High-Speed Railway and Firm Innovation: Evidence from DID Method

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Abstract: *With the launch of high-speed railways as a natural experiment, this paper finds that firms along the route became much more innovative after a high-speed railway was put into use, as reflected by the robust growth in patent licenses and applications, especially invention patents. From a dynamic view, high-speed railways' effects on firm patents increased over the years with a one-year lag in the effect on patent licenses relative to the effect on patent applications. This lag of impact reflects the normal cycle of firm innovation. Furthermore, our survey on the employees' education level at firms along the route verified that the inflow of skilled workforce helped firms innovate. After a high-speed railway was put into service, firms along the route saw a sharp rise in the percentage of college-educated personnel, most of whom were employed at technical positions. High-speed railways contributed more to the innovation output of firms in medium-sized and large cities and within innovation-oriented firms. This paper has enriched relevant research on the drivers of firm innovation and the economics of high-speed railways.*

Keywords: *high-speed railway, firm innovation, talent migration, Difference-in-Differences (DID)*
JEL Classification Codes: G30, J10, O31
DOI: 10.19602/j.chinaeconomist.2021.03.05

1. Introduction

According to the fifth *China's National Image Global Survey*, China's high-speed railway system is recognized as the nation's most recognized engineering feat globally. By the end of 2017, the length of high-speed railways in China reached 25,000 kilometers,[1] the longest in the world. Over 3,000 high-speed trains provide efficient transportation for passengers from over 180 prefectural cities, 370 county-level cities and all major cities with a population above 500,000 across China. As a new means of transportation, high-speed railways have reduced temporal-spatial distances between cities, expediting labor flow and other production factors.

Innovation is a key driver of economic growth (Solow, 1957) and firm competitiveness (Porter, 1992). Labor force, especially a highly-qualified labor force, underpins innovation (Zingales, 2000). Empirical evidence suggests that skilled immigrants supercharged innovation in the US during 1950 and 2000 (Chellaraj *et al.*, 2008; Hunt and Gauthier, 2010; Kerr and Lincoln, 2010). In China, highly

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Acknowledgement: This study is sponsored by the National Natural Science Foundation of China (NSFC) project "Study on the Cross-Sector Search Mechanism for Chinese Firms Embedded in Foreign-funded Innovation Networks: from a Value Co-creation Perspective" (Grant No.71972050) and the General Program of Humanities, Philosophies and Social Sciences "Study on the Mood and Behaviors of Financial Market Investors Based on Deep Learning Technology (Grant No.19YJA79010).
[1] Data is from the official website of the National Railway Administration.

skilled labor still accounts for a small share in the labor market, only 5% at the end of 2017 according to the Ministry of Human Resources and Social Security.[2] This percentage exceeds 40% in advanced economies in Europe and North America. More than half of the firms' demand for highly skilled labor remains unsatisfied in China. As China's economy transitions from a factor-driven to an innovation-driven one, the government must facilitate skilled workforce flow to places where their talent is needed the most.

Previous studies attributed the labor mismatch to natural and institutional factors. Lu and Chen (2009) identified the household registration (*hukou*) system as a barrier to the free flow of labor, which led to an imbalance in labor supply and demand and economic inefficiencies. Geographical barriers have also added to the cost of labor migration, causing a labor market segmentation and preventing the free allocation of the workforce (Fan, *et al*., 2017). Regarding the institutional factor, Shenzhen and other megacities in China have lifted the household registration restrictions to attract an influx of highly qualified professionals. Rapid development in transportation infrastructure has reduced frictions for the migration of skilled workforce. The construction of a "four vertical and four horizontal" high-speed railway network has shortened the spatial-temporal distances between cities, making it easier for a skilled workforce to migrate to cities along the route. In theory, such an influx will help firms along the route become more innovative (Gao, *et al*., 2015; Deng, *et al*., 2017).

As a key means of passenger transportation in China, high-speed railways facilitate the migration of a skilled workforce to places where firms are in dire need of human capital. A quantitative assessment of high-speed railways' effects on firms innovation output along the route is of great practical and theoretical importance. With the launch of high-speed railways as a natural experiment, we will employ the difference in differences (DID) method to investigate how high-speed railways helped firms along the route innovate. The result suggests that a sharp increase followed the launch of high-speed railways in both patent licenses and applications, reflecting the value of patent growth. An analysis of the intrinsic mechanism reveals that the launch of high-speed railways was followed by significant increases in the share of college-educated employees, mostly at technical positions. From a dynamic view, the launch of high-speed railways exerted growing effects over the years, causing patent applications to increase one year before increasing patent licenses. We also studied the heterogeneity of high-speed railway's effects and found that high-speed railways' firm innovation effects concentrated in highly innovative firms. Lastly, we performed a robustness test with replaced policy discontinuity points and the instrumental variable method and reached the same conclusions.

