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Abstract

This paper investigates how the reduction of the travel costs through improvement in transportation infrastructure lead to knowledge diffusion. Using the case of the opening of the Nagano-Hokuriku shinkansen, and applying the difference-in-differences approach, we estimate the impact of the high-speed rail on innovative activities along the line. We find that after the opening of the high-speed rail, innovative activities by establishments along the line significantly increased. Furthermore, collaborative patents across establishments along the line and citations of patents published by the establishments in Tokyo increased. These imply that the innovative activities along the line are increased through knowledge diffusion from nearby establishments and those in Tokyo.

Keywords: Transport infrastructure, Knowledge diffusion, Railroads

JEL classification: R12; O31

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1. Introduction

Knowledge spillovers are crucial for innovative activities. Beginning with Marshall (1890), it has been widely recognized that geographical proximity enhances knowledge spillovers. Actually, many studies find that the knowledge spillovers are localized (e.g., Jaffe, Trajtenberg, and Henderson, 1993; Murata, Nakajima, Okamoto, and Tamura, 2015; Kerr and Kominers, 2015; Inoue, Nakajima, and Saito, 2013). It would be helpful to understand a mechanism behind the localization of innovative activities.

Necessity of face-to-face communications and the accompanying trip costs for the transmission of the knowledge must be a source. Actually, Griffith et al. (2015) find that the international border effects on knowledge transmission measured by patent citation is declining in these decades. They discuss that the decline of the border in knowledge spillovers are the vast development of ICT and transportation infrastructures. On the other hand, Inoue et al. (2016) find that there is no difference in the range of knowledge spillovers measured by collaborations in this 20 years. Patent citations are the measure of explicit knowledge transfers, that is, patent is actually codified, and transmission of the knowledge are easily attained without face-to-face communications. On the other hand, collaboration is a measure of tacit knowledge spillovers that requires face-to-face communications. In this sense, transport infrastructure that reduce the trip cost and may facilitate the face-to-face communication would crucial for knowledge spillovers.

Against this backdrop, the purpose of this paper is estimating the impact of opening of the transportation infrastructure on innovative activities through knowledge spillovers. Specifically, this paper focuses on the case of opening of high-speed rail, "Nagano-Shinkansen," in Japan in 1997. This connects between Tokyo and Nagano where is the provincial city located in the middle of Japan. This opening of bullet-train dramatically reduces the travel time between Tokyo and Nagano, and may facilitate the communications between them and affect the innovative activities. Especially, Nagano city is a local provincial city, and the high-speed rail may provide access to the advanced knowledge in Tokyo. This may facilitate the innovative activities in Nagano through knowledge spillovers.

This paper estimate the impact of the opening of the Nagano Shinkansen by using the difference in difference approach. In the estimation, a unique feature of the process of opening of Nagano Shinkansen enables us to obtain an well-defined control group. The Nagano Shinkansen is a part of planned line of Hokuriku Shinkansen, and opens earlier than the whole Hokuriku Shinkansen line which actually opened in 2015. In the other words, Hokuriku Shinkansen opened by two-stages. In the first stage, Nagano Shinkansen, a part of Hokuriku Shinkansen opened, the, in the next stage, remained line is opened. Thus, the rest of the line of Hokuriku Shinkansen has high-speed rail at last, in this sense, the demand for high-speed rail is similar to the areas along Nagano Shinkansen, but, until 2015, these regions still do not have bullet-train. We can estimate the impact of the opening of the Nagano Shinkansen by using the areas along the rest of the line of Hokuriku Shinkansen as an appropriate control group.

To capture the regional innovative activities, we use patent information. Specifically, we use the establishment-level patent submission data, we capture the regional innovative activities. Furthermore, we use the patent citation relationship as a proxy for codified knowledge spillovers, and collaboration relationship as a measure of tacit knowledge transfers to detect the mechanism. We obtain the following results. First, the opening of Nagano Shinkansen increases the innovative activities of the establishments along the line in both quantity and quality. Second, the opening of the Nagano Shinkansen increases the collaboration relationships between establishments within the line. Third, the opening of the Nagano Shinkansen increases citation of patents published by establishments in Tokyo. These results imply that the opening of the Nagano Shinkansen increases the innovative activities along the line through both codified and tacit knowledge transfers.

