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How Much Has High-Speed Rail Contributed to Economic Productivity in Japan?

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ABSTRACT

This study investigates empirically the impact of high-speed rail (HSR) on regional economic productivity in the case of Japanese HSR, which has the longest history of HSR operation in the world. Empirical analyses with an econometric approach are carried out using panel data for 1981, 1986, 1991, 1996, 2001, and 2006, covering 46 prefectures in Japan. To represent regional accessibility, a gravity-model-based accessibility is formulated using the minimum travel times from origins to destinations covering multiple transportation modes. Three econometric models—a pooled model, a fixed-effect model, and a random-effect model—are then employed to estimate impacts on regional economic productivity, using accessibility as well as sociodemographic and socioeconomic factors as explanatory variables. Accessibility is also treated as an instrumental variable, because reverse causation may be expected. The results show that while accessibility has a significant and positive impact on regional productivity, the reverse causal relationship could also be suggested. The findings also show that the presence of HSR stations significantly influences regional productivity and that its impact has been increasing gradually, possibly owing to the historical pattern of agglomeration near HSR stations. The impact of HSR on economic productivity is higher in regions with HSR stations, particularly those located far from the largest cities rather than those neighboring the largest cities. The results could imply that HSR contributes to narrowing the productivity gap between peripheral and urban areas, which justifies HSR projects as a means of regional development.

Keywords. high-speed rail, economic productivity, accessibility, transportation panel data, Japan

INTRODUCTION

Transportation investment is expected to enhance economic productivity and economic growth (*1*). Many previous studies have shown a positive relationship between transportation infrastructure and economic efficiency. Canning (*2*) examined the impact of infrastructure stocks over 1950–1995 in various countries around the world and concluded that infrastructure stock including transportation infrastructure has a strong positive relationship with other development factors such as population, urbanization level, and GDP per capita. The World Bank (*3*) provided cross-sectional data in 1990, showing that the amount of infrastructure stock per capita tends to be higher in countries with higher GDP per capita. Also as shown in Crafts (4), emphasizing more capital investment especially in public stock has positive impact on economic growth. Thus, GDP growth is typically treated as one of the performance indicators of transportation infrastructure development, along with the growth of vehicle distance travel, oil usage, and other transportation data, as shown in Litman (*5*). In terms of economic productivity gains, improvement in transportation accessibility could, in the short run, directly affect industrial productivity through its impact on factors such as commercial delivery, business travel, and commuting to work and school. In the long run, it could also enlarge market areas, increase potential competitiveness, and change land-use patterns and labor markets, all of which may indirectly affect economic productivity. Banister and Thurstain-Goodwin (*6*) suggested that transportation investment affects the local economy at three levels: output and productivity at the macro level, agglomeration economies and labor market effects at the meso level, and land and property market effects at the micro level.

In terms of causation, Lakshmanan (*7*) gave a broader viewpoint of the economic consequences of transportation, including gains from trade, technology diffusion, coordination resulting from the “Big Push” effect, and gains from agglomeration. In particular, agglomeration economies have been highlighted recently by many studies such as Graham (*8*). Chatman and Noland (*9*) conducted a detailed literature review concerning the agglomeration impacts of transportation investment and concluded that public transportation improvements are capable of bringing substantial external benefits by enabling economies of agglomeration. In agglomeration perspective, our accessibility formulation used in this study can be one of examples to capture agglomeration benefits caused by transportation. Deng (*10*) pointed out that both positive and negative impacts have been reported from past studies and presented potential factors affecting the impacts of transportation infrastructure on economic productivity and economic growth. He also suggested that the contribution of transportation investment to productivity should be carefully examined, taking account of local and market contexts. Summarizing these studies, it appears that economic impacts from transportation development arise from premiums in accessibility and transportation costs, which could further expand economic productivity and economic growth, but this needs to be verified carefully through contextual empirical analysis.

Such economic impacts from transportation development, including investments in HSR, have been strongly anticipated by policy makers. HSR is typically assumed to shorten travel times significantly, which could improve accessibility and contribute to regional economic development. To verify the impacts from HSR, however, the following issues that are specific to HSR should be highlighted. First, HSR connects one region with another region; thus, its impacts on productivity are experienced across regions rather than within a region. Thus, inter-regional analysis is required to identify its widespread impact. Second, the economic impacts from HSR should be carefully observed in a historical perspective rather than with a cross-sectional approach, since they could involve long-term rather than short-term processes. Third, HSR typically faces tough market competition from alternative transportation modes; thus, multiple travel modes should be incorporated into the analysis, such as air transportation (*11*, *12*, *13*) and expressway travel (*14*, *15*). Fourth, access and/or egress travel to and from HSR stations should be taken into consideration, because the level of service of a last-mile trip could significantly affect the utility of HSR services. This study analyzes empirically the impacts of HSR on economic productivity in Japan. As the Japanese HSR system has the longest history of HSR operation in the world, it can be expected to provide the best available historical data to reveal the long-run economic effects of HSR. It should be noted that six HSR lines and two sub-HSR lines have been gradually introduced into Japan since the first HSR line started operating in the 1960s. This study collects data from 1981 to 2006 regarding regional economic productivity, along with data on HSR services and other competitive transportation modes in 46 out of 47 prefectures (first level administrative divisions, approximately equivalent to NUTS2) in Japan, apart from Okinawa prefecture located in isolated island. The access/egress details of local transportation to and from HSR stations are incorporated into the inter-regional transportation service data.

The paper is organized as follows: the next section reviews the existing literature on the economic impacts of HSR. The dataset used for an empirical analysis is then presented. The results of empirical analysis are shown and the findings are discussed. Finally, the paper concludes with further analysis and suggestions for future research.