This paper offers three contributions: First, it has broadened the research on the economic effects of high-speed railways beyond macroeconomic discussions of how high-speed railways had facilitated regional economic development, labor migration, and venture investment (Long *et al*., Li *et al*., 2017). This paper reveals the detailed effects of high-speed railways on firm innovation with firm level data, contributing to the body of literature on the economic effects of high-speed railways at the firm and capital market level.

Second, this paper has verified that the launch of high-speed railways helped increase the percentage of college-educated employees at technical positions, proving the firm innovation effect of an influx of skilled workforce, and has effectively mitigated the self-selection and endogeneity problems.

Third, with the average geographical slope of prefectural cities in which listed companies are located as the instrumental variable, the robustness of this paper's results has been further proven.

2. Literature Review and Research Hypotheses

According to the endogenous growth theory, innovation stems from technology accumulation and

[2] Data is from the official website of the Ministry of Human Resources and Social Security.

underpins long-term economic growth (Romer, 1990; Lucas, 1988). Schumpeter (1934) argued that firms and entrepreneurs created most innovations to acquire temporary monopoly and excess return. Innovation is essentially the creation of new production functions to raise productivity by recombining such factors of production as labor and capital.

Studies on workforce and innovation considered that the increase of human capital was conducive to firm innovation (Zingales, 2000; Belloc, 2012). The increase of human capital derives from internal and external sources. Internally, firms may use human capital stock more efficiently by optimizing firm incentives, e.g. adjusting employee compensation gaps to spur innovation (Gupta, 2007; Kong, *et al*., 2017). Externally, an increase in the local supply of workforce helps firms hire more hands for an absolute increase in human capital (Chen, *et al*., 2016). Chellaraj *et al*. (2008). Hunt and Gauthier (2010) and Kerr and Lincoln (2010) performed empirical research from the perspective of external labor supply, and found that pro-immigration policies led to an increase in the supply of educated workforce in the US and that the technology spillover effect had strengthened US innovation.

Human capital is an impetus of innovation, and the free flow of labor is a necessary condition to bring out the full potentials of human capital (Liang, *et al*., 2013). In China, the cross-regional flow of labor has been subject to the interference of various factors, both natural and institutional. While spatial distance is the leading natural barrier, institutional barriers are related to the household registration (*hukou*) system and local protectionism (Lu and Chen, 2009; Fan, *et al*., 2017). Bai and Bian (2016) believed that such barriers and frictions had raised the cost of free labor migration, giving rise to labor market distortions. Such distortions have limited the job choices for a skilled workforce and dented their demand, causing a labor supply and demand mismatch that impedes firm innovation.

These institutional restrictions can be curtailed by breaking through local protectionism and relaxing the household registration system to facilitate labor migration. By making the migration of skilled workforce less costly and more frequent, the abatement of institutional frictions helps firms recruit qualified workforce and thus become more innovative and efficient (Chellaraj, *et al*., 2008; Hunt and Gauthier, 2010; Kerr and Lincholn, 2010). Similarly, transportation infrastructure such as the "four vertical and four horizontal" high-speed railway network has reduced barriers to labor flow by shortening the spatial-temporal distance of travel, thus breaking through geographical labor market segmentation and expanding the radius of matching between firms and workforce (Dong, *et al*., 2016).

According to Hansen's (1959) concept of regional accessibility, transportation infrastructure increases access to regions along the route. It thus facilitates the flow of people, merchandise, and other production factors, giving rise to a redistribution of workforce along transportation routes (Knaap and Oosterhaven, 2011). With the opening of interstate highways in the US as a natural experiment, Michaels (2008) found that skilled workers were more motivated to migrate to cities along highway routes and thus promote local economic growth, demonstrating the effect of transportation infrastructure on the migration of a skilled workforce.

