HIGH-SPEED RAILROADS AND ECONOMIC GEOGRAPHY: EVIDENCE FROM JAPAN♣

(forthcoming: *Journal of Regional Science*)

Zhigang Li[1] and Hangtian Xu[2,*]

ABSTRACT

Our study shows that high-speed railroads (HSR) can either polarize or diffuse economic geography, based on the sector and distance between cities. Economic activities could agglomerate from distant to core areas, while disperse from core toward its periphery at the same time. Empirical evidence from the 1982 introduction of two major HSRs in Japan, which halved inter-city transit time, support this. Non-core areas lost 3–6 percent population; service employment declined 7 percent, while manufacturing employment increased by 21 percent. Municipalities within approximately 150 km of Tokyo expanded, while the distant ones contracted. The net result is that the Tokyo metropolitan area agglomerates because of HSR.

KEYWORDS: high-speed railroads, inclusive growth, economic corridor

JEL CLASSIFICATIONS: H54, O18, R12

♣ Acknowledgment: The authors would like to thank Jens Suedekum (the editor), two anonymous referees, Ching-mu Chen, Rana Hasan, Zhiyuan Li, Miwa Matsuo, Tomoya Mori, Se-il Mun, Kentaro Nakajima, Shang-Jin Wei, Dao-Zhi Zeng, and the participants of seminars at Asian Development Bank, Hunan University, Kyoto University, and Tohoku University for useful comments. They are also grateful to Tetsuya Suzuki for the support in data collection of the historical train timetables. Xu is grateful for the financial support from the National Natural Science Foundation of China (#71703034) and the Social Science Association (*shekelian*) of Hunan Province (#XSP17YBZZ010). The usual disclaimer applies.

[1] Address: Economic Research and Cooperation Department, Asian Development Bank, Manila, Philippines; E-mail: zli@adb.org.

[2] Address: School of Economics and Trade, Hunan University, Changsha, P.R. China; E-mail: hangtianxu@gmail.com.

[*] The corresponding author.

"There is a big debate about the economic benefits of high-speed rail. Bizarrely it has been suggested that HS2 might disadvantage the regions by sucking more economic activity into the south-east than it generates in the regions."[1]

Lord Adonis, former Secretary of State for Transport, UK, 2011

1. INTRODUCTION

Four decades after the first investments in high-speed railroads (HSR) in advanced economies, developing countries such as China, Russia, and Brazil are enthusiastic about building extensive HSR networks. The global operating length of HSR networks has grown from 4,864 km in 2000 to 22,954 km by 2014, with 12,754 km under construction and another 18,841 km planned before 2025 (US High Speed Rail Association, 2014). The significant saving in travel time improves population mobility, which could likely have a profound impact on economic geography. Limited research on HSR has resulted in lack of consensus on the spatial impacts of investments in HSR. A major policy debate is about the potential of HSR to accelerate growth in lagging economies by improving connections to core cities—commonly considered a major positive externality underlying government initiatives to support HSR development—e.g., in the UK.

Compared with other modes of land transport, HSR reduces journey time for interregional passengers, but not for cargo or intraregional commuters. This feature has rarely been explored.[2] To understand the spatial impact of HSR, we propose hypotheses to account for the passenger time saving feature of HSR. These hypotheses propose that the impact of HSR on economic geography will vary by sector, and the distance between core and non-core cities. If the distance is long, HSR would provide valuable stimulus to agglomerate the service sector toward the core area; in contrast, the manufacturing sector may shift from the core due to rising costs of urban living. If the distance between core and non-core areas is short, the service sector may decentralize toward the non-core areas. These implications are consistent with patterns scattered in the empirical literature, although systematic econometric evidence testing them is highly limited. Below, we summarize our empirical strategy and findings and compare them with the empirical literature.

We provide empirical evidence using data from Japan. In fact, Japan built the world's first HSR in 1964—the Tokaido line connecting Tokyo to major cities to its south. Two new HSRs, the Tohoku and Joetsu lines (*TJL*), were completed in 1982, connecting Tokyo to a number of major cities to its north and northwest (Figure 1). This development process of HSR provides a quasi-experimental setting to identify the causal effect of HSR on the economy. Studying Japan's HSR networks has several additional advantages. First, given Japan's relatively small geographical scope, the majority of the population has access to the three HSR lines. Hence, population flows into and out of our sample area (which covers 17 prefectures including Tokyo Metropolitan Area (MA), accounting for 59 percent of the country's population in 2003) should be limited, simplifying the empirical analysis. Second, as our sample period (1980–2003) is after the "golden era" of Japan and no major reform events occurred; thus, mitigating the confounding effects of simultaneous economic cycles.

[PLACE FIGURE 1 HERE]

We apply a standard difference-in-difference (DID) estimation on the panel dataset of Japan on population and employment, which are disaggregated at the municipality and sector levels. In our baseline exercise, the treatment group includes municipalities along the *TJL* in northern Japan, while the control group includes those along the Tokaido line, which is in southern Japan. In our augmented model, we test the non-linear distance effect of HSR on agglomeration/dispersion by allowing the effect to differ between non-core municipalities and Tokyo. Our findings, which are consolidated by various robustness tests, strongly support theoretical implications. Specifically, we find that the HSR has induced significant agglomeration in the service sector toward the Tokyo MA as well as its peripheral areas (within approximately 40 minutes of core Tokyo via HSR). In contrast, the manufacturing sector diffused toward the more distant non-core areas due to rising urban costs in the core. Overall, the Tokyo MA population increased by as much as 3 percent after the *TJL* was built. Moreover, the estimated impact of HSR seems beneficial for the working-age population, but insignificant for the youth and aged population.

Our findings are qualitatively consistent with a number of studies on HSRs in Europe, China, and Japan, even though they provide seemingly contradictory findings. Some studies, such as Qin (2017), find that non-core jurisdictions are weakened by HSR, while others such as Zheng and Kahn (2013), Ahlfeldt and Feddersen (2017), and Garcia-López et al. (2017) find the reverse. However, they may be reconciled when we take into account the distances between non-core jurisdictions and core cities: when they are close, HSRs tend to promote diffusion; when they are far away, HSRs trigger agglomeration. For example, the German (Frankfurt–Cologne) HSR, studied by Ahlfeldt and Feddersen (2017), is approximately 200 km, while the HSR destinations in China and Japan are commonly more than 500 km apart.[3] Besides distance, the service sector is also understudied in the literature. Some descriptive studies, including Chen and Hall (2011), and Murakami and Cervero (2012) examine the service sector and find evidence for the agglomeration of knowledge-intensive services in major node cities of HSR. Nevertheless, they do not study the spatial reallocation of the service sector due to HSR.

The rest of this paper is organized as follows. In Section 2, we present our hypotheses. Section 3 describes the economic background in Japan. Section 4 presents the empirical strategy and describes the datasets. Section 5 reports the baseline results and robustness checks, and section 6 concludes.

2. HYPOTHESES

Empirical studies evaluating the spatial impact of HSR have documented a series of patterns on agglomeration or diffusion. In this study, we emphasize a unique feature of HSR: it mainly impacts inter-city travel passengers, but not those who commute daily.[4] Patterns consistent with this hypothesis are scattered in existing literature, although they have not been examined systematically. Here, we propose three hypotheses to analyze the impact of HSR on economic geography.

First, for service industries with high agglomeration economies, HSR improves integration of core areas with the market, or enlarges the market hinterland. In other words, non-core areas are no longer necessary to operate these industries independently, even if the products of such industries are non-tradable. Service industries with higher sunk costs for initial establishment, such as amusement parks (e.g., the Disneyland Park), musical productions, and high-end medical services, are not likely to have a layout in Sendai—the largest city of northern Honshu, 350 km away from Tokyo—if it is sufficiently convenient for people to travel between Tokyo and Sendai by HSR. People living in non-core areas may visit core cities—with reasonable time and monetary costs during the trip—when they need to use such services. However, if there was no HSR, such industries may abandon the Sendai market (or, Tohoku region) completely because people are not able to travel freely to the core area for service consumption. Instead, such industries may operate in Sendai but would be unprofitable due to high sunk costs and insufficient market size (lack of agglomeration economies), or the service price for consumers is higher than that in the core area.

Additionally, for the people whose hometowns are in non-core areas, HSR allows them to migrate to the core if they prefer big cities (more varieties of goods, better amenities, higher productivity, etc.) to small cities, but can still conveniently go back to their hometown to visit family and friends.

[Hypothesis I] *HSR may lead to agglomeration from non-core to core areas and, under these specific assumptions, non-core areas are expected to shrink*.[5]

Second, for non-core locations, which are close to the core (periphery of the core, e.g., locations less than 100 km away from the core area), an additional mechanism may work after the establishment of HSR. The high population and economic density in the core area may increase operational costs for firms and living costs for residents, so an advanced transit system may decentralize economic and residential activities from the core to its suburbs (Baum-Snow, 2007). With this decentralization, business and people can enjoy relatively low operational and living costs, but can still freely access the core area for necessary work, given the advanced transport facilities like HSR.

[Hypothesis II] *The suburbs of the core area are expected to expand following HSR operations, i.e., economic activities decentralize from the core to its periphery*.

Next, we assume that the impact of HSR is heterogeneous between the service and manufacturing sectors. In an economy dominated by the service sector, such as Japan, locations becoming increasingly dense in service sector activities are expected to crowd out manufacturing layouts due to rising urban costs, though the transportation of manufactured goods is less likely to be affected by HSR. Therefore, responding to HSR, the reallocation dynamics of the service and manufacturing sectors tend to be opposite.

[Hypothesis III] *If HSR leads to agglomeration from non-core to core areas for the service sector, then manufacturing is expected to be crowded out from the core to non-core areas.*

Based on these three hypotheses, we make a systematic and quantitative assessment of the comprehensive impact of HSR on economic geography.

3. BACKGROUND

Our quasi-experimental exercise depends on the timing of the development of the HSR network in Japan, which we detail in this section. We also examine the macroeconomic environment, including evolution of industry structure and population dynamics, both of which are potential confounding factors.

3.1. HSR Development in Japan

Japan has 47 prefecture level jurisdictions and more than 3,000 municipalities during most of our sample period.[6] Tokyo, the capital of Japan, is located near the country's geographic center and close to the east coast. Tokyo and 33 other prefectures are located in Honshu, the largest and most populous island of Japan (Figure 2). Honshu had a population of 103 million in 2014, approximately 80 percent of Japan's total population.

[PLACE FIGURE 2 HERE]

There were no plans to develop the HSR network until after the success of the Tokaido line, which was the first HSR track completed in 1964 to connect Tokyo and Osaka, the second largest city of Japan located 515 km south of the capital. The Tokaido line halved the travel time between the two cities from 8 hours on a conventional train to 4 hours. Improved HSR technology cut travel time further to 2.5 hours by 1992. Although the Tokaido line was built amid strong opposition, it turned out to be highly successful financially. Within the first three months, the service transported 11 million passengers (Japan Times, 1965).

With the success of the Tokaido line, in March 1965 a plan to extend the Tokaido line toward southern Japan through the Sanyo line was unveiled (Japan Times, 1965). The construction of the Sanyo line began in 1967 and commercial services started in 1972. A more ambitious nationwide HSR network plan was announced in 1967, including the two major lines of Tohoku and Joetsu, which connect Tokyo with major cities in northwestern and northern Japan, respectively (Japan Times, 1967). Ministerial approval for these two lines came through on January 1971, and construction began several months later (Japan Times, 1971). For the major parts of the lines, commercial services on the Omiya-Niigata (Joetsu line) and Omiya-Morioka (Tohoku line), began in 1982.