LITERATURE REVIEW

A number of studies have addressed the impact of HSR from various viewpoints. de Rus (*16*) suggested that the introduction of HSR generates direct benefit from travel time saving, which increases economic productivity in the short run; while, in the long run, it attracts new activities, resulting in market expansion and increased firm productivity. Chen *et al.* (*17*) empirically examined the impact of HSR in a Spanish case using a structural equation modeling approach, concluding that investment in HSR had positive impacts on growth in provincial economies, stimulating GDP and increasing employment levels, leading to wider economic impacts. Case studies of the French TGV system also reported significant development in real estate and large business in Le Mans, Vendôme (*18*), and Nantes (*19*). Masson and Petiot (*20*) provided evidence to support its positive effect on tourism; for instance, data from the TGV southeast line showed growth in hotel visits as well as in the number of conferences held, although HSR also penalized tourism through shorter periods of stay. On the other hand, Chen *et al.* (*21*) reported that the introduction of HSR widened the economic gap in the Manchester sub-region, first because the regional economy had been already restructured by other transportation modes and second because intra-regional transportation connecting with HSR was not sufficient. Shen *et al.* (*14*) found that cities will receive minimal benefits from HSR if the station is located away from the city center and that the speed of land use development depends on the attractiveness of new HSR stations. Beyond direct benefit gained from reduction in travel cost, UK DfT (*22*) developed the guideline to capture “Wider Impact”, an additional benefits from transportation which is explained by agglomeration, imperfect competition, and additional tax revenue. The concept has been widely discussed by a number of research (*7*, *23*, *24*), including recent studies such as Levinson (*25*) and Melo *et al.* (*26*) which highlighted positive agglomeration effect from better accessibility due to transportation.

More specific to the HSR system, Graham and Melo (*27*) investigated the agglomeration impact from HSR. By considering a mass of population and distance travel as a transportation variable, it was concluded that long distance mode of transportation like HSR also promote more interaction between mass and more return would be expected. In Japanese context, Nakamura and Ueda (*28*) compared population growth in regions with HSR stations with those without HSR stations, concluding that the presence of HSR stations is the most important factor for population growth, with accessibility to expressway networks also supporting such growth. Amano and Nakagawa (*29*) showed that HSR induced more urban redevelopment in the vicinity of new HSR stations located in peripheral regions than did existing HSR stations located in urbanized regions. Based on empirical investigation, Han *et al.* (*15*) claimed that access time to Japanese HSR stations plays an important role in affecting industrial location, although the elasticity is smaller than for industrial interdependence and people’s consumption demand.

THE HIGH-SPEED RAIL NETWORK IN JAPAN

A huge population is squeezed into a very small extent of habitable land in Japan, creating high-density cities along plains and shorelines. This is one of the most important factors that has shaped Japan into a rail-oriented society (*30*). To serve the huge travel demand between the three largest cities in the middle part of Japan, the Japanese HSR system, called the

Shinkansen in Japanese, initially started operation in 1964, connecting Tokyo, Osaka, and Nagoya. The first HSR in the world, the Tokaido Shinkansen, was constructed mainly because the conventional lines connecting these cities had almost reached their full capacity owing to increasing demand brought about by rapid economic growth. The success of the first Japanese HSR encouraged the Comprehensive National Development Plan to incorporate further HSR construction as a means of encouraging regional development. A new line between Osaka and Okayama started to operate as part of the Sanyo Shinkansen in 1972 and was completed in 1975 by the extension to Hakata, the economic center of Kyushu region. The next HSR lines opened in 1982, with the Tohoku Shinkansen between Omiya and Morioka in northern Japan and the Joetsu Shinkansen between Omiya and Niigata. These two lines reached Tokyo prefecture in 1984 and connected with Tokyo station in 1991. Note that contrary to the Tokaido and Sanyo lines, which were constructed to meet the increasing travel demand among large cities located in the Pacific coastal belt, later HSRs such as the Tohoku and the Joetsus were constructed mainly as regional development projects.