As an essential means of travel, high-speed railways will also accelerate the flow of a skilled workforce. From a supply perspective, high-speed railways have reduced travel cost for a skilled workforce and expanded the radius of their job search, allowing them to work at firms more distant from their place of residence as with access to high-speed railways. Cities with high-speed railway access are more livable and attractive to a skilled workforce with higher efficiency of matching labor demand with supply (Gibbons and Machin, 2005).

From a demand perspective, the launch of high-speed railways has expanded firms' radius of marketing and sales, allowing consumers to travel to cities along the route for goods or services. This increase in market demand prompts firms to hire more hands and raise remuneration to attract an influx of skilled labor (Atack *et al*., 2008). The launch of high-speed railways also exposes firms along the route to more investments by addressing information asymmetry between investors and firms (Long *et al*., 2017). With more cash to spare on R&D and remuneration, firms have become more attractive to skilled technical personnel (Murphy, *et al*., 1991). Through the reduction of travel costs, a high-speed railway network has increased both the supply and demand of skilled workforce in cities along the route (Zhang, 2012).

Based on the above analysis, we put forth the following hypotheses:

Hypothesis 1: The launch of a high-speed railway will lead to a remarkable rise in the firms' innovation along the route.

Hypothesis 2: The launch of a high-speed railway will lead to a remarkable rise in the proportion of a skilled workforce at firms along the route.

3. Research Design

In this section, we will test the above hypotheses. First, data sources and research design will be explained.

3.1 Data Sources

Our samples include 1,559 A-share listed companies from 200 prefectural cities with 7,102 observations dated 2006-2016. Most information is about the patent and financial data of the listed companies, as well as regional economic data and information about high-speed railways. Among them, patent data is from the CSMAR database, financial and regional economic data is from Wind database, and information about the launch of high-speed railways is collected from Baidu.com, and the official websites of the then Ministry of Railwayusing the web crawler technology. To exclude the impact of outliers, we have winsorized data at 0.01.

3.2 Variable Design

The explained variables are firm innovation output and the percentage of a highly qualified workforce. The numbers of total patents, invention patents, utility model patents and design patents are added with 1 and then taken logarithm to measure firm innovation output. A highly qualified workforce is measured by the percentage of employees with a bachelor's degree or above and the percentage of technical personnel.

The key explanatory variable in this paper is the interaction term between "access to a high-speed railway" (HSR) and "before and after high-speed railway launch" (After). Among them, if a high-speed railway was put into service during the sample period in the city where the company was located, HSR is 1; otherwise, the value is 0; if the sample year is after the launch of the high-speed railway, the value of After is 1; otherwise, the value is 0.

Control variables are designed according to factors that may influence the output of firm innovation. They include company size (Size), age of stock-market listing (Age), and return on assets (ROA). The instrumental variable is the average geographical slope of prefectural cities obtained and calculated with the Geological Information System (GIS). The average geographical slope of prefectural cities has a significantly negative correlation with the probability of the launch of high-speed railways, and this exogenous variable does not affect the innovation output of firms. Table 1 lists key variables and their definitions.

3.3 Difference in Differences (DID) Model

To capture the net effect on the innovation output of firms along the route after a high-speed railway was put into service, we use the listed companies headquartered in cities that were connected to high-speed railways in 2006-2016 as the treatment group and those headquartered in cities that were not connected to high-speed railways in the same period as the control group for a difference in differences (DID) regression, controlling for the fixed effects of time and company, as shown in equation (1).

Table 1: List of Key Variables

Variable type	Variable name	Definition
Explained variable		
Patent licenses	*Pat*	Total number of patent licenses added with 1 and then taken logarithm
	Pat_inv	Number of invention patent licenses added with 1 and then taken logarithm
	Pat_uti	Number of new utility model licenses added with 1 and then taken logarithm
	Pat_des	Number of design patent licenses added with 1 and then taken logarithm
Patent applications	*App*	Total number of patent applications added with 1 and then taken logarithm
	App_inv	Number of invention patent applications added with 1 and then taken logarithm
	App_uti	Number of new utility model applications added with 1 and then taken logarithm
	App_des	Number of design patent applications added with 1 and then taken logarithm
Workforce structure	*Bachelor*	Number of employees with a bachelor's degree or above as a share of the company's total workforce
	Technician	Number of technical personnel as a share of the company's total workforce

Moreover, we have performed two-way clustering of the standard errors of all regression coefficients at sector and city levels.