Measured by traffic volume, HSR has emerged as an attractive alternative passenger transportation mode in Japan on routes with a distance range of 400–1,000 km (Okada, 1994). In contrast to the rapid development in HSR network, there has been little additional investment in conventional railroads in Japan after the 1960s. Moreover, highway investment was also slow during our study period.

Our empirical exercises focus on the Tokaido, Tohoku, and Joetsu HSR lines (the Hokuriku line will be examined as an additional control group in the robustness check). Tokyo, which is the core area of Japan, is a common end city for these three lines. They accounted for 69 percent of Japan's HSR network in 1982 and 75–80 percent of the HSR passenger traffic of Japan during 1980–2003 (Japan Railway Company, 2010). The Tokaido line covers seven prefectures in southern Honshu (not including Tokyo). By 1980, passenger traffic on this line stabilized at around 83 million people per year (Japan Railway Company, 2010). The Joetsu line (270 km) covers three prefectures and the Tohoku line (466 km) covers six.[7] Annual traffic on these two lines was over 100 million passengers by 2000 (Japan Railway Company, 2010). Although new HSR lines were completed in the three decades following 1982, they were short distance routes accounting for less than 6 percent of total HSR traffic (Japan Railway Company, 2010).

The high population density and simple spatial structure of the HSR network in Japan provide a favorable empirical setting to test the economic impact of HSR. The cities along the southern lines (Tokaido line) offer a natural control group, while those along the northern routes (Tohoku and Joetsu lines) are the treatment group. The geographic scope of Japan conforms well to the competitiveness range of HSR: with Tokyo located in the middle of Honshu, the majority of cities are within 600 km of Tokyo. More importantly, Tokyo MA, including the four prefectures Tokyo, Kanagawa, Chiba, and Saitama, form the largest MA of Japan, with the population accounting for 24.5 percent of Japan's population in 1980 and 27.8 percent by 2010 (Data source: Japan Statistics Bureau).[8] This gives us a mono-center setting, which helps test the hypotheses.

3.2. Macroeconomic Environment

In this section, we examine the macroeconomic factors that could confound our empirical estimates, including economic cycles, spatial population movement due to non-HSR factors, and the evolving economic structure. After World War II, Japan's annual GDP averaged 10 percent during 1961–1970, but moderated to less than 5 percent between 1971 and 1990 (Data source: Japan Statistics Bureau). During 1985–1990, commercial land prices in large cities surged by 400 percent, but declined abruptly and sharply in 1991 and dropped by 80 percent in total in the following decade (Data source: Japan Real Estate Institute).[9] After 1991, Japan's economic growth stagnated, with annual GDP averaging around 1 percent (Data source: Japan Statistics Bureau). The economic structure of Japan shifted gradually toward the service sector during our study period. The employment share of agriculture, forestry, and manufacturing decreased from 34 to 22 percent in 1980–2005, while that of the service sector increased from 55 to 67 percent (Data source: Japan Statistics Yearbook).

On the demographic front, Japan witnessed a steady but gradual slowing of urbanization, with the urbanization rate increasing from 75.8 to 78.2 percent during 1980–2003 (Data source: Japan Urban Statistics Yearbook). The agglomeration toward Tokyo was evident, with the population share of Tokyo MA increasing from 24.5 to 26.7 percent, whereas that of Kyoto-Osaka-Kobe and Nagoya MAs stagnating or declining since the 1980s (Data source: Japan Statistics Yearbook). Consequently, Japan gradually developed into a Tokyo monopolar regional system (Fujita et al., 2004).

To summarize, we need to be cautious of several simultaneous macroeconomic trends during the study period. First, the growth slowdown, especially around 1991, followed by the surge and collapse of property prices nationwide. Second, the urbanization trend is more worrisome, as it can directly confound the agglomeration effect of HSR. These concerns are addressed in our empirical strategy, which is detailed in the following section.

4. EMPIRICAL STRATEGY

Using Japan as the empirical setting and the country's comprehensive data on demographics and employment, we propose to test the theoretical implications in section 2 with a DID methodology. In this section, we first present our dataset and a pre-test which demonstrates the overall impact of Japan's HSR network, and then discuss our identification strategy and model specification.

4.1. Data

Our database is compiled from several sources. It includes annual residential population from 1980 to 2003 at the municipality level, from 1960 to 2009 at the prefecture level, and employment from 1980 to 2000 at a five-year frequency at the municipality level.[10] In addition, we also obtain information on the longitude and latitude coordinates of the municipalities to calculate their respective geographical distances to central Tokyo. Data about the timing, construction, and operation of HSR, as well as location of HSR stations are based on publicly available reports.[11]

4.2. A Pre-test

Since prefecture level population estimates are available in our dataset for a relatively long period 1960–2009, we are able to observe the overall impact of HSR on the economic geography of Japan. Therefore, prior to the tests focusing on the Tokaido, Tohoku and Joetsu lines, we first present a pre-test which gives a comprehensive estimate of the HSR effects by considering all the HSR lines of Japan.

For this, we examine the event impacts of all HSR lines (i.e., Tokaido line in 1964, Sanyo line in 1972 and 1975, Tohoku and Joetsu lines in 1982 and 1985, as well as short-distance extension lines: Yamagata line in 1992, Akita and Hokuriku lines (Nagano part) in 1997).[12] The regression equation is as follows:

$$\ln(Y_{it}) = \alpha_0 + \sum_{p=-4}^{15} \gamma_p Year_{pit} + \sum_{p=-4}^{15} \psi_p Year_{pit} \times \ln(DST_i) + \eta_i + \mu_t + \varepsilon_{it}. \qquad \text{(R.1)}$$

The dependent variable is the logarithm of residential population for prefecture i at time t. *Year* is a dummy variable identifying the number of years for a prefecture since its first HSR operation. Specifically, $Year_{pit}$ takes the value of 1 for prefecture i in year t if year t is the p-th year after its first HSR operation (for 15 or more years after the first HSR operation, we unify p to 15). A negative p (from -4 through -1) is to capture the possible short-term anticipated effects of HSR, and $p \leq -5$ is set as the reference. We insert a distance measure ($\ln(DST_i)$, i.e., the logarithm of prefecture i's distance to Tokyo) with each *Year* dummy to capture the distance effect to test the agglomeration effects (toward Tokyo) of HSR. Prefecture and year fixed effects are controlled. Furthermore, we include prefecture-specific linear trends to relieve bias from the heterogeneity of prefecture level population growth trends.

Under this specification, we may examine whether Japan's HSR network has caused a nationwide agglomeration toward its capital Tokyo, in which case γ is expected to be positive and ψ is excepted to be negative for $p > 0$. Results based on HSR connectivity for 45 prefectures of Japan (excluding two outlying islands in the southern and northern ends of Japan: Hokkaido and Okinawa prefectures) are shown in Figure 3. Observably, the effect of HSR is most significant in the first few years after the first HSR began operations. Before, and more than a decade after, the HSR started operating, the related coefficients are insignificant and small in magnitude. For the period within a decade after the first HSR operations began, we find HSR-established prefectures that are close to Tokyo began expanding, while this effect dissipated as a prefecture's distance to Tokyo increases.

[PLACE FIGURE 3 HERE]

This estimation, although preliminary due to lack of sufficient comparison group and control variables, implies an observable and sharp HSR effect, which tends to agglomerate the country's population toward Tokyo. Given the quantitative evidence of the systematic HSR impacts, it is reasonable to carry on with further econometric analysis on the specific HSR lines in our sample.

4.3. Empirical Specification

Our main regression sample covers 13 prefectures. The treatment group includes seven prefectures along the *TJL*, namely Tochigi, Fukushima, Miyagi, Iwate, Aomori, Gunma, and Niigata, consisting of a total 515 municipalities. Our control group includes six prefectures along the Tokaido line (*TL*), namely Shizuoka, Gifu, Shiga, Aichi, Osaka, and Kyoto, comprising of 450 municipalities. Table A.1

provides summary statistics on the main variables. Jurisdictions along the *TJL* and *TL* are similar in terms of average distance to Tokyo. In terms of local population and employment size bands, those along the Tokaido line are larger than the treatment group, on average. Population has grown slowly in the control group, while shrinking modestly in the treatment group. The pattern of change in the industrial structure conforms to the theoretical implication: in jurisdictions along the *TJL,* employment growth in the service sector is slower, but growth in manufacturing employment is higher than in the control group (Table A.1).

Our baseline model estimates the impact of HSR on economic activities in non-core areas:

$$\ln(Y_{it}) = \alpha_0 + \alpha_1 TJL_i \times D_t^{1982} + X_{it} + \eta_i + \mu_t + \varepsilon_{it}. \qquad \text{(R.2)}$$

The dependent variable is the logarithm of economic activity indicators, such as residential population and employment, for municipality *i* at time *t*. On the right-hand side of the model, the variable TJL_i is a dummy variable that is equal to 1 if municipality *i* is in a prefecture with stations on the Tohoku or Joetsu lines and equal to 0 for prefectures along the Tokaido line. Another dummy variable D_t^{1982} indicates whether the observation is after 1982 (1 for years later than 1982 and 0 otherwise), as the Tohoku and Joetsu lines opened during this year (November 1982). The coefficient of the interaction of TJL_i and D_t^{1982}, α_1, measures the average treatment effect of *TJL* on local economic activities. α_1 has a negative sign if lower transport costs drive economic activities to agglomerate from non-core areas toward the core, Tokyo MA in our study **[Hypothesis I]**. In contrast, a positive α_1 indicates a dispersion effect. Note that Tokyo MA is eliminated automatically from the data sample as both the Tokaido and the Tohoku/Joetsu lines cover it. Hence, the DID operation will eliminate all observations in Tokyo MA.

In this empirical model, we control for municipality and year-fixed effects, represented by η_i

and μ_t, respectively. The unobserved heterogeneity such as macroeconomic shocks or policies would be eliminated under the DID framework, given the assumption that the effects are similar on both the control and treatment groups. To address the concern that this assumption may be violated in reality, we shall provide additional evidence on the hypotheses discussed in section 2.

Then, regarding the **Hypothesis II**, we propose the following specification by augmenting model (R.2) with the distance between a jurisdiction *i* and the core area Tokyo (DST_i):

$$\begin{aligned}\ln(Y_{it}) = \beta_0 + \beta_1 \ln(DST_i) \times TJL_i \times D_t^{1982} + \beta_2 TJL_i \times D_t^{1982} + \beta_3 \ln(DST_i) \times D_t^{1982} \\ + \eta_i + \mu_t + \varepsilon_{it}\end{aligned} \quad . \qquad \text{(R.3)}$$

We expect β_1 to have a negative sign and β_2 to be positive, as the economic scale of a municipality is more likely to be negatively impacted by the HSR if the municipality is further away from Tokyo, whereas the time-saving effect of *TJL* will have a positive effect on the local economic scale if the municipality is sufficiently close to Tokyo (i.e., *DST* is small).

Another implication is that the impact of HSR differs for the service and manufacturing sectors [**Hypothesis III**]. We can test this hypothesis by applying model (R.3) to the service and manufacturing sectors, respectively.