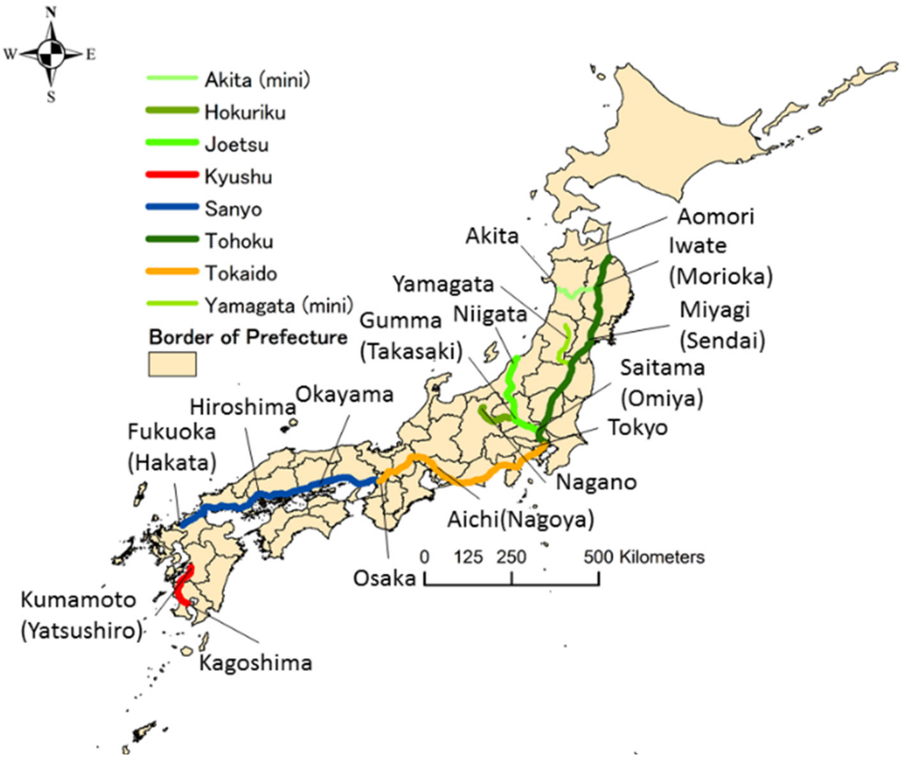

FIGURE 1 High Speed Rail Network in Japan as of 2006

After the privatization of Japan National Railways into Japan Railways in 1987, new type of HSR called "mini-Shinkansen" started operating between Fukushima and Yamagata in 1992. Unlike HSR systems in Europe, Japanese HSR is characterized by a complete separation between high-speed and conventional services, each with its own infrastructure (*16*). A new standard gauge was needed to realize high-speed operation, since the narrow gauge (1 067 mm) of the conventional rail network in Japan restricted its physical connection with high-speed services. Mini-Shinkansen, on the other hand, is characterized by the combined operation of HSR lines and conventional lines, achieved by improving the conventional track. A part of the Hokuriku Shinkansen between Takasaki and Nagano and another mini-Shinkansen called the "Akita Shinkansen" between Morioka and Akita came into operation in 1997. The Yamagata Shinkansen was extended to Shinjo in 1999, and the Tohoku Shinkansen was extended to Hachinohe in 2001. A part of the Kyushu Shinkansen between Kagoshima and Yatsushiro opened in 2004 and connected to Hakata in 2011. The Tohoku Shinkansen was also extended to Aomori in 2010. The Japanese HSR network in 2006 is illustrated in Figure 1.

DATASET

Accessibility

The introduction of HSR improves regional accessibility. This study formulates accessibility through the gravity-model approach. This assumes that the accessibility between two regions is affected by socioeconomic or sociodemographic regional factors and that it declines as travel time from one region to the other increases.

Accessibility is generally defined using travel time or cost as:

$$ACC_i = \sum_{j \neq i} a(c_{ij}) z_j \tag{1}$$

where ACC_i is the accessibility of zone i; $a(c_{ij})$ is decreasing factor along with travel time or cost between zones i and j, c_{ij}; and z_j is attractiveness of zone j such as population and number of jobs. Recent studies such as Graham and Melo (*27*) have often used the following definition of accessibility using distance between zones:

$$ACC_i = \sum_{j \neq i} d_{ij}^{-\alpha} z_j \tag{2}$$

where d_{ij} is the straight-line distance between zones i and j; and α is a positive parameter. This study also follows the definition of accessibility shown in eq. (2), assuming that the distance is replaced by travel time and that the parameter is equal to 1 for simplicity. The accessibility used in our empirical analysis is shown as:

$$ACC_i = \sum_{j \neq i} \frac{P_j}{\min_m .\left(T_{ij}^m\right)} \tag{3}$$

where i and j represent prefectures, P_i represents the population in prefecture i, and T_{ij}^m represents the minimum travel time from prefecture i to prefecture j when transportation mode m is used. This study assumes that regional population represents the regional factors, based on the existing research (*22, 27, 31, 35*). Multiple transportation modes are incorporated into the estimation of inter-regional travel time, because other inter-urban travel modes apart from HSR are also expected to influence accessibility.

Dataset

Sociodemographic, socioeconomic, and transportation panel data are prepared by prefecture in Japan for 1981, 1986, 1991, 1996, 2001, and 2006. The dataset is presented in five-year intervals, because some data are only available every five years. Note that there are 47 prefectures in Japan. As one of them—Okinawa prefecture—consists of many islands located far from the HSR network, it is excluded from our database. The sociodemographic data include prefectural population, prefectural population by gender, prefectural population by age subgroup, and prefectural employees. These data are derived from Statistic Bureau of Japan.

Next, the socioeconomic data includes the number of offices, the number of employees by industry, gross regional product (GRP) by industry, and net stock of social capital, also derived from Statistic Bureau of Japan. Industries are categorized into “primary industry,” including agriculture, forestry, and fishery; “secondary industry,” including mining, construction, and manufacturing industries; “tertiary industry,” including electricity, gas, and water, distribution businesses, finance, real estate, transportation, information and service industries, and the government sector. Note that the GRP and net stock of social capital are deflated to 2005 levels. As for “productivity,” this study assumes that labor productivity represents general economic productivity. Labor productivity is calculated as GRP per employee.

Finally, the transportation data consist of the minimum travel time between prefectures and the minimum number of transfers to the nearest HSR station in each of the three largest cities: Tokyo, Osaka, and Nagoya. Note that different data for transportation networks and services are prepared for different years based on the service availability by transportation mode in the past. A representative node in each prefecture is assumed where the prefectural capital is located. The transportation modes cover HSR, conventional rail, air, inter-city bus, and private car. In estimating the travel time of public transportation modes, the minimum access/egress travel time of local public transportation services is assumed for access/egress to and from HSR stations or airports, if such services are available. If local public transportation services are not available, private car is assumed for estimating access/egress travel time. For private car, the minimum travel time from a representative node in an origin prefecture to another representative point in a destination prefecture is computed using the road network data for each year. If the road network does not directly connect an island with others, the use of car-ferry services is assumed. Note that the calculation process above is done with National Integrated Transport Analysis System (NITAS), which was developed by Ministry of Land, Infrastructure, Transport and Tourism (MLIT). The number of transfers to and from HSR stations is collected from past rail timetables published by Japan Tourist Bureau.

TABLE 1 shows descriptive statistics of the dataset, which contains 276 records compiled from 46 prefectures over six years. First, average productivity is 7.08 million JPY per employee, ranging from 4.68 to 11.61 million JPY. Note that one US dollar was on average equal to 110.2 JPY at 2005 levels. The average productivity has been increasing, while its standard deviation has fluctuated. The standard deviation was higher in 1991, probably because the Japanese economy experienced the asset price bubble, after which economic disparities among regions become larger. It was also higher in 2006, possibly because the government of the day introduced deregulation policies following the new approach of liberalism, which led to higher economic disparities among regions.

