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Can the Opening of High-speed Rail Promote Green Innovation Behavior of Enterprises: Evidence from China

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Abstract: This study utilizes the quasi-natural experiment of China's high-speed rail opening and examines the impact on corporate green innovation using green patent data from Shanghai and Shenzhen A-share listed companies between 2007 and 2021.The difference-in-difference model is employed to empirically test the relationship between high-speed rail opening and corporate green innovation, as well as to analyze the underlying mechanisms driving this relationship. The research findings indicate a significant positive association between China's high-speed rail opening and enterprise green innovation, indicating an improvement in green innovation levels following the introduction of high-speed rail. The impact mechanism involves the enhancement of government governance capacity and overall factor productivity within enterprises. Further sub-sample test found that the opening of high-speed rail promoted enterprises' green innovation mainly in enterprises with low environmental uncertainty and enterprises in central and western regions.

Keywords: Green innovation, High-speed rail opening, Government governance capacity, Total factor productivity, Environmental uncertainty.

1. Introduction

In recent years, China has experienced rapid economic growth, leading to an increasingly severe environmental pollution problem. As a response, there has been a shift towards green and low-carbon circular development, which has become the focal point for China's future economic model. During the 75th session of the United Nations General Assembly in 2020, Chinese leader Xi Jinping proposed the goal of peaking carbon dioxide emissions by 2030 and striving for carbon neutrality by 2060. This commitment highlights the Chinese government's dedication to addressing environmental concerns. The 20th National Congress of China emphasized the fundamental importance of nature for human survival and development. The congress stressed the need to firmly establish and practice the concept that "Green mountains and clear waters are as valuable as mountains of gold and silver." Thus, future development plans must prioritize the harmonious coexistence between humanity and nature. Enterprises, as key players in the market economy, play a crucial role in both benefiting from and polluting the environment. To achieve high-quality development while ensuring effective environmental protection, enterprises have embraced the concept of "green innovation." This approach promotes innovation while considering environmental factors, aiming to improve resource utilization efficiency without causing further harm to the environment. The Chinese government advocates this approach as a significant measure to balance enterprise development and environmental protection, as it directly influences the realization of Chinese-style modernization.

In recent years, China has witnessed the rapid development of its high-speed rail network, characterized by the ongoing construction of the "eight vertical and eight horizontal" framework. This expansion has significantly reduced the temporal and spatial distances within the country. Similar to the impact of Japan's Shinkansen on the formation of urban agglomerations along the Pacific coast and the European high-speed rail on European economic integration, the construction of railroads in the United States during the 19th century brought about cost savings, improved market access, and increased agricultural land values [1][2]. Therefore, it is worth exploring whether the successful construction of China's high-speed rail will have a profound influence on the Chinese government's "carbon peak, carbon neutral" policy. Moreover, can the operation of China's high-speed rail impact the green innovation behavior of micro-enterprises? This topic presents a fresh and intriguing research opportunity.

2. Literature Review and Hypotheses

2.1. Factors influencing corporate green innovation

Research on the drivers of green innovation in enterprises has primarily focused on government macro policies and micro-level measures. From a macro perspective, national environmental protection subsidies have been found to weaken the green innovation capabilities of enterprises [3]. The green credit policy inhibits the green innovation development of heavily polluting enterprises [4]. However, the implementation of the new "Environmental Protection Law," the Central Environmental Protection Supervision Action, the "energy-saving and low-carbon" policy, and the pilot policy of green finance can promote green innovation [5] [8]. Additionally, the audit of natural resource assets of leading cadres can enhance the output of green invention patents in enterprises [9]. Furthermore, some scholars suggest a "U"-shaped relationship between macro-level environmental regulation behavior and green innovation [10] [11], while others argue that there may not be a direct relationship between the two, and that the environmental attention of the executive team has an indirect impact [12].