5. EMPIRICAL EVIDENCE

In this section, we present estimates on the spatial effects of HSR, as proposed in regression equations (R.2) and (R.3). Both short- and long-term effects are shown using different sample periods. In all regressions, test statistics based on robust standard errors clustered at the prefecture level are reported because it is reasonable to assume there are common and serially correlated shocks at the prefecture level (see a detailed discussion on this point in Bertrand et al. (2004)); to avoid overstating estimator precision due to insufficient number of clusters, we follow Donald and Lang (2007), and Cameron and Miller (2015) to use the *T* distribution with *N*-2 degrees of freedom, where

N is the number of prefectures (however, this probably still slightly overstates our precision). In addition, we report standard errors clustered at the municipality level in some specifications for reference.

5.1. Agglomeration or Dispersion: Effect by Distance

We first estimate model (R.2) for average effects of *TJL* on residential population in non-core municipalities. As shown in Figure 4, before the opening of the *TJL* in 1982, population of the treatment region was stable at a treatment/control region ratio (here we use prefecture level data since municipality level data are not available for the period prior to 1980) of 55.5 percent, but declined after HSR opened in 1982 to 53.2 percent in 2005. The expected HSR effect is reflected by the coefficient of the indicator for *TJL* completion in 1982 (Table 1). The estimate of this coefficient is negative and significant, implying that *TJL* reduced the population of non-core areas by 5 percent on average (column 1), consistent with the agglomeration trend toward core areas.

[PLACE FIGURE 4 HERE]

[PLACE TABLE 1 HERE]

A potential issue of this estimate is the pre-existing trends for migration before the opening of *TJL*. We may de-trend population data by subtracting the pre-1982 time trends in both the treatment and control groups. The municipality level data series have only two years of observations before 1982, therefore, we construct the pre-1982 trend by using prefecture level data (column 2).[13] With this approach, the estimated effect of *TJL* on the population slightly increases to 0.06. This estimate implies that approximately 800,000 residents in the treated regions migrated to Tokyo MA due to the *TJL*, that is, construction of the *TJL* increased Tokyo MA population by 3 percent, accounting for 12 percent of the increase from 1982 to 2003.[14]

Previous estimates are for long-term effects, two decades after the completion of *TJL*. A typical concern is that some other confounding factors arising during this period, such as the housing price collapse, may bias our estimates. To address this concern, we conduct a series of estimates for different sample time periods. To illustrate, columns 3 and 4 report the estimate for 1980–1985 and 1980–1990, covering three and eight years after the completion of *TJL,* respectively. The average impacts on population are estimated to be one-sixth and one-third of the estimate during 1980–2003, but remain statistically significant.

An important implication from section 2 is that the effect of HSR on a non-core area varies by its distance to the core area. To have a first-pass check of the hypothesis, we plot municipality level population growth rates during 1982–2003 against distances between the municipalities and Tokyo (Figure 5). Population growth of municipalities in the treated group shows a negative relation with the distance to Tokyo, while there is a flat (or slightly positive) relationship for the control group. Next, we examine the relationship more rigorously by estimating model (R.3) using de-trended municipality level data for 1980–2003. The coefficient of the three-way interaction between *TJL*, the D^{1982} indicators, and the distance to Tokyo is -0.09, meaning that the negative effect of *TJL* on the population of a non-core city becomes larger if it is further away from Tokyo (column 1 of Table 2). Together with the coefficient of the interaction of *TJL* and post-1982 indicators, 0.44, the model indicates that municipalities near Tokyo (within 133 km (= exp(0.44/0.09)) of central Tokyo) experienced population increase with the opening of *TJL*. In contrast, the population of more distant municipalities declined. This finding is consistent with our theoretical implication: the peripheral of the core area may benefit from spillover effects, attributable to the rising urban costs in the core city.

[PLACE FIGURE 5 HERE]

[PLACE TABLE 2 HERE]

As a robustness check, we conduct a regression using original municipality data without de-trending (column 2). The estimates are slightly smaller in magnitude, but show patterns similar to the previous regression. The implied "boundary" of the peripheral regions that benefit from the spillover effect in Tokyo MA is approximately 170 km from central Tokyo.

As shown in Figure 2, municipalities in the treatment group are remote to Tokyo. We estimate (R.3) using municipalities with a common support, namely, having similar distances to Tokyo. Results presented in column 3 are essentially unchanged. We also estimate for different sample time periods and find the aforementioned estimates robust, except that the impact of *TJL* is reduced in magnitude when the period is shorter. For example, estimates for the 1980–1985 and 1980–1990 periods are one-fourth and half of the two-decade estimates, respectively (columns 4 and 5).

In the foregoing exercises, we assume that the effects of HSR are similar on different people. Nevertheless, the working-age population should be much more responsive to HSR than youth and the aged. To test this implication, we group the population as youth (< 15 years old), aged (> 64 years old), and working age (15–64 years old), and run baseline regressions on each group separately (Table 3). Consistent with our expectation, we find that the estimate for working age population is the most significant in terms of magnitude (column 1), doubling that for the full sample. The estimated gradient of agglomeration is also steeper for the working age group (column 2). For the aged group, we find that HSR effects are highly insignificant (columns 5–6). Interestingly, for the youth we find a smaller but qualitatively similar effect as the working-age population (columns 3–4). This is because children migrate with their parents, while the elderly stay back. These findings by different age groups suggest that the patterns we find are likely to be job-related, but not due to the change of general living amenities.

[PLACE TABLE 3 HERE]

5.2. Impact by Sector

As discussed earlier, HSR has a direct impact on the service industries, while the effect on manufacturing industries is indirect and possible reverse to that for service. In this section, we test these implications using employment data disaggregated by sector and municipality levels. Municipality level employment data are available only from 1980 to 2000 at a five-year frequency. Therefore, we are not able to de-trend the employment data as we do for population. Nevertheless, according to our earlier findings, estimations based on both de-trended and original data show results that are similar both qualitatively and quantitatively.

Regression results are presented in Table 4. The average effect of HSR on employment in the service sector of non-core areas is -7 percent and statistically significant, which is consistent with agglomeration toward Tokyo (column 1). In contrast, the manufacturing sector decentralized due to HSR: employment in the manufacturing sector of non-core municipalities is estimated to increase by 21 percent after the opening of *TJL* (column 3).

[PLACE TABLE 4 HERE]

We then estimate the effect of *TJL* on municipalities with different distances to Tokyo (columns 2 and 4). Estimates for the service sector confirm the downward "gradients" in the *TJL* effect. According to the estimate, service sector employment increased in regions located within 171 km (= exp(0.72/0.14)) of Tokyo, but declined in those lying beyond; in contrast, the manufacturing sector demonstrates economic downsizing in areas within 111 km (= exp(0.99/0.21)) of Tokyo and economic upsizing for areas beyond.[15]

Moreover, we estimate using the disaggregate industry level employment for the service sector (columns 5–9). Results are highly consistent with the column 2 exercise except for *public service*. We find *public service*, which is expected to be less market-oriented and less sensitive to the scale economies of service provision, did not show a tendency of agglomeration to Tokyo MA during the period 1980–2000.

5.3. Robustness Checks

***Intraregional HSR Effect*.** Following a common empirical strategy employed in the literature, we examine the impact of HSR on municipalities with different distances to a *TJL* station (column 1 of Table 5). Dummy variables indicating whether a municipality lies within 60 km or beyond an HSR station are interacted with the indicator of HSR completion and *TJL* dummy. We find that municipalities within 60 km suffer the most from the impact of HSR, while municipalities that are 60 km or beyond *TJL* show an insignificant impact.

[PLACE TABLE 5 HERE]

Osaka Effect. Our major control group includes Osaka, the core of Japan's second largest MA, and this could affect our estimates for two reasons. First, given the size of Osaka, it could have significant economic linkages with its nearby areas. Second, the Sanyo line was completed in 1972 to extend the Tokaido line from Osaka further south of Japan (Fukuoka). Osaka being the largest city on this line could also experience agglomeration from jurisdictions along the Sanyo line. To address the potential confounding effects of Osaka, we check the robustness of our estimates by excluding Osaka (column 2 of Table 5). The estimates are generally consistent with our baseline results.

Alternative Control Group: Hokuriku Line. The control group of our baseline regressions includes prefectures along the *TL*, which were placed with HSR infrastructures earlier, but not later than *TJL*. A concern raised is that the *TL* municipalities considered in study period could enjoy some spillover effects due to the network effect caused by the extension of the overall HSR network. Thus, *TL* is not fully qualified as a control group in the DID setting. However, due to the peculiar shape of Honshu Island, during the study period we did not find sufficient control groups in southern Japan that are unconnected by the HSR and close to Tokyo MA.

As a robustness check, we consider an alternative control group, which includes jurisdictions along the Hokuriku line (Ishikawa, Nagano, and Toyama prefectures; see Figure 2). The Hokuriku line is a HSR line connecting three prefectures in the west to Tokyo and operated partly (117 km) since 1997; the route is extended to 345 km and has been in full operation since 2015 (Figure 6).[16] Both the regions covered by the Hokuriku line and the Joetsu line are located inland and mountainous.[17] Moreover, the Hokuriku line does not include large MAs, and this could affect our estimates. The disadvantage is that the Hokuriku line did not open until 1997. Hence, between 1982 and 1997, economic shocks to the Tokyo economy may have different spillover effects on jurisdictions along the Joetsu and the Hokuriku lines. In this case, the DID approach is not able to eliminate these confounding spillover effects.

[PLACE FIGURE 6 HERE]

The estimates using data from 1980–1996 are reported in Table 5 (columns 3–6) and they are all consistent with our baseline results. After the Joetsu line opened in 1982, municipalities along this line experienced notable population loss compared with that in regions along the planned Hokuriku line (column 3), and this effect is further confirmed with the de-trended population data (column 4). We also examine the effects of HSR by service and manufacturing sectors in columns 5–6. Service employment agglomerates to areas close to Tokyo, which is in line with our baseline results. For manufacturing, we find estimates under this specification become insignificant.

5.4. Identifying HSR Accessibility Using Travel Time Change

Our identification and measurement on accessibility of HSR and Tokyo MA are based primarily on HSR location at the prefecture level and distance to Tokyo at the municipality level. That is, we do not actually capture the impact of the time-saving element in economic re-distribution. We now turn to estimate using travel time as an alternative measurement and identification of HSR placement. The regression equation is as follows:

$$\ln(Y_{it}) = \alpha_1 \ln(traveltime_{it}) + \eta_i + \mu_t + \varepsilon_{it}\,. \qquad \text{(R.4)}$$

$\ln(traveltime_{it})$ is the logarithm of shortest travel time (in minutes) by rail to central Tokyo for municipality *i* in year *t*, and other variables are identical with those of equation (R.2). The estimated α_1 is referred to as the elasticity of economic agglomeration on travel time. Columns 1–3 of Table 6 present the results for population, service, and manufacturing employments, respectively, which are highly consistent with previous findings. Municipalities enjoying greater time saving by HSR suffered losses in population and service employment, while manufacturing employment expanded. According to column 1, the elasticity of time saving on population agglomeration is around 0.06. On average, HSR saves transit time by half from non-core regions to Tokyo, and these estimates suggest that HSR led to a 4 percent reduction in population in those regions. The magnitude is comparable with the results in previous sections for the same time period.

