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Double-Edged Trains: Economic Outcomes and Regional Disparity of High-Speed Railways*

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Abstract

We illuminate the causal relationship between high-speed railway (HSR) expansions and economic development, focusing on HSR in Japan–the Shinkansen–from 1983 to 2020. To address endogeneity concerns about HSR station construction, we employ a market access approach that captures both the direct and indirect impacts of HSR expansion. The results show that a 1% increase in HSR market access increases the land price by 0.176%, income by 0.425%, and income per capita by 0.023% of Japan. However, most of the benefits are focused in Tokyo and other developed areas, while the economic growth due to HSR expansion of cities outside these areas is negative or statistically insignificant. We confirm the robustness of the results through the instrumental variable (IV) approach and a series of robustness checks. Next, we conduct counterfactual analyses using regression results to evaluate future Japanese HSR plans: the Linear Shinkansen, regional expansion, and a policy that would implement both. Simulation results reconfirm that future HSR plans will induce economic growth but, at the same time, aggravate regional disparity; thus, the expected economic outcomes may be double-edged.

Keywords: High-Speed Railway; Shinkansen; Regional Disparity; Market Access; Agglomeration, Land Price

JEL classification: R1, R11, R12, L92

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1 Introduction

1.1 Research Objectives

Does transportation infrastructure induce economic development but aggravate regional disparity? If so, transportation infrastructure may be double-edged. Answering this question requires an evaluation of the world's largest and most ambitious transportation investment projects, such as China's traditional railway extensions, the United States' interstate highway system, and Japan's high-speed rail (HSR), all aimed at boosting national economic development while simultaneously promoting regional economic prosperity. However, the gains from these projects may be isolated to a handful of cities (Herzog (2021)).

In this study, we choose HSR due to its uniqueness; HSR carries people, rather than freight, and operates at a significantly faster speed than highways and conventional railways (Chang and Zheng (2022a);Bernard et al. (2019); Sahu and Verma (2022); Bracaglia et al. (2020)). Thus, the introduction of HSR rapidly reduces travel time and enhances accessibility to all connected cities. The increased accessibility will allow the people to agglomerate around station areas. Such agglomerations through transportation infrastructure can lead to economic development (Herzog (2021)).

Choosing the Shinkansen allows us to examine the long-term effects between HSR and economic outcomes. The Shinkansen was the first HSR in the world–beginning operations in 1964—and has dramatically reduced the travel times of its passengers, serving 174 million annual passengers in 2019 (Ministry of Land, Infrastructure, Transport and Tourism (2019)). The long-term expansion of this HSR network increased the connectivity of passengers and likely induced long-term structural changes in the cities and their economic activities as mentioned in H. Hanson (2005).

Our study addresses the common challenge of endogeneity in analyzing the impact of expanding transportation infrastructure. One strand of literature employs differences-in-differences (DID) estimates to deal with this concern by examining the causal relationship between treatment (i.e., cities with a new station installed) and control groups (i.e., cities without new station installed). In this case, control groups are mostly assumed not to have been affected by HSR expansions. On the other hand, we consider that cities without a new station can still be affected by new HSR expansions. This is because the expansion of the HSR network enhances the accessibility of cities with an HSR station (direct effect) and provides exogenous variation in such cities' connectivity, which does not rely on a direct connection to the HSR system since passengers from unconnected cities use HSR to travel to other cities and transfer at a nearby HSR station (indirect effect). Thus, quantifying the impact of transportation infrastructure requires examining indirect impacts.

Therefore, we employ 'market access', following Donaldson and Hornbeck (2016), defined as the quantified direct and indirect impact of the large-scale transportation network on the aggregate economic outcomes. This point clarifies the differences between our study and previous works, which employ DID methods and explore the causal effects between the treatment and control groups. To construct market access, we assemble a network database of the HSR network in Japan from 1983 to 2020, and create a travel time matrix in entire cities in Japan. Then we compute the changes in travel time and potential demands (represented by the population of the other cities), which are obtained through HSR expansion. Adopting market access provides advantages for examining counterfactual changes to the transportation network (i.e., assuming the absence of HSR) or their replacement with a series of future policy schemes.