From a micro perspective, enterprise environmental protection R&D investment is believed to improve the efficiency of green technology innovation [13]. The performance of social practices by enterprises enhances their green product innovation and green process innovation capabilities [14]. Internal control and digital transformation also contribute to the development of corporate green innovation[15][16]. CEOs with overseas experience, academic experience, and green experience have a positive effect on corporate green innovation[17][19]. However, a higher concentration of suppliers is found to be unfavorable for the green innovation of enterprises [20]. There is a "U"-shaped relationship between corporate environmental protection strategies and the external benefits of green technology innovation [21]. Furthermore, the degree of media attention, pressure from environmental public opinion, and the public's environmental concerns in the company's location have a profound impact on the company's green technology innovation [22]-[24].

2.2. Opening of high-speed rail and green innovation of enterprises

From a macroeconomic perspective, most studies suggest that the opening of high-speed rail has contributed to the economic growth of regions along its routes. By improving accessibility between cities, it has fostered closer and more frequent connections and economic activities among entities in the region. This, in turn, enhances market access, market potential, economic density, industrial structure optimization, commodity turnover, urban GDP growth, and attracts high-quality labor [25][29]. However, scholars have also raised concerns about the "siphon effect" of high-speed rail openings. While high-speed rail improves accessibility to central cities, it may also lead to the transfer of production factors from cities along the route to the central city [30][31]. From the perspective of micro-enterprises, the opening of high-speed rail has brought benefits such as improved information transparency and regulatory capabilities. It has also reduced the risk of stock price crashes [32], facilitated participation of non-local independent directors in board meetings [33], and enhanced the performance accuracy of non-local investment and listed companies in forecasting and accounting conservatism [34][36].

From a microeconomic perspective, the construction and development of high-speed railways in China have a significant impact on the green innovation behavior of enterprises. Firstly, the opening of high-speed rail provides a contextual framework for promoting green innovation. The convenience and economic development brought about by high-speed rail often make the opening sites highly sought-after resources by local governments under the central government's overall planning. The quality of governance and the emphasis on green environmental protection, which are crucial performance assessment criteria, highlight the importance of environmental issues for enterprises in the region. This context encourages enterprises to actively engage in green innovation.

Furthermore, the opening and construction of high-speed rail provide essential resources and support for green innovation in enterprises. Firstly, during the investment, construction, and operation phases of high-speed rail, there is a flow of capital elements, reduced transportation costs, increased information dissemination channels, improved speed, and enhanced sharing. These factors help reduce transaction and information costs, facilitate resource reintegration, enhance resource allocation efficiency, reduce redundancy, and provide material resources for green innovation. Secondly, high-speed rail promotes the mobility and allocation of highly skilled labor, offering better resources for green innovation in terms of human capital. Lastly, the opening and construction of high-speed rail contribute to the formation of a comprehensive and developed innovation network. This leads to increased inter-city joint patents, improved patent quality, enhanced partnerships, and collaborative innovation [37]. Moreover, the knowledge spillover effect of high-speed rail significantly enhances the innovation capabilities of enterprises along the rail line, resulting in a notable increase in patent authorizations and applications [38].

Therefore, the opening of high-speed rail improves the total factor productivity of enterprises through the efficient allocation and optimization of resources, thereby fostering a higher level of green innovation. Based on this, we propose Hypothesis 1:

Hypothesis 1: The opening of China's high-speed rail promotes green innovation in enterprises.

3. Research Design

3.1. Sample selection and data sources

This study focuses on China's Shanghai and Shenzhen A-share listed companies from 2007 to 2021. The following data processing steps are applied to the sample: (1) Exclude financial and insurance companies; (2) Exclude delisted, ST, and *ST companies during the research period; (3) Remove samples with missing variables; (4) Environmental uncertainty calculation requires 5 years of sales revenue, thus samples with less than 5 years of sales revenue are eliminated; (5) Indent continuous variables with 1% and 99% endings to reduce the infuence of outliers.

Green patent data is obtained from the China Research Data Service Platform (CNRDS). Information on the opening dates and cities of high-speed rail lines is gathered from the opening announcements provided by the National Railway Administration and other relevant websites, and manually organized. Other data sources include the China Stock Market & Accounting Research Database (CSMAR).

3.2. Variable definition

3.2.1. Explaned variables

The variable "TGreen" represents the green innovation of enterprises, which is measured by taking the natural logarithm of the sum of green invention patent authorizations and green utility model patent authorizations of listed companies adding 1, as suggested by previous research [39].