[PLACE TABLE 6 HERE]

In columns 4–6, we interact travel time with three distance dummies (within 150 km, 150–299 km, and 300–449 km to central Tokyo), respectively. Results are again consistent with that of Table 2. Municipalities located closer to Tokyo expanded from travel time saving (for municipalities within

150 km to Tokyo, the net effect is: -0.04 = 0.10-0.14; column 4) and those remote to Tokyo shrank.

5.5. Results of Synthetic Control Method

On the exogeneity of the treatment, the credibility of a quasi-experimental comparison (or a DID setup) relies on the assumption that the treatment and control groups followed the common trend in the absence of treatment. This is, however, not fully guaranteed in the previous analyses, because the pre-1982 trend is just controlled based on prefecture level data as municipality data prior to 1980 are not available. To ensure a valid evaluation of treatment effect, we create a comparison group consisting of synthetic controls to avoid problems arising in conventional DID analysis if the number of treated subjects (i.e., seven prefectures) is limited and common trend is not guaranteed.

We construct our comparison group using the synthetic control method (SCM), which was developed by Abadie and Gardeazabal (2003) and Abadie et al. (2010) and later widely adopted in empirical economics. For example, Ahlfeldt et al. (2017) use SCM to estimate the impact of HSR on the local economic levels in Germany, which is closely related to our paper. SCM aims at constructing a counterfactual unit of a treated unit using the weighted average of a set of controls, after which the outcomes of the treated and counterfactual units are compared to evaluate the treatment impact. To construct a highly comparable synthetic control, the weighted average of outcome variables and the relevant covariates of the control units in the pre-treatment periods should be as close as possible to those of a treated one.

In our case, we focus on the seven prefectures of *TJL*, which are set as the treated samples. The prefectures of Honshu that are not involved in the *TJL* (i.e., excluding the *TJL* region, Akita, Yamagata, Tokyo, and Saitama) are chosen as the donor prefectures (23 prefectures).[18] For each treated prefecture, its related synthetic control prefecture is constructed based on the pool of the 23 donor prefectures. We set the key outcome of interest as the prefecture level population index (population in 1981 = 1.00) during the period 1982–2003. Population index predictors are the population index for the period before treatment (1975–1981), population size (condition of economic scale), service employment share in total employment (condition of industrial structure), deficit revenue per capita (condition of public finance), unemployment rate (condition of employment market), and labor force rate in population (condition of population aging) in 1980. A synthetic prefecture should match its treated counterpart as closely as possible, specifically in terms of the above population growth predictors.

Following Abadie et al. (2010), we estimate the HSR treatment effect (α_t) on population index as $\widehat{\alpha_t} = p_t - \sum w_j p_{jt}$ for the years from 1982 to 2003, where p_t and p_{jt} are the population indices of a treated prefecture and a donor prefecture, weights w_j $(\sum w_j = 1)$ are chosen by minimizing the Mean Squared Prediction Error (MSPE), which depends on the pre-treatment values of predictor sets of population growth (MSPE is minimized over 1975–1981 for all the exercises; see the technique details in Abadie et al. (2010)).

We conduct seven independent exercises for the seven treated prefectures to construct the related synthetic controls.[19] The graphical results are shown in Figure 7 (summary statistics are show in Tables A.2 and A.3), which provides an overview of the comparisons between the actual and counterfactual trends we performed for the seven treated prefectures of *TJL*. In each panel, we plot the trend line of population index during the period 1970–2003 for the actual and counterfactual cases (i.e., estimated population growth trend in the absence of HSR, constructed by the weighted trends of donor prefectures).[20]

[PLACE FIGURE 7 HERE]

Compared with the synthetic control units, HSR placement led to a 6 percent decline in the population of Aomori and Iwate (the remotest *TJL* prefectures from Tokyo), Fukushima, Tochigi, Gunma and Niigata decreased by 2–4 percent, while Miyagi increased by 4 percent (Table 7). The impact was relatively weak in 1985 and 1990, as the residential reallocation took time to respond to HSR.

[PLACE TABLE 7 HERE]

Miyagi prefecture is the only prefecture of *TJL* that showed population increase due to the start of HSR operations. This is reasonable since Sendai (capital of Miyagi) is the largest city (population of 1.05 million in 2010) of northern Honshu and, therefore, it functions as a sub-core of the HSR network. Non-core areas of northern Honshu may agglomerate toward Sendai, in addition to Tokyo MA, thus expanding Miyagi.

Overall, the actual population size of *TJL* was 3 percent (approximately, 397,000 residents) lower than the case in the absence of HSR in 2003 (Table 7). The magnitude of HSR effect is half of that estimated in our DID approach using de-trended municipality level data (column 2 of Table 1).

In addition, we also present the synthetic control results for Saitama, which is one of the prefectures in Tokyo MA, and benefited most from the *TJL* (Tohoku line and Joetsu line converged on the Omiya station of Saitama). Although Saitama is not included in our regressions, it is expected to be a major "winner" of the *TJL*. Figure 7 suggests that Saitama showed strong population growth during the period 1970–2003. However, we find that Saitama showed stronger growth after 1982, compared with its synthetic controls (synthetic control is mainly constructed by two prefectures of Tokyo MA: Kanagawa (south of Tokyo) and Chiba (east of Tokyo)), implying that Saitama (north of Tokyo) grew more rapidly than the remaining areas of Tokyo MA in the post-1982 period because of

TJL. Based on the actual and synthetic population growth trends, Saitama prefecture (with 5.52 million residents in 1981) gained an additional 3 percent population by 2003 (approximately, 166,000). The balance of population loss of *TJL* (i.e., 231,000 = 397,000-166,000) is expected to be accommodated by the other areas of Tokyo MA.

6. CONCLUSION

This study shows that the spatial impact of HSR is not a simple polarization or diffusion relationship, but depends on the nature of industries and the distance between cities. We first propose theory-based hypotheses on the impact of HSR on economic geography. As HSR reduces the interregional travel costs for passengers, the service sector with agglomeration economies may cluster toward the core city if distance with the non-core city is larger; if the distance is sufficiently small, HSR leads to decentralization of the service sector because of spillover effects. The impact of HSR on the manufacturing sector may be the reverse, even though it is not directly affected by HSR. Specifically, when urban costs are present, HSR may push the manufacturing sector out of the core region toward the distant non-core areas.

These hypotheses are supported by our empirical evidence based on the municipality (or prefecture) level residential and employment data from Japan. We observe a significant trend of agglomeration of service industries toward Tokyo MA and its peripheral following the completion of HSR. In contrast, manufacturing industries decentralize toward distant non-core areas. They persist in both the short and long terms. The net impact of the new HSR increased the total scale of Tokyo MA by as much as 3 percent.

These findings reconcile contrasting findings in the literature: some researchers find that HSR leads to agglomeration, and some others show evidence of decentralization, depending on the sector and spatial scope examined by researchers. Moreover, this study has implications regarding growth strategies. One concern is inclusive growth. A common hypothesis of governments investing in HSR is to help improve the growth of distant regions. Although HSR may improve people's mobility and choice of service products, we find no evidence that employment increases in distant areas. In fact, remote non-core cities are likely to lose jobs in the service sector, and this is only partly offset by the decentralization of the manufacturing sector. Moreover, HSR could also affect the urbanization strategy of developing countries: surging HSR investments may generate significant economic agglomeration and formation of mega-cities due to further agglomeration in the service industries. This could have profound implications for urban policies on society, demographics, and environment in face of the rising wave of global HSR investments, especially in the developing countries.

ENDNOTES

[1] HS2 refers to a high-speed rail proposal in the UK, which is under preparatory work. Expected to be completed by 2026–2033, it proposes a new, dedicated "Y"-shaped high-speed rail network, initially between London and the West Midlands (Phase I) and then with "legs" to Manchester and Leeds (Phase II) (House of Commons, 2011).

[2] Existing theories analyzing the spatial impact of transport costs focus largely on the manufacturing sector (trade theory) and location preferences of residents (urban theory), and are motivated by traditional transport modes, especially trains and automobiles. Trade theory typically suggests that lower transport costs may lead to agglomeration (Krugman, 1991; Fujita et al., 1999; Ottaviano et al., 2002), while urban theory often finds a decentralization effect within transport cost reduction, such as the monocentric urban models of Alonso (1964) and Fujita (1989). In these models, the decrease in both within-region and interregional transport costs tend to induce agglomeration across regions. A series of empirical studies provide evidence on both theories (Baum-Snow, 2007; Faber, 2014; Baum-Snow et al., 2017).

[3] Econometric studies on the effect of *Shinkansen* on the distribution of economic activities in Japan are rare. Sasaki et al. (1997) uses simulation analysis to show that HSR will not necessarily contribute to regional dispersion. Mori (2012) observes that as the Tokaido line cut the Osaka–Tokyo travel time from 8 hours to 4 hours in 1964, the size of Tokyo relative to that of Osaka increased from 2.0 times in 1964 to 2.7 times in 2005. Case studies in Okada (1994) show that service industries such as tourism, conferences, and exhibitions benefit significantly from nearby HSR stations.

[4] If any, HSR is supposed to be used for weekend commuting, but not daily traveling.

[5] On the other hand, alternative mechanisms may work in a contradicting direction. For people who prefer small cities (less dense and cheaper living environments) to big cities, HSR allows them to work in the non-core areas by relieving the opportunity costs to be far away from the core. Such a scenario suggests that the operation of HSR tends to encourage dispersion from core to non-core areas. Our following empirical specification allows for testing which mechanism dominates (i.e., agglomeration or diffusion).

[6] This refers to our study period during 1980–2003. After 2003, the number of municipality level jurisdictions greatly decreased because of mergers.

[7] The Joetsu line was further extended to 301 km in 1985. The Tohoku line was further extended to 497 km, 593 km, and 675 km in 1985, 2002, and 2010, respectively.

[8] The second largest MA is the Kyoto-Osaka-Kobe MA (14.8 percent share of total population in 1980, and down to 14.4 percent in 2010, including four prefectures Kyoto, Osaka, Hyogo and Nara).

[9] Fluctuations in residential land prices were less strong, but still remarkable.

[10] Municipalities are identified by the five-digit administrative division code. Japan implemented a policy called the "Great Heisei Mergers" (*heisei-no-daigappei*) in 1999 to merge municipalities and to reduce the number of municipalities. However, large-scale mergers did not start until 2004. During 1999–2003, number of municipalities remained stable (3,232 in 1999 and 3,212 in 2003).

[11] See summary statistics in Table A.1.

[12] The Kyushu line started operations partly between Kagoshima-Chuo and Shin-Yatsushiro (southern part of Kyushu island) in 2004. The operated part is very short (less than 150 km) and disconnected with Japan's existing HSR network, we thus exclude this line in the event study approach.

[13] We first use prefecture level data from 1975 to 1980 to construct a (linear) projection of the population growth rate during 1980–2003 for each prefecture. We then de-trend the original municipality population data by subtracting them from the prefecture level population increase, implied by a pre-1982 trend. Here, we control for the pre-trend in 1975–1980, but not 1970–1980 or 1960–1980 because the Tokaido HSR line in the control group was established in 1964, and population dynamics of *TL* before 1975 tend to be affected by its reallocation cycle responding to the HSR. It is still possible that the reallocation cycle of *TL* has not yet reached steady status even during our study period; hence, we provide additional evidence utilizing alternative control groups (Sections 5.3 and 5.5).

[14] During 1982–2003, population of Tokyo MA increased from 28.7 to 35.5 million.