This paper is closely related to the recent large literature on the impact of transportation infrastructure on regional economy. In terms of railroads, Donaldson (2017) evaluates that the construction of the railroad on regional economy in Colonial India. Donaldson and Hornbeck (2016) find that the railroad construction in the US increases the agricultural land prices. Yamasaki (2017) find that the construction of railway facilitates the technology adoption in the period of modernization in Japan. In terms of highway, Baum-snow (2007) finds that the US inter-state highway facilitates the suburbanization of the large metropolitan areas. Duranton and Turner (2012) find that the US inter-state highway facilitates the urban growth. Faber (2015) investigates the construction of highway on Chinese regional economy. Xu and Nakajima (2017) also find the significant positive effects of construction of highway on regional development in China.

However, in the literature of the impact of transportation infrastructure on regional economy, high-speed rail has a unique feature; it is specialized to the inter-city passenger transportation. This means that it has no effect on input-output linkage through transportation cost for products. Also, it has no effect on commuting within a city. In terms of inter-city passenger transportation, Giroud (2013) finds that the opening of the new airline connections improves productivity of plants through intrafirm manager mobility. Bernard et al. (2016) find that the opening of the high-speed rail in Japan improves productivity through enhancing better matching between buyer and suppliers. These literatures evaluate the opening of the inter-city passenger transportation infrastructure through firm productivity. On the other hand, this paper evaluates it from the view of innovation through the reduction of the cost for face-to-face communications. From the view of innovation, most related paper is Tamura (2016) who investigates the role of high-speed rail on knowledge diffusion captured by patent citation relationships by using the opening of Nagano-Shinkansen. Our paper is different in the following sense. Our focus is not only knowledge diffusion captured by the patent citations but comprehensive activities on inventions. We investigate patent publication and quality of patent by establishments along the high-speed rail. Furthermore, we investigate collaboration pattern of the establishments as well as the knowledge diffusion captured by patent citations.

The rest of the paper is as follows. The next section describes the background information of Nagano-Shinkansen. Section 3 shows the data and empirical strategy. Section 4 shows the baseline results, conducts falsification test, and discusses on the mechanism. Section 5 concludes the paper.

2. Nagano-Hokuriku Shinkansen

Hokuriku Shinkansen was first planed in 1972 based on the Ordinance for Enforcement of the Nationwide Shinkansen Railway Development Act. In this plan, Hokuriku Shinkansen connects between Tokyo and Osaka via Nagano, Toyama, Kanazawa. Figure 1 shows the planned and actual lines of Hokuriku Shinkansen.

[Figure 1 here]

However, because of oil shock and large deficit of Japan National Railway, the construction was frozen before the construction. In 1988, Japanese government made a decision to restart the construction of Hokuriku Shinkansen. However, process of the construction was divided into multiple waves. The government decide to construct from Tokyo to Nagano in the first wave, then, construct the remained railway line of Hokuriku Shinkansen after opening the line from Tokyo to Nagano, because of the limitation of the budget.

In 1998, the line from Tokyo to Nagano was opened as Nagano Shinkansen. The line is shown as green bold line in Figure 1. From Tokyo to Takasaki has already opened as the part of line of Joetsu Shinkansen. Actually, Takasaki to Nagano actually opened in this period. After opening of Nagano Shinkansen, the construction of remained line was started. Then, in 2015, the line from Nagano to Kanazawa was opened as shown as thick blue line in Figure 1. The remained line shown by dashed blue line still in the planning process and still not in construction in the period of 2017.

Both from Takasaki to Nagano and from Nagano to Kanazawa have a Shinkansen line in the period of 2015, in this sense, the demand for Shinkansen is similar between these two areas. However, Nagano Shinkansen was opened earlier, and from 1998 to 2015, only Takasaki to Nagano has a Shinkansen, and remained areas have no Shinkansen. Thus, we can estimate the impact of Nagano Shinkansen by using areas from Nagano to Kanazawa as a well-defined control group. Hereafter, we call the rail from Takasaki to Nagano as Nagano Shinkansen, and the remained line from Nagano to Kanazawa as Hokuriku Shinkansen.