We adopt market access as an independent variable in our regression analyses and employ city-level outcome variables such as land price, income, and income per capita. We then examine whether the HSR expansions led to economic growth, dividing areas of Japan into five subgroups–including national-level analysis—Tokyo, Megacities, Regional cores, and Local cities (cities that do not belong to any of the three aforementioned categories). Such categorizations are determined based on the governmental standards of Japan.

Another challenge related to endogeneity concerns is that developed cities are likely to be targeted in station-planning policies. Thus, it would involve a strong ex-ante assumption to randomly assign railway placements on the way between targeted city centers. We therefore construct a hypothetical least-cost path between HSR stations using land-cover data and the geographical characteristics of Japan, following Faber (2014)'s optimal route algorithm. This type of instrumental variable (IV) enables us to evaluate the impact of increased market access on economic outcomes, assuming that the current HSR network is constructed based on only the lowest-cost method. We further explain this method in Section 4.2.

We reveal that HSR expansion increases economic outcomes, but regional disparity still results. For example, a 1% market access increase leads to an approximately 0.176% increase in national land price. While a 1% increase in market access will increase land price in Tokyo by 0.408%, in Megacities by 0.332%, and in Regional cores by 0.469%;

however, Local cities would not experience land price growth. Additionally, looking into other types of economic outcomes, such as income and income per capita, and using IVs provides qualitatively similar results, reaffirming our findings.

Using the estimated coefficients, we proceed to the counterfactual simulations by setting a series of scenarios. In Scenario 1, we consider the impact of the proposed Linear Shinkansen train, which connects Tokyo and Nagoya at a maximum speed of 500 km/h, halving the travel time between the two. Scenario 2 assumes that the existing HSR network undergoes regional expansion without constructing the Linear Shinkansen. For Scenario 3, we construct a scenario that adopts both actions from the previous scenarios. We find that the Linear Shinkansen would bring economic benefits greater than the construction costs while substantially exacerbating regional disparities. On the other hand, while the Regional Expansion Scenario would alleviate regional disparities, the economic benefits would not exceed construction costs. Our results reveal that implementing both plans would boost economic growth mainly in developed cities, where such growth would be fairly even across developed cities, but cities in other areas would still be left behind. Therefore, we conclude that these future HSR plans in Japan are a double-edged sword.

1.2 Literature Review

This study mainly contributes through evaluating the impact of the transportation infrastructure to the economic development. Many countries put tremendous efforts on transportation investments to promote economic and regional growth and alleviate regional disparities by enhancing accessibility to lagging areas. The Japanese government, for example, has spent 1% of GDP on infrastructure building and maintenance, while China has spent 5.5 percent, and the European Commission has initiated a significant transport infrastructure program with 30 priority projects totaling about 600 billion euros (Koster et al. (2021)), urging for the researches evaluating the economic impacts of such projects. Previous works, thus have studied the impact of HSR networks on gains from trade (Donaldson and Hornbeck (2016) and Bernard et al. (2019)), specialization pattern (Lin (2017)), benefits to the peripheral cities (Faber (2014)), and agglomeration effects (Ahlfeldt and Feddersen (2017)). Continued from these works, interestingly, we find that market access expansion induces economic development, focusing on the diverse types of economic indicators: land price, income and income per capita.

Furthermore, we add additional contribution by revealing that the regional disparity in economic benefits exists. Despite the importance of considering both economic growth, which is usually through agglomeration, and dispersion, previous works considering both aspects at the same time are rare. On the one hand, sufficient literature shows that introducing HSR, which usually starts from the capital cities, would boost central and national-level economic developments. The findings from these works are based on the conventional wisdom of the New Economic Geography holds that such economic integration will significantly affect agglomerations of economic activities (Okamoto and Sato (2021), Fujita and Thisse (1996), Maparu and Mazumder (2017) and Bernard et al. (2019)). On the other hand, there are a handful numbers of literature showing that the HSR construction can induce regional disparity as the benefits of them are to concentrate to the developed cities (Vickerman (2015), Qin (2016) and Herzog (2021)). Other strands of literature show the asymmetric benefits on core and peripheral cities (Faber (2014); Deng et al. (2019)), urging for the empirical contributions on the evaluations on whether transportation infrastructure investment leads to economic growth. By presenting how different the impact of HSR is according to the regional groups, we reaffirm that HSR induces regional disparity.