$$y_{i,t} = \alpha_i + \beta_1 After_{i,t} \times HSR_{i,t} + \delta_t + \varphi_i + \gamma CV_{i,t} + \varepsilon_{i,t} \tag{1}$$

4. Regression Analysis

4.1 Descriptive Statistics

Table 2 presents the descriptive statistics of key variables. Among them, the mean value of the logarithms of sample companies' total patent licenses is 2.016, the median value is 1.946, the minimum value is 0, and the maximum value is 6.605. The mean value of the logarithm of invention patent licenses is 1.013, the median value is 1.010, the minimum value is 0, and the maximum value is 5.663. The mean value of the logarithm of invention patent applications is 0.915, the median value is 0.897, the minimum value is 0, and the maximum value is 4.700. Among the sample companies, 26.891% of their personnel had a bachelor's degree or above, and technical employees accounted for 17.426%.

4.2 Effects of High-Speed Railways on Firm Innovation

Table 3 shows the regression results of equation (1). We are mainly concerned with the regression coefficient of After×HSR term, which represents a change in the patents of listed companies along the route before and after a high-speed railway was put into service. As can be learned from Columns (1) through (4), firm patent licenses increased by 0.103 units after a high-speed railway was put into service, including 0.090 units of invention patent licenses, and utility model patent licenses increased by 0.029 units. Judging by the magnitude and significance of the coefficients, invention patent licenses increased the most. Results in Columns (5) through (8) suggest that firm patent applications increased by an average of 0.110 units after a high-speed railway was put into service, including 0.102 units of invention

Table 2: Descriptive Statistics

Variable type	(1)	(2)	(3)	(4)	(5)	(6)
	Observations	Mean	Standard deviation	Median	Min.	Max.
Explained variable						
Pat	7,102	2.016	1.930	1.946	0.000	6.605
Pat_inv	7,102	1.013	1.278	1.010	0.000	4.942
Pat_uti	7,102	1.527	1.755	1.693	0.000	6.078
Pat_des	7,102	0.756	1.365	0.821	0.000	5.375
App	7,102	1.409	1.559	1.456	0.000	5.663
App_inv	7,102	0.915	1.196	0.897	0.000	4.700
App_uti	7,102	0.913	1.285	1.052	0.000	4.868
App_des	7,102	0.348	0.882	0.411	0.000	4.143
Bachelor	7,102	26.891	1.941	27.992	5.290	77.213
Technician	7,102	17.462	15.062	12.937	0.130	56.311
Explaining variable						
After×HSR	7,102	0.505	0.500	1.000	0.000	1.000

patent applications and 0.023 units of utility model patent applications. Judging by the magnitude and significance of the impact coefficients, invention patent applications increased the most.

The launch of high-speed railways led to an increase in firm innovation output, especially invention patents that are deemed as more technical and valuable than utility model patents. Simultaneous increases in both patent licenses and applications explain that the innovation effects of high-speed railways are sustainable considering that current patent applications are a key driver of growth in future patent licenses.

4.3 Mechanism Analysis

In this section, we attempt to further verify that the increase in firm innovation output was driven by an influx of more skilled labor after a high-speed railway was put into service. To do so, we looked at changes in the percentage of college-educated employees and technical personnel at firms along the high-speed railway route. As shown by the regression coefficient of After×HSR in Column (1) of Table 4, the percentage of employees with a bachelor's degree or above rose by 2.079 percentage points after the launch of a high-speed railway. As shown by the regression coefficient of Bachelor in Column (2), most of the college-educated personnel were employed in technical positions. In Columns (3) through (6), we performed an analysis of the intermediate effect (Ren and Zhang, 2013), and found a significantly positive correlation between the percentage of technical employees and firm patent licenses and applications. This result explains that high-speed railways brought an influx of skilled workforce to cities along the route, thus inducing an increase in innovation output.