3. Data and Empirical Strategy

3.1. Data

First, to capture the innovative activities in establishments, we use the patent data. Specifically, we utilize the Institute of Intellectual Property (IIP) patent database (Goto and Motohashi, 2007), which includes Japanese patent publications (the Patent Gazette) over more than two decades. This is patent-level database that includes basic patent information, such as patent IDs, publication dates, names and addresses of applicants, and names and addresses of inventors for each patent. The database also includes citation information on each patent, such as the number of times the patent has been cited.

From this patent-level database, we construct an establishment-level database of all patents published from 1993 to 2008. To do so, first, we identify the patent-creating establishments from the patent database, taking advantage of a convention in the Japanese patent application where inventors register the address of the establishments to which they belong as the "inventor's address" (Inoue, Nakajima, and Saito, 2013). The detail of identifying establishments from the patent database is in Appendix. Then, by using the establishment information from the database, we construct establishment-year aggregated database. Specifically, we construct establishment-year level data that contains the number of patent submission, the number of citations received, and the normalized number of citations, i.e. the number of received citations that is divided by the average in the same technology and in the same year of publication.

3.2. Empirical strategy

We use difference-in-difference approach to estimate the impact of the opening of Nagano Shinkansen on the innovative activities of establishments along the line. The estimation equation is as follows,

$$y_{imt} = \alpha + \beta(T_i \times I[t \geq 1997]) + \eta_{mt} + \xi_i + \zeta_t + \varepsilon_{it},$$

where y_{imt} is innovation performance of establishment i located in municipality m in period t, T_i is a dummy takes one if establishment i belongs to the treatment group (locates near the Nagano-Shinaknasen stations), $I[t \geq 1997]$ is a dummy takes one if period t is later than 1997, ξ_i is establishments fixed effects, ζ_t is year fixed effects, and ε_{it} is a stochastic disturbance. The variable η_{mt} is municipality-year fixed effects. Instead of using municipality-year fixed effects to avoid the computational infeasibility by the high number of pairs of dummy variables, we include the average performance (y_{imt}) in a municipality-year. The coefficient, β, for the interaction term, $T_i \times I[t \geq 1997]$, is the treatment effects by the opening of Nagano Shinkansen on innovation performance along the line.

Then, we define establishments along the Shinkansen line. We use establishments located within 30 km radius from stations of Nagano-Hokuriku Shinkansen as a sample for the analysis. Then, we divide sample to treatment group and control group. Treatment group is establishments located along the Nagano Shinkansen line. That is, establishments located within 30 km radius from stations of Nagano Shinkansen line. Note that several stations of Nagano Shinkansen near Tokyo have been already opened as stations of another Shinkansen line (Joetsu Shinkansen line) before opening of Nagano Shinkansen. Thus, we omit establishments near these stations (specifically, Tokyo, Ueno, Omiya, and Takasaki stations.) Control group is establishments located along the rest of Nagano-Hokuriku Shinkansen line opened in 2014. That is, establishments located within 30 km radius from stations of the rest of Nagano-Hokuriku Shinkansen line. Figure 2 shows establishments of treatment and control groups. Red dots represent the treatment establishments, and blue dots represent control ones.

[Figure 2 here]

4. Results

4.1. Baseline Results

First, we compare average number of patents submitted between establishments in treatment and control groups. Figure 3 shows the results.

[Figure 3 here]

The solid line represents the average number of patents submitted by treatment establishments. The dashed line is that by control ones. The vertical line represents the year of opening of Nagano-Shinkansen. The figure shows that before opening of Nagano-Shinkansen, number of patents submitted is very similar between two groups. This implies that the control group will be an appropriate counterfactual of treatment group. Furthermore, after opening the Nagano-Shinkansen, the growth rate of number of patents submitted in treatment group is increased. This implies the opening of the Nagano-Shinkansen facilitates the innovative activities of the establishments along the line.

Table 1 shows the baseline estimation results.

[Table 1 here]

Column (1) shows the results using log of number of patents submitted as an outcome variable. The treatment effects that is the coefficient for $T_i \times I[t \geq 1997]$ is positively significant. That is, after opening of Nagano-Shinkansen, patent submission by establishments locating near by the station of the bullet train is significantly increased. This implies that the opening of Nagano-Shinkansen facilitates the innovative activities in establishments along the line. Column (2) shows the results using number of citations received per patent as an outcome variable. The coefficient for $T_i \times I[t \geq 1997]$ is also positively significant. This implies that the opening of the Nagano-Shinkansen improves the innovative activities in the sense of quality as well as the quantity. Finally, Column (3) shows the result using impacts per patent as an outcome variable. Similar to the results in Column (2), the treatment effect is positively significant. Even if we control for the heterogeneity of the citation tendency between patent classes and years, the positive effects of the opening of Nagano-Shinkansen is observed.

