impact of Economic Growth Target Constraints on Enterprise Technological Innovation: Evidence from China. *PLoS ONE* **2022**, *17*, e0272003. [CrossRef] [PubMed]
45. Li, P.; Zhu, J.Z. A Literature of Organizational Resilience. *Foreign Econ. Manag.* **2021**, *43*, 25–41.
46. Liu, X.X.; Zhang, X.; Li, S. Measurement of China's Macroeconomic Resilience: A Systemic Risk Perspective. *Soc. Sci. China.* **2021**, *1*, 12–32.
47. Bai, J. Panel Data Models with Interactive Fixed Effects. *Econometrica* **2009**, *77*, 1229–1279.
48. Li, J.M.; Luo, N. Has the Opening of the High-speed Rail Improved the Level of Urban Air Pollution? *China Econ. Q.* **2020**, *19*, 1335–1354.
49. Wu, A. The Signal Effect of Government R&D Subsidies in China: Do Ownership Matter? *Technol. Forecast. Soc. Chang.* **2017**, *117*, 339–345.
50. Wen, H.W.; Zhao, Z. How does China's industrial policy affect firms' R&D investment? Evidence from 'Made in China 2025'. *Appl. Econ.* **2021**, *53*, 6333–6347.
51. Li, P.; Lu, Y.; Wang, J. Does Flattening Government Improve Economic Performance? Evidence from China. *J. Dev. Econ.* **2016**, *123*, 18–27. [CrossRef]
52. Chernozhukov, V.; Chetverikov, D.; Demirer, M.; Duflo, E.; Hansen, C.; Newey, W.; Robins, J. Double/Debiased Machine Learning for Treatment and Structural Parameters. *Econom. J.* **2018**, *21*, C1–C68. [CrossRef]
53. Ghani, E.; Goswami, A.; Kerr, W. Highway to Success: The Impact of the Golden Quadrilateral Project for the Location and Performance of Indian Manufacturing. *Econ. J.* **2016**, *126*, 317–357. [CrossRef]
54. Holl, A. Highways and Productivity in Manufacturing Firms. *J. Urban Econ.* **2016**, *93*, 131–151. [CrossRef]
55. Fan, J.H.; Wang, B.; Yan, L.; Qu, J.J. The Influence of Digital Inclusive Finance on the Innovation Resilience of High-tech Manufacturing Industry: A Test Based on System GMM and Threshold Effects. *Sci. Technol. Prog. Policy* **2022**, *39*, 51–61.
56. Du, X.Q.; Peng, M.W. Do High-Speed Trains Motivate the Flow of Corporate Highly Educated Talents? *Econ. Manag. J.* **2017**, *39*, 89–107. [CrossRef]
57. Zhang, M.T.; Yu, F.; Zhong, C.B.; Lin, F.Q. High-speed Railways, Market Access and Enterprises' Productivity. *China Ind. Econ.* **2018**, *5*, 137–156. [CrossRef]