Second, the accessibility has a wide range, from 3.08 to 10.08. This has increased gradually from 1981 to 2006, indicating that the transportation network has been developed, which improved regional accessibility. The standard deviation of accessibility has also been increasing, which may imply that accessibility has improved only in specific regions where there was investment in transportation infrastructure.

Third, the number of transfers to any of the three largest cities is 0.42 on average and has been generally decreasing. This may imply that the local access/egress public transportation services in the largest cities have been significantly improved in the past decades. This includes the expansion of local public transportation networks in these cities, enabling passengers to travel directly to the nearest HSR station.

Fourth, the average GRP share of primary, secondary, and tertiary industries are 2.82, 31.32, and 54.55 percent, respectively. The GRP share of primary industry decreased from 1981 to 2006, while that of tertiary industry increased, apart from 2001 to 2006. The GRP share of finance, insurance, and real estate (FIRE) industries is 16.38 percent on average. Note that the FIRE industries are parts of the tertiary industry. Note that the FIRE industry is typically regarded as one of the high-productivity sectors.

EMPIRICAL ANALYSIS

Comparative Analysis between Prefectures with HSR Stations and Prefectures without HSR Stations

First, prefectures are classified into two subgroups: those with Shinkansen stations and those without Shinkansen stations in each year. TABLE 2 shows differences of productivities between the two subgroups by year. Welch's *t*-test shows that the mean of the productivity is significantly higher in prefectures with Shinkansen stations than that of prefectures without Shinkansen stations in all years. This may suggest that accessibility to HSR stations has significant positive impacts on regional productivity. The results also show that the statistical significances of the *t*-test became weaker in 2001 and 2006. This may imply that HSR stations introduced by later HSR lines have lower impacts on productivity than those introduced by earlier HSR lines.

TABLE 1 Descriptive Statistics of Dataset

Productivity (Mil. JPY/employee)	Total	1981	1986	1991	1996	2001	2006
Minimum	4.68	4.68	5.19	5.92	6.34	6.74	7.37
Median	7.13	5.40	5.99	7.00	7.24	7.65	8.47
Maximum	11.61	7.04	8.40	9.51	9.42	10.50	11.61
Mean	7.08	5.52	6.13	7.11	7.35	7.74	8.61
Standard deviation	1.23	0.57	0.65	0.79	0.67	0.65	0.85
Accessibility (100 Thousand Person/minutes)							
Minimum	3.08	3.08	3.52	3.61	3.67	3.75	4.00
Median	5.21	4.46	4.97	5.14	5.25	5.51	5.72
Maximum	10.08	8.34	8.96	9.25	9.43	9.67	10.08
Mean	5.68	5.05	5.40	5.67	5.80	6.00	6.15
Standard deviation	1.59	1.42	1.48	1.56	1.58	1.61	1.68
Number of transfers to any of three largest cities							
Minimum	0	0	0	0	0	0	0
Median	0	0	0	0	0	0	0
Maximum	4	4	4	2	2	2	2
Mean	0.42	0.59	0.57	0.33	0.33	0.33	0.37
Standard deviation	0.77	1.09	1.07	0.52	0.52	0.52	0.61
GRP share of primary industry (%)							
Minimum	0.07	0.21	0.18	0.10	0.08	0.07	0.07
Median	2.50	4.00	3.36	2.53	2.28	1.98	1.78
Maximum	9.03	8.40	9.03	5.86	5.52	5.11	4.86
Mean	2.82	4.09	3.72	2.67	2.40	2.14	1.91
Standard deviation	1.88	2.17	2.21	1.64	1.45	1.27	1.22
GRP share of secondary industry (%)							
Minimum	13.81	19.55	17.47	19.52	18.10	16.82	13.81
Median	31.32	31.77	30.20	33.04	32.45	29.20	31.72
Maximum	47.48	43.43	43.44	47.48	46.73	42.42	47.27
Mean	31.32	31.70	30.10	32.95	31.76	29.47	31.93
Standard deviation	6.43	5.36	5.95	6.29	6.32	6.20	7.86
GRP share of tertiary industry (%)							
Minimum	37.75	37.75	39.08	37.75	40.71	46.33	45.01
Median	54.30	50.79	53.34	53.60	56.12	58.12	55.23
Maximum	77.86	60.73	72.26	71.26	75.53	77.86	71.20
Mean	54.55	50.51	53.78	53.58	56.38	57.80	55.28
Standard deviation	6.30	5.30	6.17	6.08	6.26	5.96	5.61
GRP share of FIRE industry (%)							
Minimum	11.08	11.08	12.07	11.44	14.17	13.34	13.31
Median	16.15	14.67	16.22	15.16	17.28	16.28	16.60
Maximum	28.07	19.62	28.07	25.85	26.52	23.42	23.06
Mean	16.38	14.80	16.42	15.61	17.77	16.77	16.90
Standard deviation	2.73	2.39	2.90	2.74	2.73	2.29	2.34
Office density (offices/km^2)							
Minimum	3.02	3.41	3.48	3.50	3.44	3.24	3.02
Median	14.70	14.58	14.91	15.00	14.88	14.29	13.20
Maximum	379.04	375.73	379.04	369.53	366.76	344.48	328.22
Mean	34.22	34.43	35.51	35.65	35.45	33.32	30.94
Standard deviation	64.35	66.81	68.02	67.38	66.83	62.08	57.79

TABLE 2 Difference of Productivity between Prefectures With and Without HSR Stations