3.2.2. Explanatory variables

The explanatory variables in this study include "HSR" and "After". "HSR" indicates whether the office location of the listed company experienced the opening of high-speed rail during the sample period. If the company is located in a city that underwent high-speed rail opening during the sample period, it is assigned a value of 1, representing the experimental group. Otherwise, it is assigned a value of 0, representing the control group. "After" indicates whether the company's office is connected to the high-speed rail in the sample year, the value of 1 is assigned to the year in which the high-speed rail is opened and subsequent years, the value of 0 is assigned in the year prior to the opening.

3.2.3. Control variables

The selected control variables in this study are chosen based on their potential impact on green innovation. Refer to relevant research [40][3], the following control variables are considered: Enterprise size (Size), Leverage (Lev), Return on assets (Roa), Cash flow level (Cfo), Capital density (Density), Enterprise value Tobin's Q(TQ), Nature of property rights (Soe), Enterprise growth (Growth), Proportion of independent directors (Inde), Dual positions (Dual), Board size (Board), Ownership concentration (Top10). Additionally, industry and year variables are included as control variables. Table 1 provides detailed descriptions of the variables.

Table 1. Variable description

Symbol	Definitions
Size	Take the natural log of total assets
Lev	Total Liabilities/Total Assets of the Enterprise
Roa	Enterprise net profit/total assets
Cfo	Net cash flow from operating activities/total assets
Density	Natural logarithm of net fixed assets/number of employees
TQ	Natural logarithm of corporation market value/total assets
Soe	1 for state-owned enterprises, 0 otherwise
Growth	Operating income growth rate
Inde	The ratio of the number of independent directors to the number of board members
Dual	Whether the chairman and the general manager are concurrently held by the same person, if so, take 1, otherwise 0
Board	The natural logarithm of the board size
Top10	Shareholding ratio of the Top 10 shareholders
Year	Year dummy variable
Ind	Industry dummy variable

3.3. Model construction

To examine the impact of the high-speed rail opening on corporate green innovation, this study employs the following difference-in-difference (DID) model:

$$\mathrm{TGreen}_{i,t} = \alpha + \beta_1 \mathrm{HSR}_{i,t} \times \mathrm{After}_{i,t} + \beta_2 \mathrm{Controls}_{i,t} + \sum \mathrm{Year} + \sum \mathrm{Ind} + \varepsilon_{i,t} \quad (1)$$

The focus of this study lies in the coefficient of β1 in model (1). A significantly positive coefficient of β1 indicates that the opening of high-speed rail promotes corporate green innovation, while a significantly negative coefficient suggests an inhibitory effect on green innovation. In the empirical regression results, "DID" refers to the interaction term "HSR i,t × After i,t".

4. Demonstration Results and Analysis

4.1. Descriptive statistics

Table 2 presents the descriptive statistics of the main variables in this study. The mean value of green innovation (TGreen) is 0.229, with a standard deviation of 0.578. There are certain differences between enterprises, which is similar to the conclusion of the existing literature [3][7].The mean value of DID is 0.799, indicating that around 79.9% of the samples in the study period are from the period after the opening of the high-speed rail. Among the control variables, the standard deviations of enterprise size (Size) and capital density (Density) are both greater than 1, while the standard deviations of the other variables are less than 1, which is generally consistent with existing literature.

Table 2. Descriptive analysis

Variables	Obs	Mean	S.D.	Min	Max
TGreen	24953	0.229	0.578	0	2.944
DID	24953	0.799	0.401	0	1
Size	24953	22.389	1.280	19.941	26.280
Lev	24953	0.464	0.199	0.069	0.896
Roa	24953	0.033	0.062	-0.253	0.196
Cfo	24953	0.049	0.069	-0.154	0.248
Density	24953	12.664	1.135	9.555	15.848
TQ	24953	0.578	0.495	-0.166	2.141
Soe	24953	0.486	0.500	0	1
Growth	24953	0.173	0.431	-0.559	2.822
Inde	24953	0.373	0.053	0.308	0.571
Dual	24953	0.214	0.410	0	1
Board	24953	2.148	0.200	1.609	2.708
Top10	24953	0.554	0.149	0.228	0.897