5. Robustness Test

5.1 Test of Parallel Trend Hypothesis

The basic hypothesis of the difference-in-differences (DID) model is the parallel trend hypothesis, i.e. the difference in the trends of the treatment group and the control group may only occur after the event (policy) time point. Before the time point, the treatment group and the control group should share similar

Table 3: Firm Innovation Effects of High-Speed Railways

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Pat	*Pat_inv*	*Pat_uti*	*Pat_des*	*App*	*App_inv*	*App_uti*	*App_des*
After×HSR	0.103*** (0.022)	0.090*** (0.010)	0.029* (0.015)	0.034 (0.027)	0.110*** (0.023)	0.101*** (0.016)	0.023** (0.010)	0.027 (0.019)
Observations	7,102	7,102	7,102	7,102	7,102	7,102	7,102	7,102
Number of companies	1,559	1,559	1,559	1,559	1,559	1,559	1,559	1,559
Fixed effect of company	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
Fixed effect of year	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
R^2	0.213	0.293	0.284	0.161	0.157	0.162	0.179	0.145

Note: *, ** and *** denote significance levels at 10%, 5% and 1%, respectively, and the numbers in parenthesis are Heteroskedasticity-robust standard error, the same below.

Table 4: Labor Inflow Effect of High-Speed Railways

	(1)	(2)	(3)	(4)	(5)	(6)
	Bachelor	*Technician*	*Pat*	*Pat_inv*	*App*	*App_inv*
After×HSR	2.079*** (0.512)	0.428* (0.242)	0.072** (0.030)	0.060* (0.031)	0.064** (0.031)	0.047** (0.020)
Bachelor		0.539*** (0.073)				
Technician			0.020** (0.008)	0.025** (0.011)	0.023** (0.010)	0.030*** (0.009)
Observations	7,102	7,102	7,102	7,102	7,102	7,102
Number of companies	1,559	1,559	1,559	1,559	1,559	1,559
Fixed effect of company	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
Fixed effect of year	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
R^2	0.288	0.121	0.223	0.217	0.239	0.227

Note: In the interest of length, the regression results of control variables are not reported, the same below.

trends of change; otherwise, the coefficient thus estimated could be driven by certain factors before the event (policy) time point rather than the event (policy) itself. Hence, we need to verify that treatment-group firms and control-group firms shared a similar trend in innovation output, which started to change after the launch of a high-speed railway.

We have defined the dummy variables of seven years, including Year-2, Year-1, Year0, Year1, Year2, Year3 and Year4, which denote two years before the launch of a high-speed railway, one year before the launch of a high-speed railway, the year when a high-speed railway was put into service, and one year, two years, three years and four years after a high-speed railway was put into service, respectively. Then, we replaced After×HSR in equation (1) into the products between the seven dummy variables of time and HSR for regression analysis.

First, we paid attention to the coefficients of Year-2×HSR and Year-1×HSR, whose significance and magnitude indicate whether any difference occurred in the trends of innovation output between the treatment group and the control group before a high-speed railway was put into use. Table 4 shows that the coefficients of Year-2×HSR and Year-1×HSR are both insignificant, i.e. the hypothesis that these two

Table 5: High-Speed Railway's Dynamic Effects on Firm Innovation

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Pat	*Pat_inv*	*Pat_uti*	*Pat_des*	*App*	*App_inv*	*App_uti*	*App_des*
Year-2×HSR	0.021	0.032	0.046	0.007	0.069	0.079	0.176	-0.027
	(0.125)	(0.075)	(0.089)	(0.033)	(0.105)	(0.093)	(0.183)	(0.113)
Year-1×HSR	-0.014	-0.026	0.041	-0.015	0.028	0.081	0.147	-0.049
	(0.122)	(0.086)	(0.055)	(0.036)	(0.129)	(0.096)	(0.138)	(0.096)
Year0×HSR	-0.069	-0.033	-0.009	-0.031	0.005	0.054	0.118	-0.062
	(0.102)	(0.049)	(0.011)	(0.052)	(0.107)	(0.062)	(0.119)	(0.115)
Year1×HSR	0.062	0.023	0.022	0.064	0.072	0.021	0.065	0.112
	(0.097)	(0.038)	(0.083)	(0.059)	(0.124)	(0.038)	(0.093)	(0.157)
Year2×HSR	0.051	0.043	0.016	0.045	0.051**	0.045**	0.011*	0.031
	(0.063)	(0.053)	(0.033)	(0.083)	(0.020)	(0.021)	(0.006)	(0.063)
Year3×HSR	0.088**	0.067**	0.019**	0.059	0.082***	0.073**	0.019**	0.123
	(0.041)	(0.031)	(0.010)	(0.066)	(0.017)	(0.031)	(0.009)	(0.097)
Year4×HSR	0.125***	0.103***	0.036**	0.068	0.122***	0.109***	0.032**	0.145
	(0.036)	(0.031)	(0.015)	(0.087)	(0.041)	(0.031)	(0.016)	(0.139)
Observations	7,102	7,102	7,102	7,102	7,102	7,102	7,102	7,102
Number of companies	1,559	1,559	1,559	1,559	1,559	1,559	1,559	1,559
Fixed effect of company	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
Fixed effect of year	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
R^2	0.228	0.217	0.183	0.171	0.152	0.165	0.171	0.133

coefficients are 0 cannot be rejected. The test of the parallel trend hypothesis is thus passed.