Year	Condition of Prefecture	Mean (Mil. JPY/employee)	Var. (Mil. JPY/employee)	*N*	Deg. of freedom	*t*-value
1981	without HSR station	5.33	0.23	33	22	–4.23***
	with HSR station	6.01	0.24	13		
1986	without HSR station	5.91	0.29	26	35	–2.87***
	with HSR station	6.42	0.47	20		
1991	without HSR station	6.78	0.36	26	34	–3.61***
	with HSR station	7.53	0.67	20		
1996	without HSR station	7.09	0.28	26	35	–3.35***
	with HSR station	7.69	0.48	20		
2001	without HSR station	7.51	0.23	25	33	–2.64**
	with HSR station	8.01	0.54	21		
2006	without HSR station	8.34	0.48	22	43	–2.17*
	with HSR station	8.86	0.84	24		

Note: "***": p<0.01; "**": p<0.02; and "*": p<0.05, "" p<0.10

Regression Analysis

Three types of estimation approaches are applied to regression analysis to correlate prefectural productivity with explanatory variables using a Cobb-Douglas function: a pooling ordinary least square (OLS) model, a fixed effect model, and a random effect model. To select a combination of appropriate explanatory variables, the following process is implemented. First, variables whose absolute value of correlation coefficient with accessibility is over 0.6 are excluded. Next, the remaining variables are examined to see whether they significantly reduce the Akaike information criterion. Finally, a step-wise estimation approach is used to check whether the variance inflation factor is lower than 10 to avoid multicollinearity.

TABLE 3 summarizes the estimation results of the three models achieved through the above process of selecting explanatory variables. HSR station dummies of "HSR_81," "HSR_86," "HSR_91," "HSR_96," "HSR_01," and "HSR_06" are defined to be 1 if an HSR station is located in a prefecture in 1981, 1986, 1991, 1996, 2001, and 2006 respectively and 0 otherwise. They are expected to positively affect the productivity because business persons working in prefecture with HSR stations could communicate more with business persons in other prefectures than those in prefecture without it. "Transfer time to largest cities" is equal to 1 if two or more transfers are required in the local public transportation network of a prefecture to reach the HSR stations in the largest cities and 0 otherwise. Business persons working in the prefecture where more transfers are required to reach HSR stations in the largest cities are expected to have poorer business opportunities than those in better accessible prefectures. "Port and airport" is equal to 1 if a prefecture has a large-scale seaport and airport and 0 otherwise. Better accessibility to airports and/or seaports could enhance communications among business persons as well as improve logistic efficiency, which could lead to better productivity. "GRP share of FIRE industry" represents the share of production of the Finance, Insurance, and Real Estate (FIRE) industries out of total GRP in a prefecture. They are assumed to increase the regional productivity. Office density means the number of offices per square kilometers. Prefecture with more agglomeration of the offices is expected to have higher productivity.

The results of F tests indicate that all models have p-values lower than 0.01. This suggests that the fixed effect model is significantly favored over the pooling OLS. The results of Breusch-Pagan tests also show that all models have p-values lower than 0.01. This suggests that the pooling OLS model is significantly favored over the random effect model. Finally, the results of Hausman tests indicate that all models have p-values lower than 0.01. This suggests that the fixed effect model is significantly favored over the random effect model. Consequently, these results together suggest that the fixed effect model should be the most favorable.

Among the four fixed effect models, Model F4 may be the most preferable. All the estimates show significant effects on productivity. Adjusted R-squared is 0.602, which may be an acceptable fitness of the model. The results show that the accessibility has a significant and positive impact on productivity. This means that the introduction of not only HSR, but also expressways and airports that could contribute to saving travel time, have a positive impact on productivity. The results also show that the HSR station dummies are significant and positive except for HSR_81. This means prefectures with better accessibility to HSR stations have higher productivity than those without HSR station in them as shown in TABLE 2. The estimated coefficients of the HSR station dummies become gradually larger as the year comes closer to the present. This seems, at a glance, inconsistent with the findings from TABLE 2. One of the possible explanations for this is a dynamic process in which the economy of agglomeration gradually works stronger nearby HSR stations. As time passes after an HSR station has been installed, more business is agglomerated in the vicinity of the HSR station, which may gradually increase business efficiency in the region. On the other hand, it is expected that regions where a new HSR station has been recently introduced may have weaker productivity gains, since the economy of agglomeration has not worked well. The number of transfers to largest cities has a significant and negative impact on productivity, which means that the quality of local public transportation services, particularly the frequency of transfers, could affect the impacts of HSR on regional productivity. This may suggest that additional efforts in improving last-mile public transportation services are significant for a better contribution of HSR to economic development. The GRP share of the FIRE industry has a significant and positive impact on productivity. This indicates that a higher share of the FIRE industry leads to higher productivity, which seems reasonable as the FIRE industry is often mentioned as a highly productive sector (*32*). Finally, the office density has, unexpectedly, negative impact on productivity. It should be noted that the office density has decrease since 1991 as shown in TABLE 1. This may indicate that only highly-productive firms survived through market competition among firms during prolong economic recession after the collapse of bubble economy in early 1990s.

Although the above model assumes that improvement of accessibility through introducing HSR contributes to regional productivity, the reverse effect may also be possible: that the HSR network was constructed in those prefectures where productivities are higher. It is well known that the parameters of the OLS method could be biased if both directions of causal relationship exist in a model. An additional model is thus estimated assuming that accessibility is an instrumental variable that is explained endogenously by other explanatory variables.

TABLE 4 shows the results of the pooling regression model, random effect model, and fixed effect model with the instrumental variable (IV) method with the relevant statistical tests. Both models have sufficiently high fitness and have similar estimates. This implies that the reverse causal relationship—that accessibility affects productivity—may be supported, while the other way around is also possible. This is quite reasonable, because the reverse effect corresponds to the fact that the inter-urban transportation infrastructure has been developed to connect regions between large cities, which usually have relatively higher productivity than rural or peripheral areas.