4.2. Analysis of regression results

The regression results for the impact of China's high-speed rail opening on corporate green innovation are presented in Table 3. In column (1), no control variables are included. The results show that the regression coefficient of high-speed rail opening (DID) is 0.044, and it is significantly positive at the 1% level. This indicates that the opening of high-speed rail has a positive effect on promoting corporate green innovation. In column (2), control variables are included in the regression analysis. Among them, the regression coefficient of the explanatory variable high-speed rail opening (DID) is 0.029, and it remains significantly positive at the 1% level. This

suggests that even after controlling for other factors, the opening of high-speed rail continues to have a significant and positive impact on promoting green innovation in enterprises. These findings provide empirical evidence that supports Hypothesis 1 of this study, confirming that the opening of high-speed rail can indeed promote corporate green innovation.

Table 3. High-speed rail opening and corporate green innovation

Variables	(1)	(2)
	TGreen	TGreen
DID	0.044***	0.029***
	(3.95)	(2.64)
Size		0.108***
		(25.92)
Lev		0.025
		(1.10)
Roa		0.062
		(0.91)
Cfo		0.093*
		(1.71)
Density		-0.006
		(-1.60)
TQ		0.047***
		(4.88)
Soe		0.024***
		(3.06)
Growth		-0.052***
		(-6.38)
Inde		0.129*
		(1.75)
Dual		0.010
		(1.20)
Board		0.081***
		(3.86)
Top10		-0.079***
		(-3.17)
Year/Ind	Yes	Yes
Constant	-0.085*	-2.559***
	(-1.91)	(-23.18)
Adjusted R^2	0.138	0.180
Obs	24953	24953

Note: ***, **, * indicate statistical significance at the 1%, 5%, and 10% levels, respectively. The t-value is reported in parentheses.

4.3. Robustness test

4.3.1. Parallel trend test

To examine the parallel trend assumption, this study investigates the dynamic effect of high-speed rail opening on corporate green innovation. The original model is expanded to include two years before the opening of high-speed rail (Pre2), the year before the opening (Pre1), the first year after the opening (Post1), and the subsequent years after the opening (Post2) to construct a dynamic effect model. The results are presented in Table 4. The coefficients for Pre2, Pre1, and Post1 are not statistically significant. However, the coefficient for Post2 is 0.036, and it is significantly positive at the 1% level. This indicates that the opening of high-speed rail has a significant positive effect on promoting corporate green innovation in the second year and subsequent years after the opening. These findings provide further evidence that supports the base regression results and confirm that the difference-in-difference model (DID) is effective. Thus, the parallel trend assumption is satisfied in this analysis.

Table 4. Parallel trend test

Variables	(1)
	TGreen
Pre2	0.027
	(1.37)
Pre1	0.017
	(0.95)
Post1	0.023
	(1.27)
Post2	0.036***
	(2.93)
Controls	Yes
Year/Ind	Yes
Constant	-2.564***
	(-23.22)
Adjusted R^2	0.179
Obs	24953

4.3.2. Placebo test

To ensure the robustness of the research findings, this study conducts a placebo test by introducing two placebo time points for high-speed rail opening prior to the actual opening. Pre3 represents the third year before the high-speed rail opening. For the sample year, if it falls within the third year before the actual opening of the high-speed rail in the city where the enterprise is located, it is assigned a value of 1; otherwise, it is assigned a value of 0. The same procedure is applied to Pre4, representing the fourth year before the opening. The regression results incorporating the placebo variables into Model (1) are reported in Table 5.The coefficients for the high-speed rail opening in columns (1) and (2) are not statistically significant. This indicates that the placebo high-speed rail opening times have no direct impact on the green innovation of enterprises. Therefore, the results confirm that the opening of high-speed rail indeed promotes corporate green innovation. The reliability of the base regression findings is further supported by the placebo test.