Then, the dynamic change in the high-speed railway's effects on firm innovation is observed. As can be learned from the coefficients of Year1×HSR, Year2×HSR, Year3×HSR and Year4×HSR, total firm patent licenses, invention patent licenses and design patent licenses increased remarkably three years after a high-speed railway was put into service. After the fourth year, the coefficient increased year by year as the high-speed railways' effects continued to grow. Similarly, high-speed railways' effects on firm patent applications became significant two years after a high-speed railway was put into service, and continued to increase in the subsequent years. The high-speed railways' effect on firm patent licenses occurred one year after the effect on patent applications, and such a one-year lag is consistent with firms' innovation cycle since it takes some time for patent applications to be approved and licensed.

5.2 Change of Time Point of High-Speed Railway Launch

To ensure that change in the innovation output of listed companies along the route resulted from the launch of high-speed railways rather than other policy events, we have performed a placebo test by changing the discontinuity points of DID,[3] assuming that a high-speed railway had been put into service one year before the actual date, and created a pseudo-dummy variable After*HSR_1 for high-speed railway launch date to be included into the equation for another round of regression. The coefficients of After*HSR_1 shown in Table 6 are all insignificant, and change in the patent licenses and applications of companies along the route did not occur before high-speed railway launch and only occurred afterward,

[3] We appreciate comments from reviewers.

Table 6: High-Speed Railways' Effects on Firm Innovation after Change of Discontinuity Points

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Pat	*Pat_inv*	*Pat_uti*	*Pat_des*	*App*	*App_inv*	*App_uti*	*App_des*
After×HSR_1	-0.033 (0.045)	-0.042 (0.055)	-0.017 (0.031)	-0.035 (0.029)	-0.054 (0.062)	-0.029 (0.032)	-0.043 (0.039)	-0.015 (0.021)
Observations	7,102	7,102	7,102	7,102	7,102	7,102	7,102	7,102
Number of companies	1,559	1,559	1,559	1,559	1,559	1,559	1,559	1,559
Fixed effect of company	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
Fixed effect of year	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
R^2	0.219	0.224	0.214	0.167	0.143	0.159	0.173	0.113

Table 7: High-Speed Railways' Effects on Firm Innovation under the Instrumental Variable Method

	(1)	(2)	(3)	(4)	(5)
	Pat	*Pat_inv*	*App*	*App_inv*	*After×HSR*
$\widehat{After*HSR}$	0.079** (0.040)	0.067*** (0.021)	0.088*** (0.034)	0.071** (0.035)	
*Slope**2008					-0.059*** (0.015)
*Slope**2009					-0.024*** (0.008)
*Slope**2010					-0.072** (0.030)
*Slope**2011					-0.796*** (0.186)
*Slope**2012					-0.913** (0.415)
*Slope**2013					-0.496** (0.226)
*Slope**2014					-0.337*** (0.102)
Observations	7,102	7,102	7,102	7,102	7,102
Number of companies	1,559	1,559	1,559	1,559	1,559
Fixed effect of company	Controlled	Controlled	Controlled	Controlled	Controlled
Fixed effect of year	Controlled	Controlled	Controlled	Controlled	Controlled
R^2	0.219	0.233	0.165	0.147	0.199

thus verifying the robustness of high-speed railways' effects.