[15] For estimates using employment data to be comparable with those using population data, we repeat the regression for population using observations in the same years as those for employment data. We find that the estimate for this sub-sample of population is almost the same as that for the full sample (results are available upon request).

[16] Hokuriku line shares the same track with the Joetsu line for the section from Takasaki to Tokyo, as shown in Figure 6.

[17] For comparability, we keep only the prefectures along the Joetsu line as the treatment group in this study.

[18] Akita, Yamagata, Tokyo, and Saitama are affected by the *TJL* severely, although they are not included in the treatment group. Geographically, Akita and Yamagata are surrounded by *TJL* prefectures, and Tokyo and Saitama (prefectures of Tokyo MA) are connected by the *TJL*.

[19] We use the Stata ado file "*synth*" compiled by Abadie, Diamond, and Hainmueller to generate the synthetic control prefectures.

[20] The predictors of SCM include the population index of 1975–1981. Population index of synthetic control units in 1970–1974 and 1982–2003 are constructed by the related weight of donor prefectures.

REFERENCES

Abadie, Alberto, Alexis Diamond, and Jens Hainmueller (2010). Synthetic Control Methods for Comparative Case Studies: Estimating the Effect of California's Tobacco Control Program, *Journal of the American Statistical Association*, 105: 493–505.

Abadie, Alberto and Javier Gardeazabal (2003). The Economic Costs of Conflict: A Case Study of the Basque Country, *American Economic Review*, 93: 113–132.

Ahlfeldt, Gabriel M. and Arne Feddersen (2017). From Peripheral to Core: Measuring Agglomeration Effects Using High-Speed Rail, *Journal of Economic Geography*, forthcoming. doi:10.1093/jeg/lbx005

Alonso, William (1964). *Location and Land Use*. Cambridge: Harvard University Press.

Baum-Snow, Nathaniel (2007). Did Highways Cause Suburbanization? *Quarterly Journal of Economics*, 122: 775–805.

Baum-Snow, Nathaniel, Loren Brandt, Vernon Henderson, Matthew A. Turner, and Qinghua Zhang (2017). Roads, Railroads and Decentralization of Chinese Cities, *The Review of Economics and Statistics*, 99: 435–448.

Bertrand, Marianne, Esther Duflo, and Sendhil Mullainathan (2004). How Much Should We Trust Differences-in-Differences Estimates? *Quarterly Journal of Economics*, 119: 249–276.

Cameron, Colin and Douglas L. Miller (2015). A Practitioner's Guide to Cluster-Robust Inference, *Journal of Human Resources*, 50: 317–372.

Chen, Chia-Lin and Peter Hall (2011). The Impacts of High-Speed Trains on British Economic Geography: A Study of the UK's InterCity 125/225 and Its Effects, *Journal of Transport Geography*, 19: 689–704.

Donald, Stephen G. and Kevin Lang (2007). Inference with Difference-in-Differences and Other Panel Data, *The Review of Economics and Statistics*, 89: 221–233.

Faber, Benjamin (2014). Trade Integration, Market Size, and Industrialization: Evidence from China's National Trunk Highway System, *Review of Economic Studies*, 81: 1046–1070.

Fujita, Masahisa (1989). *Urban Economic Theory: Land Use and City Size*. Cambridge: Cambridge University Press.

Fujita, Masahisa, Paul Krugman, and Anthony J. Venables (1999). *The Spatial Economy: Cities, Regions, and International Trade*. Cambridge: The MIT Press.

Fujita, Masahisa, Tomoya Mori, Vernon Henderson, and Yoshitsugu Kanemoto (2004). Spatial Distribution of Economic Activities in Japan and China, *Handbook of Regional and Urban Economics*, in: Vernon Henderson, Jacques-François Thisse (ed.), edition 1, vol. 4, chapter 65, 2911–2977.

Garcia-López, Miquel‐Àngel, Camille Hémet, and Elisabet Viladecans-Marsal (2017). How Does Transportation Shape Intrametropolitan Growth? An Answer from the Regional Express Rail, *Journal of Regional Science*, 57: 758–780.

House of Commons (2011). High Speed Rail: Tenth Report of Session 2010–12. London: House of Commons.

Japan Railway Company (2010). Japan High Speed Rail Passenger Traffic Statistics. Tokyo.

Japan Times (1965). New Tokaido will Reach Hakata in 1975. March 20, 1965: 4.

Japan Times (1967). JNR Reveals 20-Yr. Plan for more "Bullet Trains". September 1, 1967: 4.

Japan Times (1971). Move on New Tohoku Line Seen Soon. October 2, 1971: 3.

Krugman, Paul (1991). Increasing Returns and Economic Geography, *Journal of Political Economy*, 99: 483–499.

Mori, Tomoya (2012). Increasing Returns in Transportation and the Formation of Hubs, *Journal of Economic Geography*, 12: 877–897.

Murakami, Jin and Robert Cervero (2012). High-Speed Rail and Economic Development: Business Agglomeration and Policy Implications. Working Paper, UC Berkeley.

Okada, Hiroshi (1994). Features and Economic and Social Effects of The Shinkansen, *Japan Railway and Transport Review*, 10: 9–16.

Ottaviano, Gianmarco I.P., Takatoshi Tabuchi, and Jacques-François Thisse (2002). Agglomeration and Trade Revisited, *International Economic Review*, 43: 409–436.

Qin, Yu (2017). 'No County Left Behind?' The Distributional Impact of High-Speed Rail Upgrades in China, *Journal of Economic Geography*, 17: 489–520.

Sasaki, Komei, Tadahiro Ohashi, and Asao Ando (1997). High-Speed Rail Transit Impact on Regional Systems: Does the Shinkansen Contribute to Dispersion? *Annals of Regional Science*, 31: 77–98.

US High Speed Rail Association (2014). High Speed Lines in The World. http://www.uic.org/IMG/pdf/20140901_high_speed_lines_in_the_world.pdf

Zheng, Siqi and Matthew E. Kahn (2013). China's Bullet Trains Facilitate Market Integration and Mitigate the Cost of Mega City Growth, *Proceedings of the National Academy of Sciences of the United States of America (PNAS)*, 110: 1248–1253.

TABLE 1: Average impact of *TJL*

	(1)	(2)	(3)	(4)
	ln(pop)			
TJL*(year>1982)	-0.05 (0.02)** [0.01]***	-0.06 (0.03)** [0.01]***	-0.01 (0.01)* [0.00]***	-0.02 (0.01)** [0.00]***
De-trend	N	Y	Y	Y
Period	1980–2003	1980–2003	1980–85	1980–90
N	22,624	22,624	5,636	10,340
R^2	0.023	0.034	0.134	0.111

Notes: Dependent variable is the logarithm of population at municipality level. All data are at annual frequency. All regressions control for municipality and year fixed effects. The constant term coefficients are not reported (same as in the other tables). R-square excludes the effect of fixed-effect dummies. Robust standard errors (clustered at prefecture level) in parentheses, robust standard errors (clustered at municipality level) in bracket: $^{*}p< 0.1$, $^{**}p< 0.05$, $^{***}p< 0.01$. In the case that the standard errors are clustered at prefecture level, the *t*-value cutoff for being statistically significant is set as 1.796, 2.201, and 3.106 (*T* distribution with 11 degrees of freedom: Number of prefectures - 2) for *, **, and ***, respectively. This also applies for Tables 2, 3, 4, 6, and column 1 of Table 5.

TABLE 2: Impact of *TJL* by distance to Tokyo

	(1)	(2)	(3)	(4)	(5)
			ln(pop)		
TJL*(year>1982)	0.44	0.41	0.62	0.11	0.20
	(0.28)	(0.13)***	(0.29)*	(0.07)	(0.12)
	[0.10]***	[0.09]***	[0.12]***	[0.03]***	[0.05]***
TJL*(year>1982)	-0.09	-0.08	-0.13	-0.02	-0.04
*ln(DST)	(0.05)*	(0.02)***	(0.05)**	(0.01)*	(0.02)*
	[0.02]***	[0.02]***	[0.02]***	[0.01]***	[0.01]***
De-trend	Y	N	Y	Y	Y
Symmetry	N	N	Y	N	N
Period	1980–2003	1980–2003	1980–2003	1980–85	1980–90
N	22,624	22,624	19,742	5,636	10,340
R^2	0.041	0.042	0.048	0.146	0.123

Notes: All data are at annual frequency. Dependent variable is the logarithm of population at municipality level. All regressions control for municipality and year fixed effects. The coefficient of term ln(DST) * (year>1982) is not reported for succinct presentation (same as in the other tables). Symmetry: restrict samples to jurisdictions with similar distances to Tokyo in both the treatment and control groups. R-square excludes the effect of fixed-effect dummies. Robust standard errors (clustered at prefecture level) in parentheses, robust standard errors (clustered at municipality level) in bracket: $^{*}p<0.1$, $^{**}p<0.05$, $^{***}p<0.01$.

TABLE 3: Heterogeneity of the HSR Effects in terms of age

	(1)	(2)	(3)	(4)	(5)	(6)
	ln(pop): age 15–64		ln(pop): age <15		ln(pop): age >64	
TJL*(year>1982)	-0.10*	2.19***	-0.03	1.28	-0.01	-0.07
	(0.05)	(0.57)	(0.02)	(0.78)	(0.03)	(0.42)
TJL*(year>1982)*ln(DST)		-0.41***		-0.24		0.01
		(0.10)		(0.14)		(0.08)
N	14,575	14,575	14,477	14,477	14,575	14,575
R^2	0.091	0.107	0.728	0.729	0.929	0.929

Notes: Data are not de-trended. Time coverage: 1980–2003 at annual frequency. All regressions control for municipality and year fixed effects. R-square excludes the effect of fixed-effect dummies. Robust standard errors (clustered at prefecture level) in parentheses: $^{*}p< 0.1$, $^{**}p< 0.05$, $^{***}p< 0.01$.

TABLE 4: Impact of *TJL* by service and manufacturing industries

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	ln(service employ)		ln(manu. employ)		ln(service employ)				
					RWC	FIRE	Trans.	Public	General
TJL*(year>1982)	-0.07^{*}	0.72^{***}	0.19^{***}	-0.99^{**}	0.35	1.05^{**}	1.42^{**}	0.06	1.06^{***}
	(0.03)	(0.18)	(0.05)	(0.38)	(0.23)	(0.40)	(0.54)	(0.14)	(0.14)
TJL*(year>1982) *ln(DST)		-0.14^{***}		0.21^{**}	-0.08^{*}	-0.20^{***}	-0.27^{**}	-0.02	-0.20^{***}
		(0.03)		(0.07)	(0.04)	(0.07)	(0.10)	(0.02)	(0.02)
N	4,714	4,714	4,714	4,714	4,714	4,714	4,714	4,714	4,714
R^2	0.472	0.487	0.188	0.198	0.134	0.126	0.131	0.224	0.667

Notes: Data are not de-trended. Time period is 1980–2000 at five-year frequency. All regressions control for municipality and year fixed effects. “service employ” contains the aggregated employment of retail, wholesale, and catering (RWC), finance, insurance, and real estate (FIRE), transportation and telecom (Trans.), public service (Public), and the other unclassified services (General). For the municipalities with zero employment in a specific industry, the related employment is set as 1, that is, ln(employment) = 0. R-square excludes the effect of fixed-effect dummies. Robust standard errors (clustered at prefecture level) in parentheses: $^{*}p< 0.1$, $^{**}p< 0.05$, $^{***}p< 0.01$.