There are many studies directly investigating the relationship between travel time and productivity. For instance, Preston and Wall (*33*) and Preston (*34*) reviewed past studies and insisted that the elasticity of productivity with respect to travel time ranges between 0.12 and 0.29. However, most of the literature may focus on agglomeration effect to productivity (*8*). Nevertheless, some studies observed the distance between economies which can be assimilated to our travel time. For example, elasticities of 0.129 and 0.043 were suggested by Graham (*8*) and by Graham *et al.* (*35*) respectively. Note most of the past studies estimated the elasticity with cross-sectional data.

The elasticity can be transformed as follows:

$$-\frac{dy/y}{dt/t} = -\frac{dy/y}{dACC/ACC} \cdot \frac{dACC/ACC}{dt/t} = -\beta_{ACC} \cdot \frac{dACC/ACC}{dt/t} \tag{4}$$

where y is the productivity, t is the travel time, ACC is the accessibility, and β_{ACC} is the elasticity of productivity with respect to accessibility. $dACC/ACC$ is computed as 0.01 with eq. (1) when dt/t is 0.01, using our dataset. As the elasticities of productivity with respect to accessibility estimated with the OLS model and the IV model $\hat{\beta}_{ACC}$ are 0.049 and 0.054 respectively, as shown in TABLE 4, the elasticities of productivity with respect to travel time are estimated to be 0.049 and 0.054 respectively. Our estimates are very close to those in Graham *et al.* (*35*) which were suggested in the official DfT Wider Impact guideline (*22*).

TABLE 3 Estimation Results of Pooling OLS Models, Random Effect Models, and Fixed Effect Models

Pooling OLS model	Model P1			Model P2			Model P3			Model P4		
	Estimate	Std. Error	*t*-value	Estimate	Std. Error	*t*-value	Estimate	Std. Error	*t*-value	Estimate	Std. Error	*t*-value
Intercept	6.271	0.247	25.425 ***	6.282	0.246	25.554 ***	6.220	0.251	24.744 ***	6.230	0.250	24.873 ***
ln (Acc)	-0.016	0.031	-0.494	-0.018	0.031	-0.579	-0.028	0.032	-0.870	-0.030	0.032	-0.951 ·
HSR_81	-0.147	0.042	-3.495 **	-0.147	0.042	-3.491 **						
HSR_86	-0.081	0.033	-2.459 *	-0.082	0.033	-2.470 *	-0.060	0.033	-1.818 **·	-0.061	0.033	-1.829
HSR_91	0.080	0.034	2.376 *	0.081	0.034	2.422 *	0.104	0.034	3.097 **	0.105	0.034	3.141 **
HSR_96	0.087	0.033	2.611 *	0.091	0.033	2.764 **	0.104	0.034	3.062 **	0.107	0.033	3.213 **
HSR_01	0.136	0.033	4.165 ***	0.140	0.032	4.359 ***	0.154	0.033	4.670 ***	0.157	0.032	4.863 ***
HSR_06	0.255	0.030	8.398 ***	0.259	0.030	8.684 ***	0.271	0.031	8.800 ***	0.274	0.030	9.083 ***
Transfer time to largest cities	-0.135	0.033	-4.128 ***	-0.130	0.032	-4.108 ***	-0.129	0.033	-3.888 ***	-0.125	0.032	-3.876 ***
Port and airport	0.016	0.026	0.623				0.015	0.026	0.564			
ln (GRP share of FIRE industry)	0.089	0.058	1.538	0.090	0.058	1.549	0.144	0.057	2.523 *	0.144	0.057	2.533 *
ln (Office density)	0.035	0.011	3.092 **	0.037	0.011	3.355 **	0.022	0.011	1.997 *	0.023	0.010	2.233 *
Adj. *R*-Squared	0.420			0.421			0.421			0.634		
Random effect model	**Model R1**			**Model R2**			**Model R3**			**Model R4**		
	Estimate	Std. Error	*t*-value	Estimate	Std. Error	*t*-value	Estimate	Std. Error	*t*-value	Estimate	Std. Error	*t*-value
Intercept	5.697	0.288	19.757 ***	5.711	0.288	19.826 ***	5.646	0.290	19.496 ***	5.670	0.289	19.606 ***
ln (Acc)	0.000	0.035	0.013	-0.004	0.034	-0.111	-0.004	0.035	-0.111	-0.010	0.034	-0.279
HSR_81	-0.076	0.041	-1.855 ·	-0.079	0.041	-1.938 ·						
HSR_86	-0.017	0.034	-0.509	-0.019	0.034	-0.570	0.011	0.031	0.362	0.009	0.031	0.297
HSR_91	0.155	0.034	4.563 ***	0.157	0.034	4.597 ***	0.185	0.031	6.050 ***	0.187	0.031	6.109 ***
HSR_96	0.129	0.034	3.768 ***	0.135	0.034	3.974 ***	0.153	0.032	4.747 ***	0.160	0.032	5.058 ***
HSR_01	0.181	0.033	5.473 ***	0.187	0.033	5.721 ***	0.205	0.031	6.625 ***	0.213	0.030	7.011 ***
HSR_06	0.306	0.030	10.087 ***	0.311	0.030	10.394 ***	0.326	0.029	11.434 ***	0.333	0.028	11.907 ***
Transfer time to largest cities	-0.211	0.031	-6.709 ***	-0.208	0.031	-6.654 ***	-0.212	0.031	-6.735 ***	-0.208	0.031	-6.622 ***
Port and airport	0.032	0.031	1.061				0.038	0.031	1.235			
ln (GRP share of FIRE industry)	0.298	0.070	4.253 ***	0.300	0.070	4.279 ***	0.333	0.068	4.865 ***	0.335	0.068	4.889 ***
ln (Office density)	-0.009	0.017	-0.527	-0.006	0.017	-0.347	-0.021	0.016	-1.266	-0.017	0.016	-1.045
Adj. *R*-Squared	0.506			0.507			0.505			0.694		
Fixed effect model	**Model F1**			**Model F2**			**Model F3**			**Model F4**		
	Estimate	Std. Error	*t*-value	Estimate	Std. Error	*t*-value	Estimate	Std. Error	*t*-value	Estimate	Std. Error	*t*-value
ln (Acc)	0.050	0.031	1.635	0.047	0.031	1.545	0.052	0.031	1.691 ·	0.049	0.030	1.617
HSR_81	0.045	0.038	1.160	0.037	0.038	0.991						
HSR_86	0.120	0.034	3.529 ***	0.115	0.034	3.418 ***	0.095	0.026	3.595 ***	0.094	0.026	3.566 ***
HSR_91	0.319	0.034	9.479 ***	0.317	0.034	9.436 ***	0.294	0.026	11.262 ***	0.296	0.026	11.358 ***
HSR_96	0.260	0.035	7.434 ***	0.262	0.035	7.505 ***	0.238	0.029	8.142 ***	0.243	0.029	8.475 ***
HSR_01	0.241	0.033	7.257 ***	0.243	0.033	7.332 ***	0.219	0.027	7.980 ***	0.224	0.027	8.327 ***
HSR_06	0.263	0.032	8.204 ***	0.264	0.032	8.256 ***	0.244	0.028	8.843 ***	0.247	0.027	9.109 ***
Transfer time to largest cities	-0.204	0.027	-7.619 ***	-0.204	0.027	-7.598 ***	-0.202	0.027	-7.543 ***	-0.202	0.027	-7.544 ***
Port and airport	0.029	0.030	0.982				0.023	0.029	0.775			
ln (GRP share of FIRE industry)	0.482	0.069	7.009 ***	0.484	0.069	7.037 ***	0.475	0.069	6.925 ***	0.477	0.068	6.973 ***
ln (Office density)	-1.330	0.118	-11.283 ***	-1.333	0.118	-11.318 ***	-1.322	0.118	-11.228 ***	-1.326	0.118	-11.278 ***
Adj. *R*-Squared	0.599			0.600			0.600			0.602		
F test	$F = 10.346$; $p < 2.2e{-16}$			$F = 10.348$; $p < 2.2e{-16}$			$F = 11.003$; $p < 2.2e{-16}$			$F = 11.028$; $p < 2.2e{-16}$		
Breusch-Pagan test	$\chi^2 = 39.004$; $p < 4.23e{-10}$			$\chi^2 = 38.016$; $p < 7.02e{-10}$			$\chi^2 = 42.677$; $p < 6.46e{-11}$			$\chi^2 = 41.312$; $p < 1.30e{-10}$		
Hausman test	$\chi^2 = 24.522$; $p < 0.0107$			$\chi^2 = 29.303$; $p < 0.001113$			$\chi^2 = 59.618$; $p < 4.28e{-09}$			$\chi^2 = 68.277$; $p < 3.31e{-11}$		