The findings from previous works are mixed, that some of them show HSR constructions lead to economic growth, while some of them present that the regional disparity exists in the benefits of economic outcomes. These findings motivate us to evaluate the causal impact between HSR expansions and economic outcomes on each region to examine whether HSR expansions achieve both national and regional developments.

1.3 Paper Structure

The remainder of this paper is structured as follows. Section 2 provides background information. The data and model are presented in Section 3. Section 4 reports the regression results. Results of Counterfactual Simulations are presented in Section 5. Section 6 concludes the paper.

2 Research Backgrounds

The Japanese government officially stated that it (1) aims to boost the national economy and (2) promotes regional development by enhancing residents' accessibility through HSR expansion (Ministry of Land, Infrastructure, Transport and Tourism (2020)). The

Japanese government has aimed to achieve the former by constructing HSR networks starting from Tokyo and the latter by establishing a series of HSR expansion plans that connecting other regions, such as Fukuoka and Hokkaido to Tokyo. The Japanese government initiated the former and then proceed to the latter. In what follows, we briefly explain the history of Japanese HSR, and then explain our research motivations.

The history of the Japanese HSR, Shinkansen, begins with the Tokaido Shinkansen, which was opened in 1964. As the world's first HSR, the Tokaido Shinkansen was stretched from Osaka to Tokyo, substantially decreasing the travel time from the connected regions to Tokyo. Furthermore, it enriched the national economy by improving consumers' accessibility by reducing the transaction and transportation costs of services (Okamoto and Sato (2021)).

On the other side, the Tokaido Shinkansen contributed to the concentration of the Japanese population around the Tokyo area. The Japanese government, responding to this concentration of the population, then established a new goal of promoting the economic development of regions other than Tokyo. To this end, the Japanese government proposed a 7,200-kilometer national HSR network plan as part of the National Shinkansen Railway Improvement Act in 1970 to uplift regional economic growth by building additional HSR lines. Consequently, Japanese HSR networks have continuously expanded from the capital (Tokyo area) to central cities such as Nagoya and Osaka and to other regions such as Hiroshima and Fukuoka (1970-1980), Niigata and Sendai (1980-1990), Nagano (1997), Kagoshima (2011), Ishikawa (2015) and Hokkaido (2016), as presented in Figure 1.[1]

From the brief history mentioned above, while HSR achieves economic growth, it also contributes to the regional disparity by inducing the concentrations of the population to the developed area. Our motivation starts from whether HSR expansion has alleviated such concentrations through regional development or encouraged them–by enhancing the accessibility of the people residing in the connected areas. If the economic agglomerations around Tokyo become strong relative to the regional development, we will ob-

[1] Detailed information such as the opening date and region, is presented in Table A1. Specifically, the Japanese government announced a series of long-term plans that account for HSR construction; while the first long-term plan mainly focuses on improving the passenger capacities of conventional railways (i.e., increasing the numbers of railways and passenger railroad cars) and replacing old transportation facilities, the second long-term plan includes the construction of the Tokaido Shinkansen Line connecting Tokyo and Shin-Osaka, which was completed in 1964 and greatly increased transportation accessibility among Tokyo, Nagoya, and Osaka, Japan's three largest cities. The third long-term plan included the construction of the Sanyo Shinkansen, which opened between Shin-Osaka and Okayama in 1972 and between Okayama and Hakata (Fukuoka) by 1975. The three long-term plans completed the connection of Tokyo and Hakata.

serve a more intense concentration of economic activities. If the opposite occurs, we will observe a greater dispersion of economic activities. Thus, we evaluate the economic impacts of HSR considering economic growth and regional disparity.