In sum, the opening of Nagano Shinkansen increases the innovative activities of establishments along the line in the sense of both quantity and quality. Furthermore, the magnitude is not so small. The opening of Nagano Shinkansen increases the submission of patents by establishments along the line 4.6%.

4.2. Placebo tests

This section tests robustness of the baseline results. A potential concern of the estimation is establishments along Nagano Shinkansen are potentially innovative, and improve their innovative activities faster than that in establishments in control group. To address this concern, we conduct a placebo test. Specifically, we set 2003 as the year of opening of Nagano Shinkansen incorrectly, and estimate the equation again. In the estimation, we restrict sample from 1990 to 1996 (just before the opening of Nagano Shinkansen).

The results are shown in Table 2. Column (1) shows the results using log of number of patents submitted as an outcome variable, Column (2) shows the results using number of citations received per patent as an outcome variable. Column (3) shows the result using impacts per patent as an outcome variable. In all the specifications, the coefficients for $T_i \times I[t \geq 1993]$ are not significant. Thus, there is no pre-trend diversifications.

[Table 2 here]

4.3. Mechanism

We found that the opening of the Nagano-Shinkansen positively increases the innovative activities of the establishments along the line both in quantity and quality. This subsection investigates the mechanism of the improvement of the innovative activities by the opening of the Nagano-Shinkansen.

The opening of Nagano-Shinkansen dramatically reduces the travel time between areas along the line and Tokyo. This may facilitate the knowledge diffusion from Tokyo to regions along the line, and improve the innovative activities of the establishments locating there. We measure the knowledge diffusion by two ways. We first consider the channel through collaborations. As Inoue, Nakajima, and Saito (2013) pointed out, collaboration relationships between establishments are localized. Furthermore, they find that the tendency of localization is unchanged in this 20 years in spite of the vast development of ICT in the periods. This implies that the importance of the face-to-face communications in the collaborative research. The opening of the Nagano Shinkansen dramatically reduces travel time for the face-to-face communications, and may facilitate the collaborative research between establishments along the line.

According to Inoue, Nakajima, and Saito (2013), we identify collaboration relationships as the following way. First, we identify establishments to which the inventors belong in each patent. Then, if there are multiple establishments registered in a patent, we regard the patent is invented by the collaborative work across the establishments. Based on the definition, we construct the following variables as measures of collaboration. The first variable is number of patents by collaboration. This variable counts patents by collaboration regardless of its partners. The second one is number of patents by collaboration with establishments locating in Tokyo. This captures knowledge diffusion from establishments in Tokyo through collaborative work. The third one is number of patents by collaboration with establishments locating along the Shinkansen line. The opening of Nagano Shinkansen decrease travel time within a region along the Shinkansen as well as to Tokyo. This may facilitate the knowledge diffusion through collaboration between establishments along the line. The third variable captures this effect. Finally, we also estimate number of patents by non-collaboration.

Table 3 shows the results. Column (1) shows the result using log of number of patents submitted by non-collaboration as the outcome variable. The treatment effect is significantly positive. This implies that the opening of the Nagano Shinkansen increases innovative activities not through the collaborating channel. Column (2) shows the result using log of number of patents submitted by collaboration regardless of the partners' locations as the outcome variable. We cannot observe any significant treatment effects. The opening of the Nagano Shinkansen does not increase collaboration overall. Column (3) shows the result using number of patents by collaboration with establishments locating in Tokyo as the outcome variable. The treatment effect is not significant. This implies that the opening of Nagano Shinkansen does not affect number of collaborations with establishments in Tokyo. Finally, Column (4) shows the result using number of patents by collaboration with establishments locating along the Shinkansen line as the outcome variable. The treatment effect is positively significant. The opening of Nagano Shinkansen increases the collaborating patent with establishments along the Shinkansen line 0.60%. This implies that the reduction of travel time across establishments along the Shinkansen line facilitates the collaborations across the establishments.