Table 5. Placebo test

Variables	(1)Third year before opening	(2) Fourth year before opening
	TGreen	TGreen
Pre3	0.000	
	(0.02)	
Pre4		-0.032
		(-1.26)
Controls	Yes	Yes
Year/Ind	Yes	Yes
Constant	-2.568***	-2.564***
	(-23.24)	(-23.23)
Adjusted R^2	0.179	0.179
Obs	24953	24953

5. Analysis and Inspection of The Impact Mechanism

As mentioned above, the opening of high-speed rail improves the level of green innovation within enterprises by improving governance capacity of the Chinese government and total factor productivity. To investigate both the pathways of government governance capacity and total factor productivity, we construct the following model for scrutiny, drawing inspiration from the work of Jiang et al. (2022) [41].

$$\mathrm{Gov}_{i,t} = \alpha + \beta_1 \mathrm{HSR}_{i,t} \times \mathrm{After}_{i,t} + \beta_2 \mathrm{Controls}_{i,t} + \sum \mathrm{Year} + \sum \mathrm{Ind} + \varepsilon_{i,t} \quad (2)$$

$$TFP_{i,t} = \alpha + \beta_1 HSR_{i,t} \times After_{i,t} + \beta_2 Controls_{i,t} + \sum Year + \sum Ind + \varepsilon_{i,t} \quad (3)$$

Among them, model (2), denoted as Gov, captures the governance capacity of local governments, drawing upon existing literature [42][43]. It encompasses five dimensions: government performance, rule of law construction, regulatory quality, economic development, and people's livelihood security. The entropy method is employed to construct a comprehensive index that measures the local government's governance capacity. Model (3), referred to as TFP, represents total factor productivity and is supported by previous studies [44][45].TFP is evaluated using the OP method. The remaining variables in the model maintain consistency with model (1), and the term "DID" below still means HSR i,t ×After i,t.

5.1. Governance capacity of local governments

To examine the role of local government governance capacity as a specific pathway through which the opening of high-speed rail influences green innovation in enterprises, this study employs model (2) to regress the opening of high-speed rail against local government governance capacity. The results are presented in column (1) of Table 6. The findings indicate that the opening of high-speed rail has enhanced the governance capacity of local governments, thereby creating a conducive environment for enterprise innovation and providing financial support. This, in turn, motivates enterprises to engage in green innovation activities.

5.2. Total factor productivity

Using model (3), this paper investigates whether total factor productivity serves as another specific pathway through which the opening of high-speed rail affects green innovation in enterprises. The regression results are reported in column (2) of Table 6. The findings reveal that the opening of high-speed rail facilitates an increase in the total factor productivity of enterprises. This, in turn, enables enterprises to receive financial, technical, and talent support for their green innovation endeavors. Consequently, the level of green innovation within enterprises is elevated as a result of the enhanced total factor productivity.

Table 6. Test of influence mechanism

Variables	(1)Local government governance	(2) Total factor productivity
	Gov	TFP
DID	0.130***	0.123***
	(32.58)	(11.28)
Controls	Yes	Yes
Year/Ind	Yes	Yes
Constant	-0.364***	-3.731***
	(-9.05)	(-33.87)
Adjusted R2	0.208	0.704
Obs	24953	24629

6. Further Analysis

6.1. Environmental uncertainty

To examine the influence of the external environment on the opening of high-speed rail and the green innovation of enterprises, this paper adopts the approach used by Shen et al. (2012)[46]. The authors estimate abnormal sales revenue by considering the company's sales revenue over the past five years. They calculate the standard deviation of abnormal sales revenue over this period and divide it by the average of the five-year abnormal sales income. This yields the unadjusted measure of environmental uncertainty. Subsequently, the median value of unadjusted environmental uncertainty is calculated for each industry and year. The unadjusted environmental uncertainty is then divided by this median value to obtain the industry-adjusted environmental uncertainty. Based on the median of the industry-adjusted environmental uncertainty, the groups are divided. Companies with industry-adjusted environmental uncertainty greater than the median are classified as belonging to the high environmental uncertainty group, while those with values lower than the median are classified as belonging to the low environmental uncertainty group. The specific results are presented in Table 7.