3 Empirical Strategy

In this section, we explain the data we used in the empirical analysis. In Section 3.1, we show how we collect socioeconomic variables from multiple sources, and then we explain how we calculate market access in Section 3.2. Next, we present how we classify the region according to the governmental standards of Japan in Section 3.3. Finally, we discuss our empirical model in Section 3.4.

3.1 Data

For our empirical analysis, we derive data from multiple sources. First, city boundary, HSR network information and land price data are obtained from the National Land Numerical Information database.[2] Second, city-level socioeconomic data (taxable income and population) are obtained from the System of Social and Demographic Statistics (SSDS) provided by the Ministry of Internal Affairs and Communications.[3] We set the target period as 38 years from 1983 to 2020, in which the land price data, one of our main outcome variables, are available.

City boundary The city boundary data covers the information of the geographical locations of 1741 cities Japan: 1718 cities and 23 districts of Tokyo. Although there have been some changes in city boundaries during the past 38 years, this study uses the boundaries as of 2020, for the consistency with the land price in the analysis. A gravity center of each city is used for calculating the travel time matrix, referring to Allen and Arkolakis (2014). For example, when we calculate the traveling time between an origin city and a destination city, we assume that people move from the gravity center of the origin city to that of the destination city. [4]

[2]The data from the National Land Numerical Information Database are available at: https://nlftp.mlit.go.jp/ksj/

[3]The data from the SSDS are available at: https://www.stat.go.jp/data/ssds/index.html

[4]We also calculate market access based on the populous centroid of each city. However, among some cities, the populous may be concentrated around the boundaries of nearby cities, which may cause the travel time between the populous center of these two cities to become nearly zero. To avoid such problems,