TABLE 5: Estimates with modified (alternative) control groups

	(1)	(2)	(3)	(4)	(5)	(6)
	ln(pop)	ln(pop)	ln(pop)	ln(pop)	ln(service employ)	ln(manu. employ)
JL*(year>1982)		0.36^{**} (0.15)	0.33^{**} (0.09)	0.48^{**} (0.11)	0.63^{***} (0.09)	0.53 (0.52)
JL*(year>1982) *ln(DST)		-0.07^{**} (0.03)	-0.07^{**} (0.02)	-0.10^{**} (0.02)	-0.12^{***} (0.02)	-0.08 (0.10)
TJL*(year>1982) *HSR (<60km)	-0.06^{**} (0.02)					
TJL*(year>1982) *HSR (≥60km)	-0.03 (0.04)					
(year>1982) *HSR (<60km)	0.02 (0.02)					
(year>1982) *HSR (≥60km)	-0.01 (0.04)					
De-trend	N	N	N	Y	N	N
Samples: Treated&Control	TJL&TL	TJL&TL (ex Osaka)	JL&HL	JL&HL	JL&HL	JL&HL
Period	1980–2003	1980–2003	1980–96	1980–96	1980–95	1980–95
Data frequency	annual	annual	annual	annual	five-year	five-year
N	22,624	21,042	6,290	6,290	1,480	1,480
R^2	0.025	0.045	0.048	0.048	0.466	0.150

Notes: All regressions control for municipality and year fixed effects. *JL*: Niigata and Gunma prefectures, which are along the Joetsu line; *HL*: Toyama, Nagano and Ishikawa prefectures, which are along the Hokuriku line. R-square excludes the effect of fixed-effect dummies. Robust standard errors (clustered at prefecture level) in parentheses: $^{*}p< 0.1$, $^{**}p< 0.05$, $^{***}p< 0.01$. For column 2, the t-value cutoff for being statistically significant is set as 1.812, 2.228, and 3.169 (T distribution with 10 degrees of freedom) for *, **, and ***, respectively, as the number of sample prefectures is 12. For similar reasons, in columns 3–6, the t-value cutoffs for being statistically significant are set as 2.353, 3.182, and 5.841 (three degrees of freedom), as the number of sample prefectures is five.

TABLE 6: Alternative measurement of HSR connection: travel time

	(1)	(2)	(3)	(4)	(5)	(6)
	ln(pop)	ln(service employ)	ln(manu. employ)	ln(pop)	ln(service employ)	ln(manu. employ)
ln(travel time)	0.06**	0.09***	-0.23***	0.10***	0.11***	-0.33***
	(0.02)	(0.03)	(0.05)	(0.01)	(0.02)	(0.06)
ln(travel time)* Tokyo (<150km)				-0.14***	-0.21***	0.06
				(0.02)	(0.03)	(0.06)
ln(travel time)* Tokyo (150–299km)				-0.05*	-0.02	0.16***
				(0.02)	(0.03)	(0.05)
ln(travel time)* Tokyo (300–449km)				-0.07***	-0.04	0.13**
				(0.01)	(0.03)	(0.06)
N	22,624	4,714	4,714	22,624	4,714	4,714
R^2	0.027	0.476	0.199	0.040	0.486	0.207

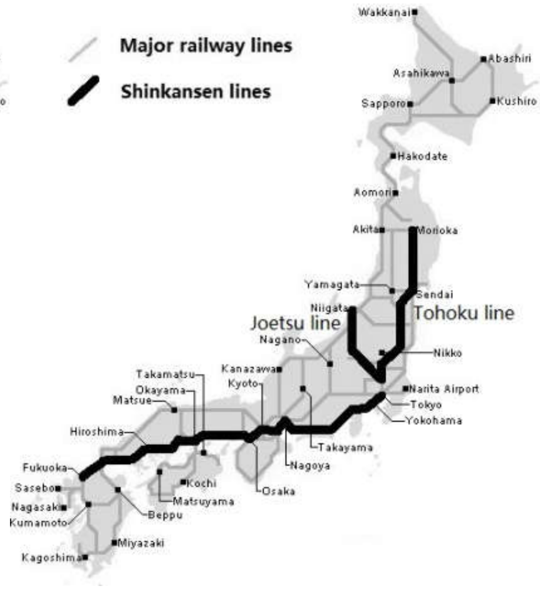
Notes: ln(*travel time$_{it}$*): logarithm of the shortest travel time to Tokyo for municipality *i* (in minutes) through rail in year *t*. Samples: *TJL* & *TL*. We use the travel time data of 1980 to proxy the travel time for the period 1980–1982, that of 1983 to proxy 1983–1985, and that of 1986 to proxy 1986–2003. For other years in the study period, the travel time change is limited for *TJL* region. For the control group *TL*, the travel time change is limited in the study period (Data source: Japan Train Time Table 1980, 1983, 1986). Tokyo(<150km; 150–299km; 300–449km) are dummy variables take the values as 1 for the municipalities located in the related distance range to Tokyo, and 0 otherwise. Data are not de-trended. Time coverage: 1980–2003 at annual frequency for population and 1980–2000 at five-year frequency for employment. All regressions control for municipality and year fixed effects. R-square excludes the effect of fixed-effect dummies. Robust standard errors (clustered at prefecture level) in parentheses: $^{*}p< 0.1$, $^{**}p< 0.05$, $^{***}p< 0.01$.

TABLE 7: Comparison between treated and synthetic control samples

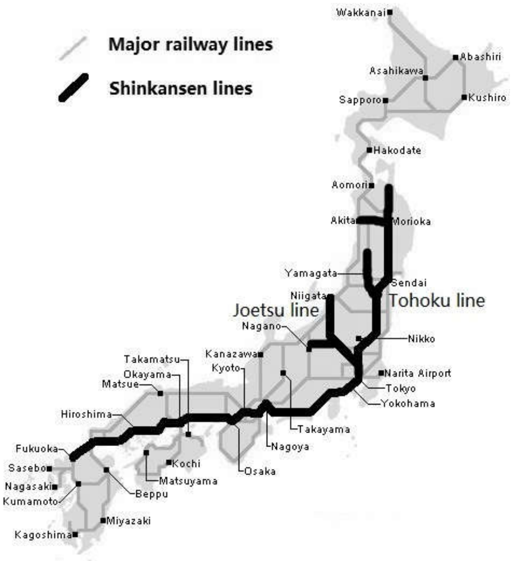
Prefecture	Pop. in 1981 (million)	ΔPop. index (treated$_t$-synth.$_t$) (pop. index 1981=1.00)		
		1985	1990	2003
Aomori	1.53	-0.01	-0.04	-0.06
Iwate	1.43	-0.01	-0.04	-0.06
Miyagi	2.10	0.00	0.01	0.04
Fukushima	2.04	0.00	0.00	-0.03
Tochigi	1.81	0.00	0.00	-0.02
Gunma	1.86	0.00	-0.01	-0.03
Niigata	2.46	-0.01	-0.04	-0.04
Saitama	5.52	0.00	0.02	0.03
		ΔPop. (treated$_t$-synth.$_t$)/Pop.$_{1981}$		
		1985	1990	2003
TJL (sum of seven pref.)	13.23	-0.00	-0.02	-0.03

Notes: Population index of 1981 is set as the baseline (= 1.00). Related data are obtained and calculated based on the results of Figure 7. Saitama is not included in *TJL* since it is a prefecture of Tokyo MA. ΔPop.index(treated$_t$-synth.$_t$) = Pop. index of treated prefecture in year *t* - Pop. index of related synthetic control unit in year *t*. ΔPop.(treated$_t$-synth.$_t$)/Pop.$_{1981}$ = (Population of *TJL* in year *t* - (counterfactual) Population of *TJL* in year *t* based on the population growth trend as predicted by the synthetic control units)/ Population of *TJL* in 1981.

(a) 1980



(b) 1982



(c) 2003

FIGURE 1: Japan HSR network in 1980, 1982, 2003

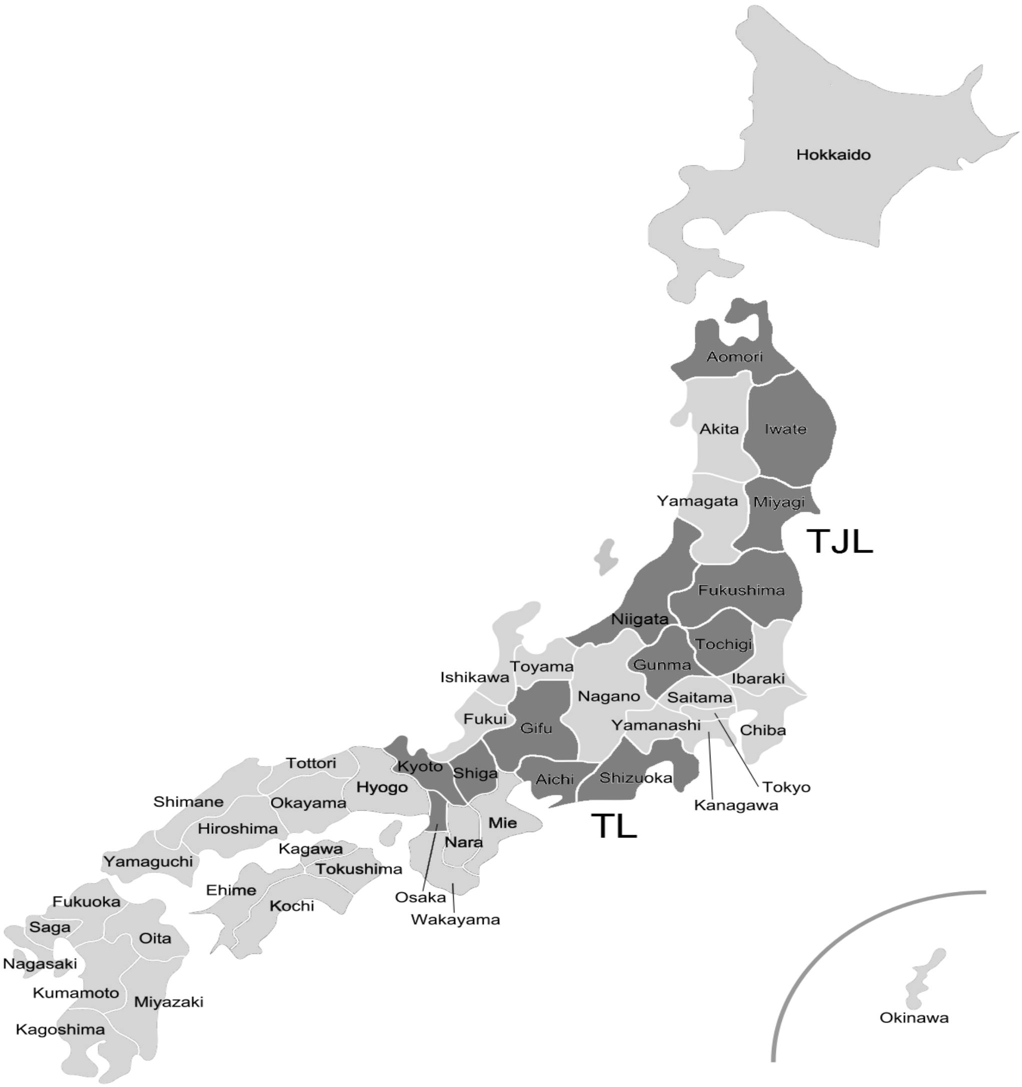


FIGURE 2: Sample prefectures

Notes: Prefectures connected by Tohoku and Joetsu lines (*TJL*) are Tochigi, Niigata, Gunma, Fukushima, Miyagi, Iwate, Aomori; Prefectures connected by Tokaido line (*TL*) are Shizuoka, Aichi, Gifu, Shiga, Kyoto, and Osaka.