The findings indicate that the positive impact of the opening of high-speed rail on the green innovation of enterprises is mainly observed in the low environmental uncertainty group, whereas it is not significant in the high environmental uncertainty group. This observation can be attributed to the fact that, in a low environmental uncertainty scenario, enterprises may find it easier to leverage the resource advantages brought about by the introduction of high-speed rail. This can stimulate their motivation for innovation, prompting them to enhance their research and development efforts in green innovation and boost their competitiveness.

Table 7. Heterogeneity test of environmental uncertainty

Variables	(1) Low environmental uncertainty group	(2) High environmental uncertainty group
	TGreen	TGreen
DID	0.035**	0.023
	(2.24)	(1.52)
Controls	Yes	Yes
Year/Ind	Yes	Yes
Constant	-2.708***	-2.517***
	(-17.13)	(-16.18)
Adjusted R^2	0.210	0.153
Obs	12856	12097

6.2. Regional heterogeneity

To investigate the influence of the opening of high-speed rail on green innovation in different regions, this study divides the samples based on the economic development level of the locations where Chinese listed companies are situated. The regions are categorized into the eastern region and the central and western regions. Group regression analysis is then performed on these regions, and the results are presented in Table 8. The findings reveal that in the central and western regions, the positive impact of the opening of high-speed rail on corporate green innovation is more pronounced, whereas such a significant impact is not observed in the eastern region. This distinction could be attributed to the fact that the introduction of high-speed rail has enhanced the level of transportation infrastructure development in the central and western regions. Consequently, it has facilitated the transportation of essential resources such as talent, capital,

and technology, thereby enhancing the total factor productivity of local enterprises and stimulating their vitality for green innovation.

Table 8. Heterogeneity test of the influence of the location of the enterprise

Variables	(1) Central and Western Regions	(2) Eastern Region
	TGreen	TGreen
DID	0.050***	0.025
	(3.21)	(1.56)
Controls	Yes	Yes
Year/Ind	Yes	Yes
Constant	-2.446***	-2.580***
	(-13.15)	(-17.31)
Adjusted R^2	0.184	0.193
Obs	7866	17087

7. Conclusions

Based on the green patent data of China's Shanghai and Shenzhen A-share listed companies from 2007 to 2021, this paper empirically tests the impact of the opening of high-speed rail on the green innovation behavior of enterprises by using the differential differential model, and analyzes the specific impact mechanism between the two. The results show that the opening of high-speed rail has a significant positive impact on green innovation of enterprises, that is, after the opening of high-speed rail, the level of green innovation of enterprises is improved; the specific influence mechanism is to improve the governance ability of government and the total factor productivity of enterprises to promote green innovation. Further sub-sample test found that the green innovation behavior of enterprises promoted by the opening of high-speed rail was mainly manifested in enterprises with low environmental uncertainty and enterprises in central and western regions.

Based on the conclusions drawn, this article presents the following policy suggestions and insights. Firstly, the opening of high-speed rail can stimulate enterprises' motivation to engage in green innovation activities. Consequently, relevant departments should continue improving transportation infrastructure, optimizing the high-speed rail network system, and enhancing transportation development capabilities in areas where enterprises are located. This will guide enterprises towards undertaking green innovation activities. Secondly, heterogeneity exists in the relationship between high-speed rail opening and green innovation. The opening of high-speed rail in China's central and western regions has contributed to local infrastructure development. Therefore, enterprises located in these regions should seize the opportunities brought about by high-speed rail, utilize the talents, capital, technology, and effective government governance capabilities facilitated by high-speed rail, enhance their own total factor productivity, and subsequently improve their green innovation capabilities. It is also important for enterprises to recognize that lower environmental uncertainty is more conducive to green innovation activities. Enterprises should correctly assess the impact of environmental changes on green innovation, seize external opportunities, and adjust green innovation strategies accordingly. Lastly, improving green innovation capabilities depends not only on external conditions but also on enterprises' own efforts. Enterprises need to cultivate a culture of green innovation, formulate targeted green innovation strategies, allocate sufficient research and development funds towards green innovation, enhance market competitiveness, and achieve sustainable development.

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