[Table 3 here]

Then, we check another channel of knowledge spillovers. Nagano-Shinkansen gives establishments along the line a better access to Tokyo. This means that they have a better access to advanced knowledge concentrated in Tokyo. Thus, diffusion of advanced knowledge concentrated in Tokyo might be increased by the opening of the Nagano Shinkansen, and the diffused advanced knowledge might facilitate the innovative activities. This would be represented as the citation of patents that is published by the establishments in Tokyo. Specifically, we focus on the patents published by the establishments in Tokyo as originating patents, and identify patents that cite the originating patents, submitted by the treatment and control establishments. We calculate the share of originating patents published by establishments in Tokyo in all the originating patents cited by patents submitted by each treatment and control establishment as the measure of establishment-level knowledge diffusion from Tokyo. Furthermore, the opening of the Nagano Shinkansen also reduces travel time between areas along the line, and may facilitate knowledge diffusion within the area. To test it, we also construct the share of originating patents published by the treatment establishments in all the originating patents cited by patents submitted by each treatment and control establishment.

Table 4 shows the results. Column (1) shows the results using log of total number of citations by patents submitted by each treatment and control establishment as an outcome variable. The treatment effect is positively significant. This implies that after opening of the Nagano Shinkansen, number of patents cited is increased in the patents submitted by treatment establishments. This may be interpreted as the opening of the Nagano Shinkansen facilitates the knowledge spillovers from the outside of the region where the establishment locates. Column (2) shows the results using share of citations of patent in Tokyo as an outcome variable. The treatment effect is positively significant. This implies that after the opening of Nagano Shinkansen, diffusion of advanced knowledge in Tokyo is facilitated. This may come from the improved accessibility to Tokyo.[1] Column (3) shows the results using share of citations of patent published by

[1] We conduct an interview to firms locate in Nagano city. Managers mentioned that after opening of the Shinkansen, they can easily to visit to technology exhibition held in Tokyo areas. Furthermore, if they find a useful technique or module in the exhibition, they can call the engineers in Nagano to the exhibition to study the technology. Before the opening of the Shinkansen, it was difficult because the one-way trip takes more than four hours.

establishments along Shinkansen as an outcome variable. In the estimation, we cannot observe significant treatment effect. That is, there is no increase of the knowledge diffusion along the Shinkansen line after opening of the Nagano Shinkansen. This implies that opening of the Nagano Shinkansen facilitates the diffusion of advanced knowledge clustered in Tokyo areas, but not facilitate the diffusion from the establishments along the rail.

[Table 4 here]

5. Conclusion

This paper investigates the effects of reduction of travel cost on innovative activities through knowledge diffusions. By focusing on the case of the opening of Nagano Shinkansen in Japan in 1997 and using difference-in-differences approach, we estimate the impact of the event on the innovative activities of establishments along the rail. We found that the opening of the Nagano Shinkansen significantly increased the innovative activities of the establishments near the stations of the rail in both quantity and quality. Furthermore, collaborations with establishments along Shinkansen line and citations of patents submitted by establishments in Tokyo are significantly increased. These imply that the opening of the Nagano Shinkansen improves the knowledge production of establishments along the rail through knowledge diffusion by collaboration and citations.