5.3 Use of Geographical Slope as Instrumental Variable

The siting of high-speed railways could be related to a city's economic development, which would also influence firm innovation. To further ensure the robustness of results, we have created an instrumental variable with geographical slope referencing Li *et al*. (2017). The higher the average slope of the place where a listed company is located, the more difficult it is for a high-speed railway to be constructed, i.e. there is a negative correlation between geographical slope and the launch of a high-speed railway. Moreover, the geographical slope is an exogenous geographical variable and does not influence firm innovation. Stage I regression equation is equation (2), with which we performed a regression analysis of the average slope of the places where listed companies were located as an instrumental variable with respect to whether their prefectural cities where listed companies were located were connected to the high-speed railway network (After*HSR), and estimated the probability for the places of the listed companies to be connected to high-speed railways prob(After*HSR). Stage II regression is shown in equation (3), which deals with the effects of the probability for the places of the listed companies to be connected to high-speed railways on patent applications of companies along the route.

$$After_{i,t} \times HSR_{i,t} = \alpha_i + \beta_1 Slope_{i,t} + \gamma CV_{i,t} + \delta_t + \varphi_i + \varepsilon_{i,t} \quad (2)$$

$$y_{i,t} = \alpha_i + \beta_1 prob\left(After_{i,t} \times HSR_{i,t}\right) + \gamma CV_{i,t} + \delta_t + \varphi_i + \varepsilon_{i,t} \quad (3)$$

Regression results are shown in Table 7. As can be learned from Columns (1) through (4), under the instrumental variable regression, patent licenses and applications of firms along the route all significantly increased after a high-speed railway was put into service, primarily driven by invention patents. Column (5) is first-stage regression results, which show a negative correlation between geographical slope and the probability of high-speed railway launch. The instrumental variable's effectiveness is thus proven. In the first-stage regression, F statistic is 17.8, which is greater than 10, and thus passes the effectiveness test of the instrumental variable; Hausman test statistic is 2.7, and p value is 0.44, which passes the exogeneity test of the instrumental variable.

6. Heterogeneity Analysis

6.1 Effects on Firms in Cities of Different Types

To discuss high-speed railway's effects on firm innovation, we have classified sample cities in two various types. While municipalities and provincial capitals such as Beijing, Shanghai, Guangzhou, Shenzhen, Tianjin, Chongqing, Wuhan, Nanjing and Hangzhou are classified as large and medium-sized cities, other cities are classified as small cities. We use the dummy variable City_Size for differentiation. If a company is located in a large or medium-sized city, the value of City_Size is 1; otherwise, it is 0. The coefficient of the cross-product term (AH_CS) between City_Size and After*HSR is the difference of high-speed railway's effects between various types of cities.

Results in Table 8 suggest that after a high-speed railway was put into service, firms in large and medium-sized cities saw their total patent licenses increase by 0.065 units and invention patent licenses increase by 0.051 units more than those by firms in small cities. Such differences are all significant at 1% confidence level. In terms of total patent and invention patent applications after a high-speed railway launch, firms in large and medium-sized cities recorded much more robust growth than their peers in small cities.

6.2 Effects on Firms with Different Innovation Intensities

Theoretically, sectors more dependent on innovation should experience more growth in innovation output after a high-speed railway launch. Therefore, we define 15 sectors[4] above the 75th percentile

[4] These 15 sectors include computers, communications and other electronic equipment, electric machinery and equipment, chemical raw materials and chemical products, special equipment, general equipment, pharmaceuticals, automobiles, non-ferrous metal smelting and rolling processing, fabricated metal products, non-metallic mineral products, rubber and plastic products, ferrous metal smelting and rolling processing, alcohols, beverage and refined tea manufacturing, software and information technology services.

Table 8: Effects of High-Speed Railway Launch on the Innovation of Firms in Different Types of Cities

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Pat	*Pat_inv*	*Pat_uti*	*Pat_des*	*App*	*App_inv*	*App_uti*	*App_des*
AH_CS	0.065***	0.051***	0.016	0.010	0.069**	0.055**	0.009	0.012
	(0.014)	(0.019)	(0.021)	(0.045)	(0.033)	(0.026)	(0.011)	(0.033)
After×HSR	0.027**	0.032*	0.014**	0.028**	0.034**	0.023**	0.010**	0.017**
	(0.013)	(0.018)	(0.007)	(0.013)	(0.016)	(0.011)	(0.005)	(0.008)
City_Size	0.088**	0.069*	0.072**	0.063**	0.052*	0.021*	0.015**	0.034**
	(0.039)	(0.040)	(0.035)	(0.030)	(0.031)	(0.012)	(0.007)	(0.016)
Observations	7,102	7,102	7,102	7,102	7,102	7,102	7,102	7,102
Number of companies	1,559	1,559	1,559	1,559	1,559	1,559	1,559	1,559
Fixed effect of company	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
Fixed effect of year	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
R^2	0.207	0.211	0.183	0.195	0.218	0.193	0.198	0.186