Note: "***": $p<0.01$; "**": $p<0.02$; and "*": $p<0.05$, "·" $p<0.10$

TABLE 4 Estimation Results with IV Method

Pooling IV model	Estimate	Std. Error	*t*-value
Intercept	6.197	0.252	24.614***
ln (Acc)	-0.025	0.032	-0.779**
HSR_86	-0.061	0.033	-1.831
HSR_91	0.105	0.034	3.141
HSR_96	0.107	0.033	3.213
HSR_01	0.157	0.032	4.851
HSR_06	0.274	0.030	9.075***
Transfer time to largest cities	-0.124	0.032	-3.867*
ln (GRP share of FIRE industry)	0.144	0.057	2.535***
ln (Office density)	0.023	0.010	2.230*
Adj. *R*-Squared	0.397		
Random effect model	**Estimate**	**Std. Error**	***t*-value**
Intercept	5.625	0.291	19.336***
ln (Acc)	-0.003	0.035	-0.079**
HSR_86	0.009	0.031	0.295
HSR_91	0.187	0.031	6.111
HSR_96	0.160	0.032	5.057***
HSR_01	0.212	0.030	6.997***
HSR_06	0.333	0.028	11.901***
Transfer time to largest cities	-0.208	0.031	-6.629***
Adj. *R*-Squared	0.523		
Fixed effect model	**Estimate**	**Std. Error**	***t*-value**
ln (Acc)	0.055	0.031	1.800*
HSR_86	0.094	0.026	3.568***
HSR_91	0.296	0.026	11.366***
HSR_96	0.243	0.029	8.478***
HSR_01	0.223	0.027	8.314***
HSR_06	0.247	0.027	9.100***
Transfer time to largest cities	-0.202	0.027	-7.558***
Adj. *R*-Squared	0.602		

Note 1: “***”: $p<0.01$; “**”: $p<0.02$; and “*”: $p<0.05$, “.” $p<0.10$

Note 2: Endogenous variable: Accessibility; Instrumental variables: Accessibility five years ago

Note 3: F test: $F = 11.027, p < 2.2\text{e-}16$; Breusch-Pagan test: $\chi^2 = 41.319, p < 1.293\text{e-}10$; and Hausman Test: $\chi^2 = 67.521, p < 4.652\text{e-}11$.