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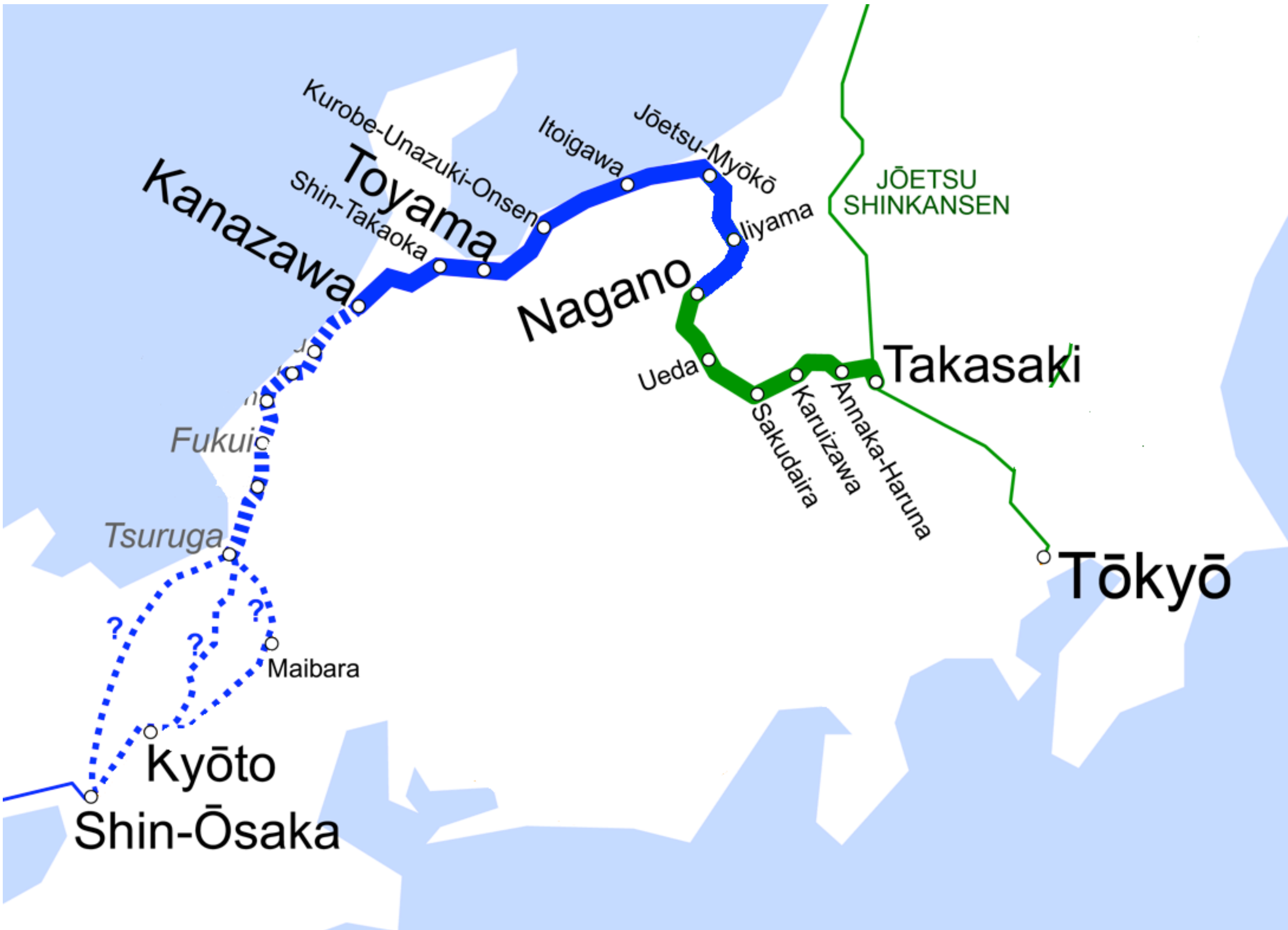

Source: Wikipedia. Modified by the authors.