Table 9: Effects of High-Speed Railway Launch on Firms with Different Innovation Intensities

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Pat	*Pat_inv*	*Pat_uti*	*Pat_des*	*App*	*App_inv*	*App_uti*	*App_des*
AH_RI	0.047***	0.043***	0.013**	0.017	0.059***	0.039**	0.010**	0.062
	(0.013)	(0.012)	(0.006)	(0.031)	(0.014)	(0.018)	(0.005)	(0.059)
After×HSR	0.068**	0.041**	0.019*	0.034	0.064***	0.057***	0.016*	0.054
	(0.034)	(0.020)	(0.011)	(0.039)	(0.020)	(0.021)	(0.009)	(0.046)
Rd_intense	0.118**	0.057	0.107	0.051*	0.046	0.017	0.009	0.039
	(0.059)	(0.043)	(0.176)	(0.027)	(0.052)	(0.019)	(0.012)	(0.028)
Observations	7,102	7,102	7,102	7,102	7,102	7,102	7,102	7,102
Number of companies	1,559	1,559	1,559	1,559	1,559	1,559	1,559	1,559
Fixed effect of company	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
Fixed effect of year	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
R^2	0.226	0.237	0.219	0.224	0.198	0.187	0.191	0.203

of the number of patent licenses as sectors with high innovation intensity and the rest as sectors with low innovation intensity, and created a dummy variable Rd_intense. If a firm is in a sector with high innovation intensity, the value of Rd_intense is 1; otherwise, it is 0. To estimate differences in high-speed railway's effects on firms with high innovation intensity and those with low innovation intensity, we introduce a cross-product term between whether a company is a high-innovation-intensity one and whether it is located in a place with access to high-speed railway (AH_RI) into equation (1) for regression.

Results in Table 9 suggest that high-innovation-intensity firms recorded an increase in patent licenses 0.047 units higher than that for low-innovation-intensity firms; an increase in invention patent licenses 0.043 units higher than that for low-innovation-intensity firms; and an increase in utility model patent licenses 0.013 units higher than that for low-innovation-intensity firms. The above-mentioned coefficients are also significant at 1% and 5% confidence levels, respectively.

In addition, high-innovation-intensity firms recorded an increase in their total patent applications 0.059 units higher than that for low-innovation-intensity firms; an increase in invention patent applications 0.039 units higher than that for low-innovation-intensity firms; and an increase in utility model patent applications 0.010 unit higher than that for low-innovation-intensity firms. These coefficients are also significant at 1% and 5% confidence levels, respectively.

7. Conclusions and Policy Advice

Labor force, especially the skilled labor force, is a key factor of production underpinning innovation (Zingales, 2000). Overall, the skilled workforce remains in short supply in China. Rapid development of a high-speed railway helps increase mobility and improve the allocation of a skilled labor force, thus enhancing firm innovation.

With the launch of high-speed railways as a natural experiment, this paper found that after their implementation, a sharp increase in firm innovation, as reflected in the robust growth of patent licenses and applications, was observed. Invention patent licenses and applications increased the most, indicating a high value of the innovation capacity stemming from effects of high-speed railways. From a dynamic view, the effects of high-speed railways on firm patents increased year by year. The effects on patent licenses occurred one year later than the effects on patent applications, reflecting a normal firm innovation cycle.

Moreover, our study on the education of employees at firms along the newly launched high-speed railway routes has verified that the increased innovation stemmed from an inflow of skilled labor force, i.e. the launch of a high-speed railway was followed by a sharp rise in the percentage of personnel with bachelor's degree or degrees of higher education at firms along the route, most of whom were employed within technical positions. The launch of high-speed railways helped increase the innovation output of firms in large and medium-sized cities and high-innovation-intensity firms.

This paper has enriched relevant research on the driving forces behind firm innovation by discussing how high-speed railways are a conduit of labor influx and have influenced firm innovation output. It has also enriched relevant literature on high-speed railways' economic effects by revealing high-speed railways positive externalities on firm innovation. Policy-wise, China should improve its workforce structure by increasing the supply of a skilled workforce and remove barriers to labor flow of the skilled workforce to regions where their talents are needed most. CE

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