Scenario Analysis: Estimation of HSR’s Impact on Regional Productivity

According to our definition of accessibility, improvement of accessibility is not caused necessarily by the introduction of HSR. Thus, to evaluate the impact only from the HSR, a simple scenario analysis is implemented where expected regional productivities in the scenario where HSR exists (with-scenario) are compared with those in another scenario where no HSR exists (without-scenario) using the estimated model. It is assumed that the without-scenario has the same conditions as the with-scenario except for the HSR network in each year. FIGURE 2 illustrates the productivity gains from the HSR network by prefecture. This shows that the impact of the HSR network on regional productivity is larger in prefectures along the HSR lines, and is especially large in the prefectures located between the largest cities. Prefectures located near the largest cities, such as those located near Tokyo and Osaka, do not seem affected much by HSR. This is because HSR significantly improves accessibility from peripheral regions to the largest cities, which enables more business communication and/or opportunities in the peripheral regions. On the other hand, HSR contributes less to productivity improvements in the vicinity of the largest cities for three reasons: first, because the HSR has fewer advantages against competitive urban high-speed rail services; second, because the HSR usually has few stations in the metropolitan areas; and third, because the marginal benefit of HSR introduction is smaller owing to the richer infrastructure stock in metropolitan areas. This could lead to the idea that the productivity of peripheral areas may be increased through the introduction of HSR lines, which may justify HSR projects as a means of narrowing the economic inequalities among regions. This is supported by past studies; for instance, Sasaki *et al.* (*36*) concluded that the HSR network does not

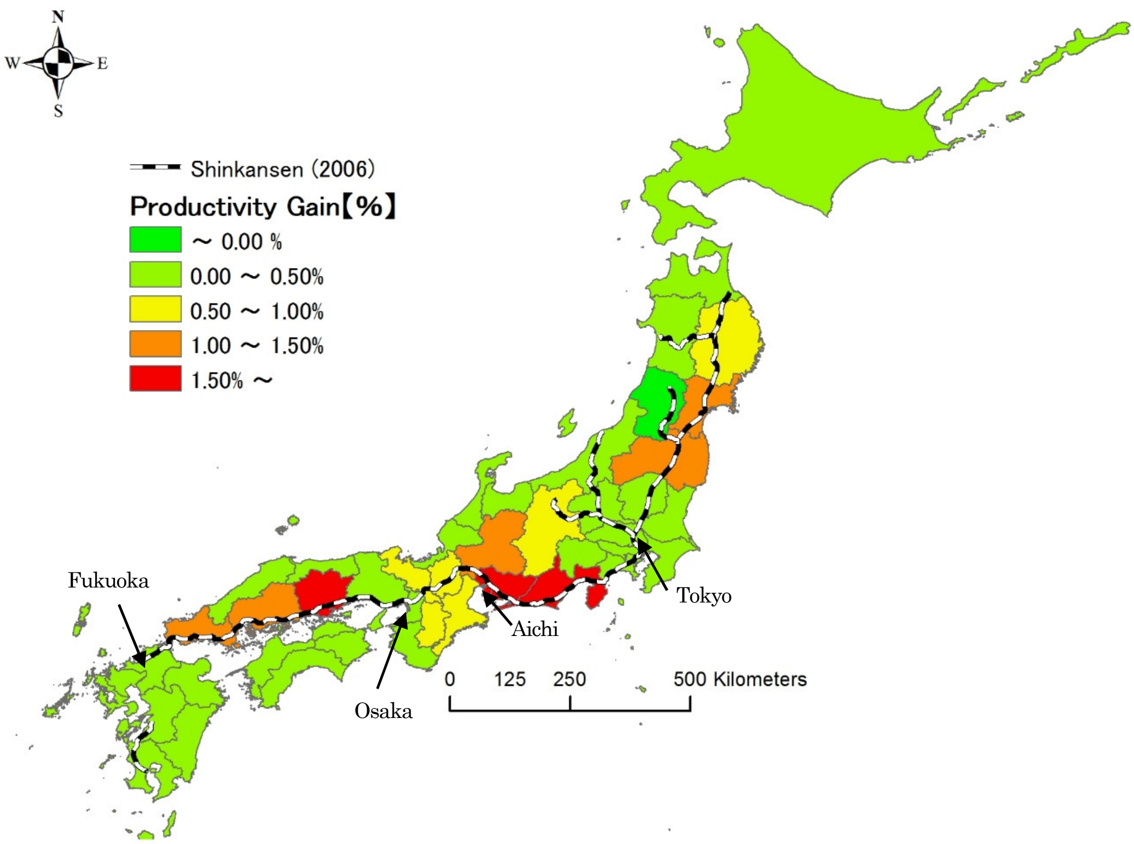

FIGURE 2 Productivity Gain from HSR Network by Prefecture in Japan (in 2006)

contribute to regional dispersion between developed regions and remote regions, while the European Union (*31*) showed that HSR contributes only marginal benefits in regions where transportation infrastructure has been highly developed.

CONCLUSION

This study empirically analyzed the impact of the Japanese HSR system on regional productivity. The main findings are as follows: (1) accessibility has a significant and positive impact on productivity, while the reverse causal relationship could also be suggested; (2) the existence of HSR stations significantly influences regional productivity and its impact has been increasing gradually, possibly owing to the historical pattern of agglomeration near HSR stations; and (3) the impact of HSR on productivity is larger in regions along the HSR network, especially those located in peripheral areas rather than urban centers. The results suggest that HSR may contribute to narrowing the productivity gap between peripheral and urban areas, which implies that HSR projects can be justified as a means of regional development. However, the findings also suggest that the productivity gap between the regions with HSR and those without HSR becomes larger. As the expansion of HSR to regions all over the nation is not financially feasible despite the presentation of many proposals to extend HSR, remedy policies for those regions inaccessible to HSR should be investigated further.

Many unexplored issues remain for future research. First, although this study revealed the impact of HSR on regional productivity, its processes are not well specified. As pointed out by Graham (*8*), the introduction of transportation infrastructure could induce and promote the agglomeration of businesses and/or labor forces around it; our study did not explicitly take this into consideration, although the results suggest such effects. To identify agglomeration effects on productivity, further empirical analysis is required in the context of HSR. Case studies in specific regions may also be meaningful in comprehending exactly what is happening around HSR stations. From a technical viewpoint, the model should also be elaborated further. While our study assumed that all passengers would use the minimum travel time route, modal choice models can be incorporated in order to reflect the preferences of passengers in reality.

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