Figure 1 Hokuriku and Nagano Shinkansen

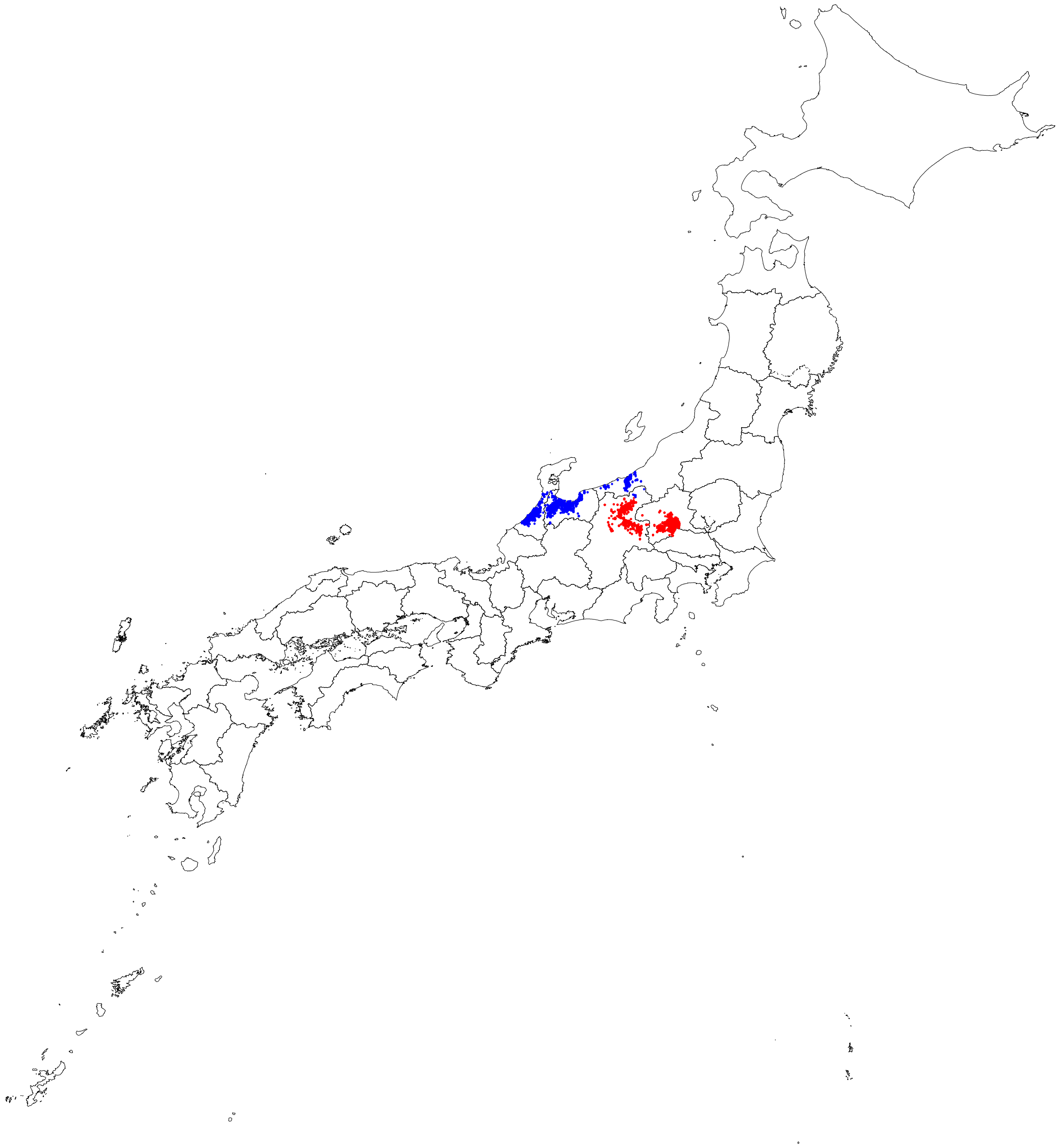

Figure 2: Establishments close to the Nagano-Hokuriku Shinkansen stations

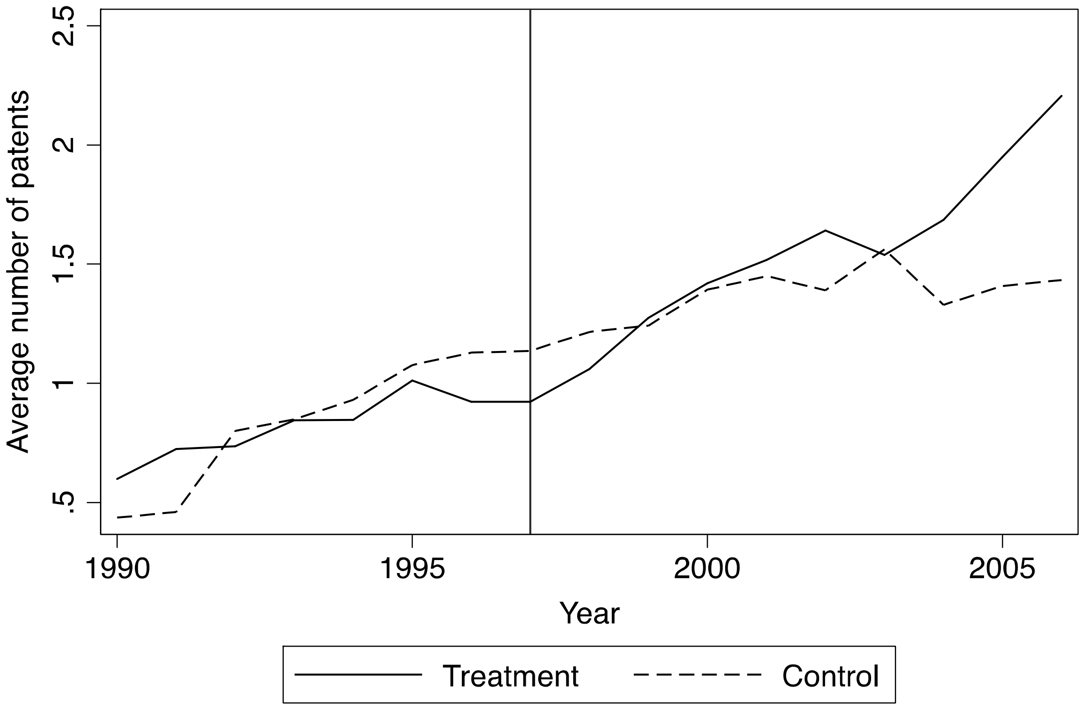

Figure 3: Average number of patents by establishments in treatment and control groups

Table 1 Baseline results

	(1)	(2)	(3)
Dependents	ln(No. of patents)	No. of citations received per patent	Impacts per patent
I(t ≧ 1997)	0.158***	-0.102***	0.0754
	(0.0198)	(0.0165)	(0.0558)
Treat × I(t ≧ 1997)	0.0463***	0.137***	0.106***
	(0.0176)	(0.0225)	(0.0231)
Constant	0.0856***	0.0881***	0.0646***
	(0.00826)	(0.0109)	(0.00981)
Year FE	yes	yes	yes
Establishment FE	yes	yes	yes
Municipality-year effects	yes	yes	yes
Observations	28390	28390	28390
R-squared	0.604	0.153	0.105

Clustered robust standard errors are parenthesis. *** p<0.01, ** p<0.05, * p<0.1.

Table 2 Placebo test

	(1)	(2)	(3)
Dependents	ln(No. of patents)	No. of citations received per patent	Impacts per patent
I(t ≧ 1993)	0.103***	0.104***	0.0594***
	(0.0161)	(0.0249)	(0.0158)
Treat × I(t ≧ 1993)	-0.0194	-0.0326	-0.0198
	(0.0139)	(0.0255)	(0.0161)
Constant	0.0525***	0.0734***	0.0536***
	-0.00893	-0.0121	-0.0082
Year FE	yes	yes	yes
Establishment FE	yes	yes	yes
Municipality-year effects	yes	yes	yes
Observations	28390	28390	28390
R-squared	0.491	0.127	0.122