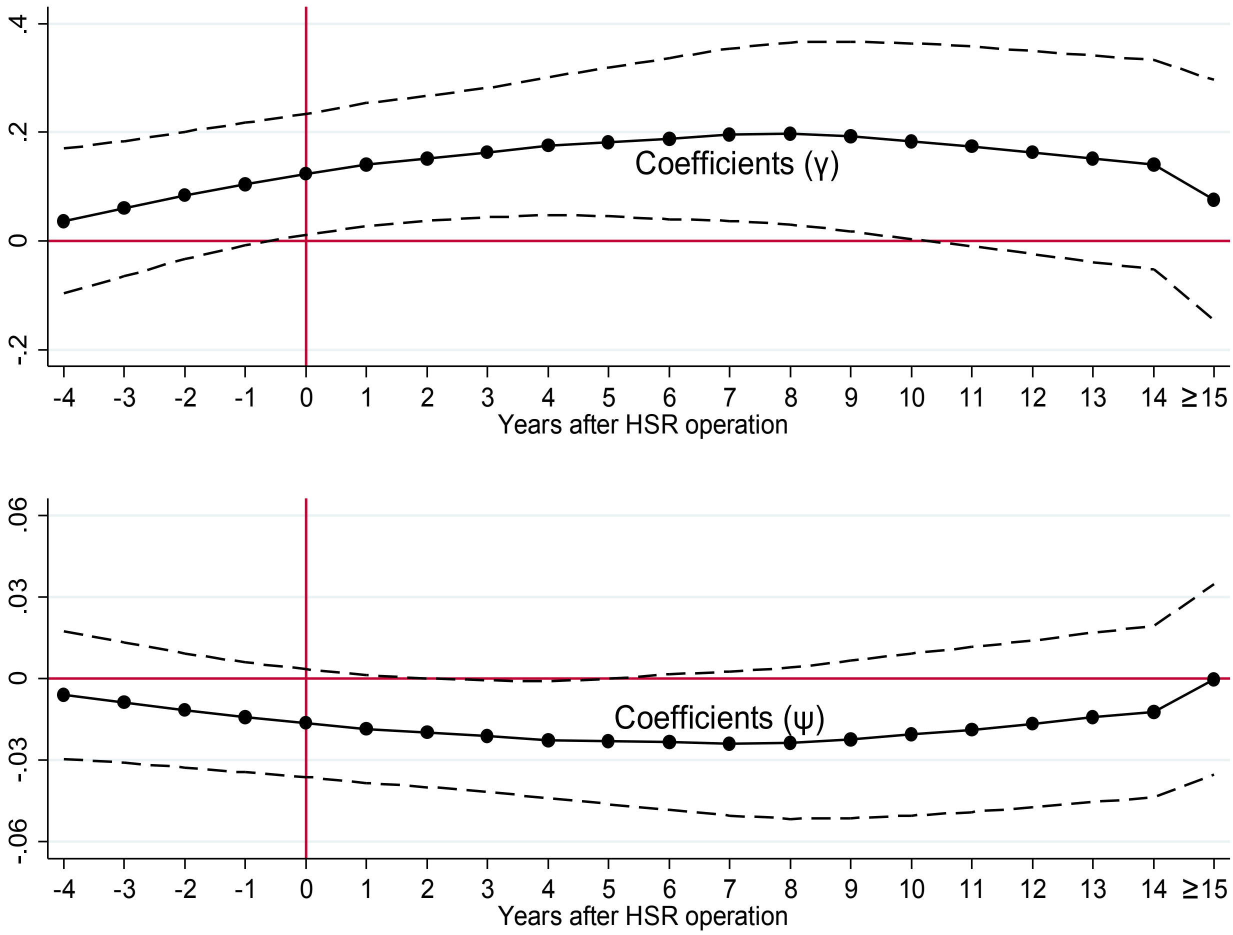


FIGURE 3: A comprehensive test for the time paths of HSR effects

Notes: The top graph presents the estimates of γ of equation (R.1) and the bottom graph shows the coefficients of ψ; the dashed lines are the related 90 percent confidence intervals calculated using robust standard errors clustered at prefecture level (the *t*-value cutoff is set based on a *T* distribution with 43 degrees of freedom; see the first parapraph of section 5 for more details). The vertical reference line refers to the year that the first HSR line of the treated prefectures started operation. Our specifications include prefecture and year fixed effects, as well as prefecture-specific linear trend.

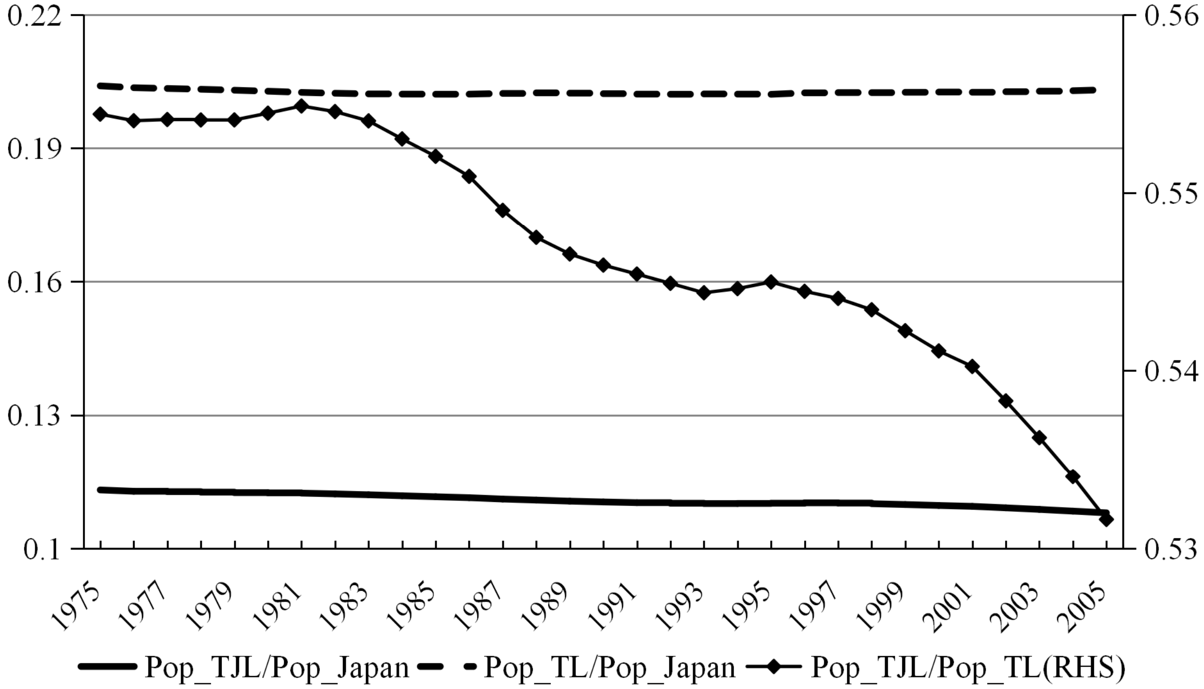


FIGURE 4: Population share of treatment and control regions

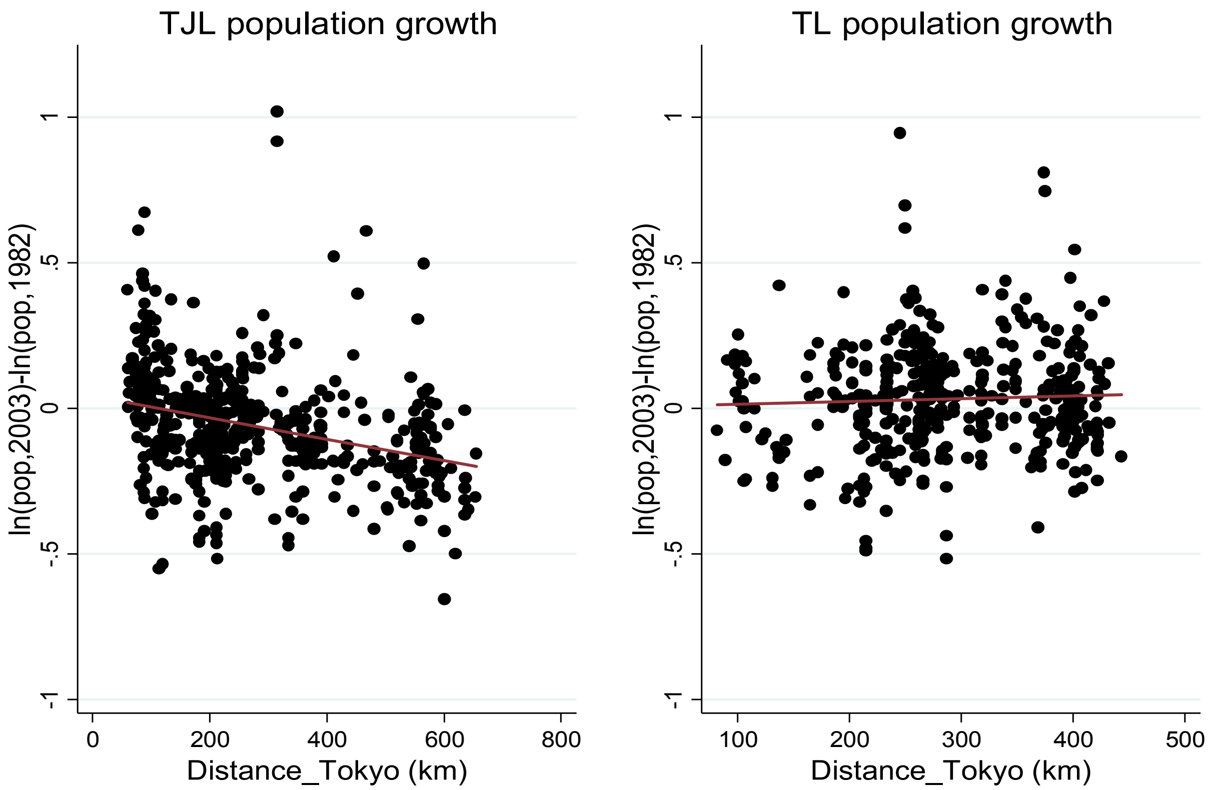


FIGURE 5: Population growth in treatment and control municipalities (*TJL* vs. *TL*)

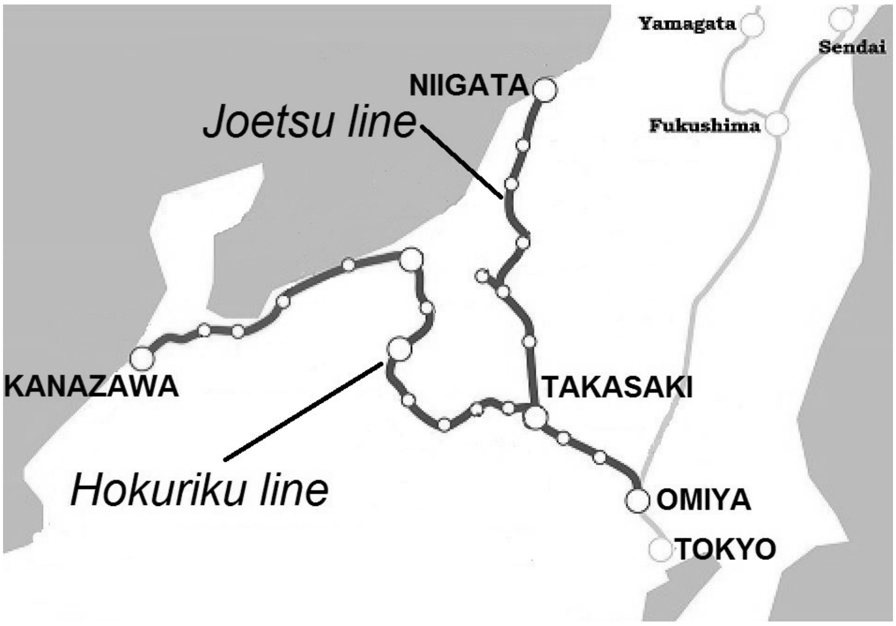


FIGURE 6: Impact of Joetsu line: taking the planned Hokuriku line as the control

Notes: In our robustness tests, we consider only the part of Joetsu line between Niigata and Takasaki as the treated area (i.e., Gunma and Niigata), because the Joetsu line overlaps with the Hokuriku line between Takasaki and Tokyo.