Clustered robust standard errors are parenthesis. *** p<0.01, ** p<0.05, * p<0.1.

Table 3 Knowledge diffusion through collaborations

	(1)	(2)	(3)	(4)
Dependents	ln(No. of patent by single)	ln(No. of patent by collaboration)	ln(No. of patent with establishments in Tokyo	ln(No. of patent with establishments along shinkansen
I(t ≧ 1997)	0.146***	0.0595***	0.0154***	0.0101***
	(0.0192)	(0.00832)	(0.00317)	(0.00328)
Treat × I(t ≧ 1997)	0.0456***	-0.00566	-0.00167	0.00603**
	(0.0174)	(0.00614)	(0.00228)	(0.00297)
Constant	0.0799***	0.0240***	0.00448***	0.00437***
	(0.00813)	(0.00386)	(0.00114)	(0.00166)
Year FE	yes	yes	yes	yes
Establishment FE	yes	yes	yes	yes
Municipality-year effects	yes	yes	yes	yes
Observations	28390	28390	28390	28390
R-squared	0.613	0.523	0.265	0.318

Clustered robust standard errors are parenthesis. *** p<0.01, ** p<0.05, * p<0.1.

Table 4 Citation

	(1)	(2)	(3)
Dependents	ln(No of citations)	Share of citations of Tokyo patent	Share of citations of patent along shinkansen
I(t ≧ 1997)	0.994**	0.0552***	0.0342***
	(0.434)	(0.00987)	(0.00714)
Treat × I(t ≧ 1997)	0.630	0.0196*	-0.00319
	(0.435)	(0.0115)	(0.00763)
Constant	0.0689***	0.000350	0.000267
	(0.00960)	(0.000577)	(0.000501)
Year FE	yes	yes	yes
Establishment FE	yes	yes	yes
Municipality-year effects	yes	yes	yes
Observations	28390	28390	28390
R-squared	0.515	0.148	0.223