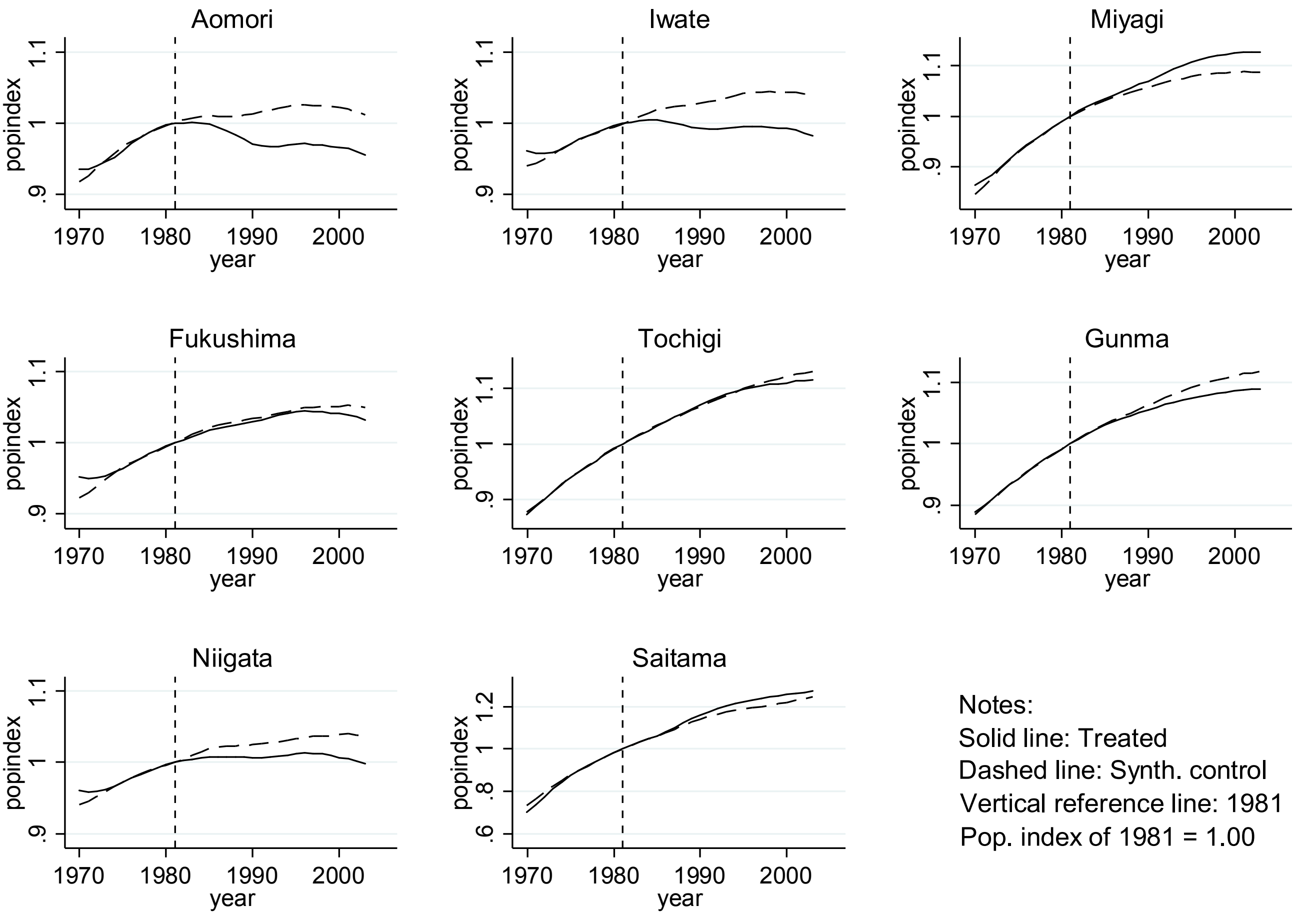


FIGURE 7: Results of synthetic control methods (*TJL* and Saitama prefecture)

TABLE A.1: Descriptive summary of dataset

	Tohoku and Joetsu lines (treatment)			Tokaido line (control)		
No. of prefectures		7			6	
No. of municipalities		515			450	
	Obs.	Mean	Std. dev.	Obs.	Mean	Std. dev.
Distance to Tokyo (km)	515	280	158	450	287	86
Population (pref. level, thou.)	168	1,845	407	144	4,091	2,585
Population (muni. level)	12,181	24,689	47,377	10,443	55,816	86,061
# Age 15–64 (% of population)	8,086	62.4	4.8	6,489	65.7	5.7
# Age >64 (% of population)	8,086	19.3	6.1	6,489	16.0	6.3
# Age <15 (% of population)	8,086	17.1	3.2	6,391	18.0	3.5
Employ-service (% of total employment)	2,538	39.4	12.8	2,176	46.9	14.3
Employ-manufacturing (% of total employment)	2,538	21.9	11.3	2,176	31.2	13.5
Population growth (%, annual)	11,666	-0.28	1.22	9,993	0.15	1.34
Employ growth-service (%, five-year)	2,027	5.80	10.10	1,735	7.94	9.83
Employ growth-manufacturing (%, five-year)	2,027	3.64	23.00	1,735	-2.20	16.72
Service-manufacturing employment ratio	2,538	3.04	5.51	2,176	2.32	3.22
Employ-manufacturing	2,538	2,802	5,420	2,176	8,255	13,092
Employ-retail, wholesale and catering	2,538	2,420	7,037	2,176	6,962	15,232
Employ-finance, insurance and real estate	2,538	320	1,314	2,176	1,163	3,916
Employ-transportation and telecom	2,538	609	1,785	2,176	1,766	3,488
Employ-public service	2,538	413	1,095	2,176	756	1,633
Employ-general service	2,538	2,478	6,523	2,176	6,095	11,697
Travel time to Tokyo by rail (minute)	12,181	143.2	98.7	10,443	157.1	39.3

Notes: Municipality level population data are at annual frequency in 1980–2003 (1981–2003 for annual population growth data); municipality level employment data are at five-year frequency, 1980, 1985, 1990, 1995, 2000 (1985, 1990, 1995, 2000 for employment growth data). Data source: 1) Data of residential population are from "Residential Population Survey" conducted by Local Administration Bureau, Ministry of Internal Affairs and Communications annually from 1980–2003; Annual data for prefecture level population are from "Historical Statistics of Japan," Statistics Bureau, Ministry of Internal Affairs and Communications; 2) Data on employment by industry are from "Population Census of Japan" by Statistics Bureau, Ministry of Internal Affairs and Communications; 3) Longitude and latitude data for each municipality are obtained from Center for Spatial Information Science, The University of Tokyo (CSV Address Matching Service), by which we calculate municipality's distance to core Tokyo; 4) Data on travel time are estimated based on the historical Train Time Tables of Japan.

TABLE A.2: Synthetic control predictors

	Aomori		Iwate		Miyagi		Fukushima	
	Treat	Synth.	Treat	Synth.	Treat	Synth.	Treat	Synth.
Pop. index (1975–1981)	0.98	0.99	0.99	0.99	0.97	0.97	0.98	0.98
Population (1980) (million)	1.52	2.06	1.42	0.86	2.08	2.08	2.04	1.99
Service employ. share (1980)	0.52	0.54	0.47	0.49	0.56	0.56	0.45	0.49
Deficit revenue p.c. (1980)	80.08	62.5	85.36	76.41	42.12	42.19	57.06	56.92
Pop. in labor force/pop. (1980)	0.49	0.47	0.52	0.52	0.49	0.48	0.52	0.51
Unemployment rate (1980)	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02
	Tochigi		Gunma		Niigata		Saitama	
	Treat	Synth.	Treat	Synth.	Treat	Synth.	Treat	Synth.
Pop. index (1975–1981)	0.97	0.97	0.97	0.97	0.99	0.99	0.94	0.94
Population (1980) (million)	1.79	2.12	1.85	2.28	2.45	2.24	5.42	4.93
Service employ. share (1980)	0.45	0.47	0.46	0.47	0.48	0.48	0.50	0.54
Deficit revenue p.c. (1980)	37.77	39.93	35.71	38.41	62.94	59.48	18.41	20.51
Pop. in labor force/pop. (1980)	0.51	0.51	0.51	0.51	0.53	0.53	0.46	0.47
Unemployment rate (1980)	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02

Notes: Population index of 1981 is set as 1.00. Deficit revenue p.c. = Deficit revenue/population (thousand JPY); All the data are from "Historical Statistics of Japan," Statistics Bureau, Ministry of Internal Affairs and Communications.

TABLE A.3: The weights of donor prefectures in synthetic control units

Aomori		Iwate		Miyagi		Fukushima	
Pref.	*Weight*	*Pref.*	*Weight*	*Pref.*	*Weight*	*Pref.*	*Weight*
Chiba	0.144	Fukui	0.480	Chiba	0.078	Fukui	0.389
Osaka	0.060	Yamanashi	0.304	Kanagawa	0.001	Nagano	0.102
Wakayama	0.797	Wakayama	0.215	Ishikawa	0.374	Shizuoka	0.058
				Aichi	0.044	Mie	0.267
				Kyoto	0.309	Osaka	0.084
				Nara	0.194	Wakayama	0.100
Tochigi		**Gunma**		**Niigata**		**Saitama**	
Pref.	*Weight*	*Pref.*	*Weight*	*Pref.*	*Weight*	*Pref.*	*Weight*
Nagano	0.216	Toyama	0.042	Fukui	0.225	Chiba	0.595
Shizuoka	0.309	Nagano	0.129	Nagano	0.468	Kanagawa	0.287
Mie	0.178	Shizuoka	0.388	Wakayama	0.307	Shiga	0.118
Shiga	0.298	Mie	0.233				
		Shiga	0.207				