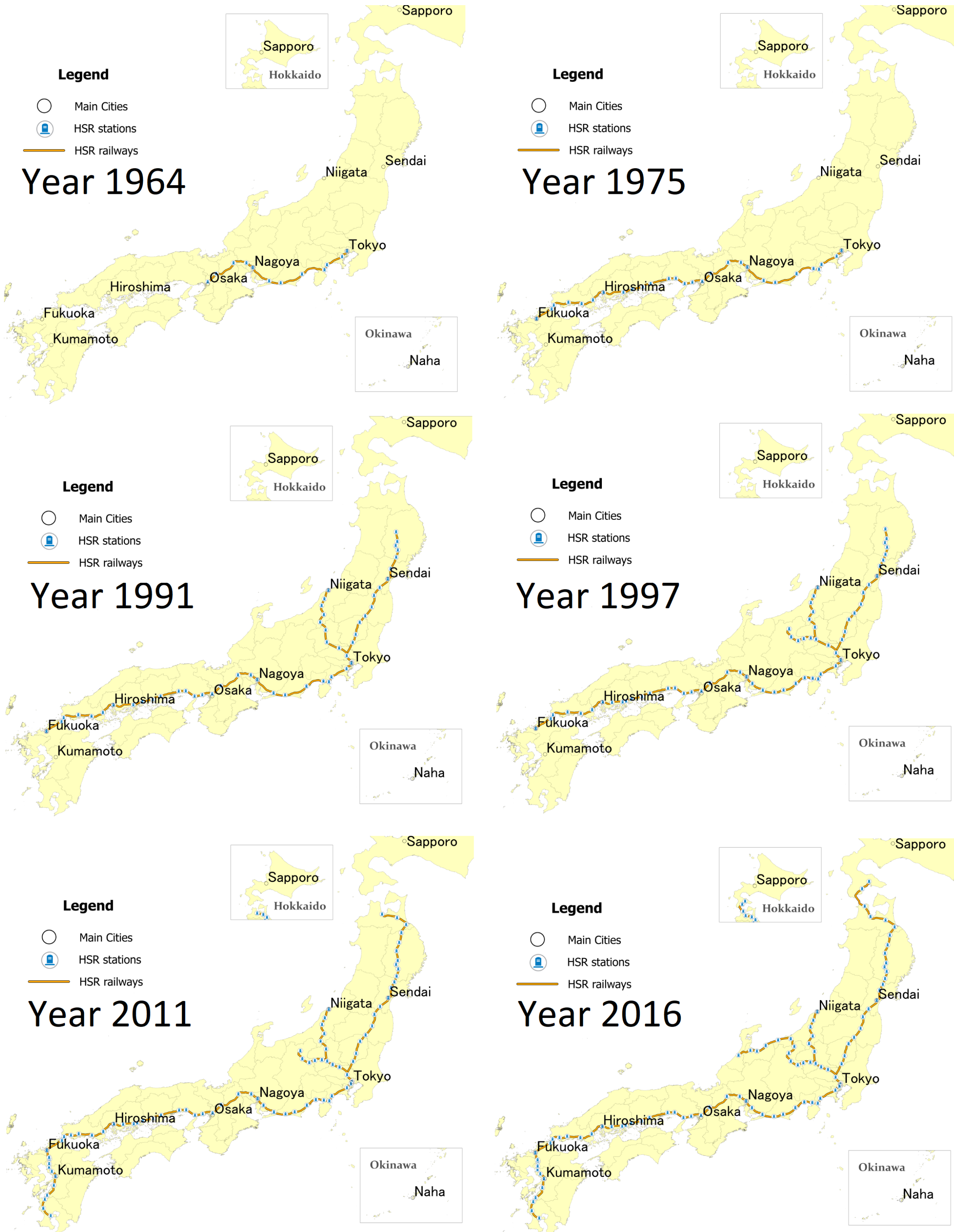

Figure 1: Historical Evolution of HSR networks in Japan

HSR Network Time-series data of railway network from 1950 to 2020 in Japan are obtained from the National Land Numerical Information database, Japan. Based on the railway network data, we acquire geographical locations of HSR networks during 1983-2020, conforming with the land price data. The data are prepared for each time period when there were any changes in the HSR network (the construction of new station or line). [5]

Land price We use officially published land price data, which are announced by the Ministry of Land, Infrastructure, Transport and Tourism in Japan as the standard land price as of January 1st every year. The sample plots of land price, called standard sites, are distributed across 26,000 points all over Japan as of 2021. The points exist in 1374 out of 1741 cities, covering 98.6% of the total population of Japan. The selection of standard sites for land price is based on the Public Notice of Land Prices Act. The sites are distributed within the area of each city so as to represent the overall level of the land price of the entire cities. By averaging all land price values within each city, we obtain a city-level land price. To control for inflation over time, the land price value is adjusted using a consumer price index (CPI) of each year, published by the Ministry of Internal Affairs and Communications of Japan. [6]

Sociodemographic variables From the SSDS, we obtain data for other sociodemographic variables: taxable income and population. The annual total taxable income in each city is reported from 1985 to 2019. This variable represents the overall economic situation at the city level. To investigate the impact of market access on individual-level economic conditions, we calculate the variable of income per capita by dividing the total taxable income by the number of taxpayers. The population at the city level is reported in the SSDS every 5 years from 1980 to 2015, and we estimate the annual number of populations through linear interpolation. Because our city-level population data ends at 2015, we extrapolate the population for the period from 2016 to 2020.[7]

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we use market access based on each city's geographical gravity center as a centroid point. The results based on the market access and calculated based on population centroid are available upon request.

[5]We exclude Yamagata and Akita Shinkansen in our market access calculation, as these two lines do not exceed the maximum speed of commercial operation of 200 km/h. This is because the Japanese government defines railroads exceeding 200 km/h as HSR. Therefore, Yamagata and Akita Shinkansen do not fall under the definition of HSR.

[6]The consumer price index is available at: https://www.stat.go.jp/data/cpi/

[7]The aggregate number of our extrapolated population in 2020 (126.2 million) is almost the same as the actual total population in 2020 (125.8 million).

Note for income and income per capita This study also employs income and income per capita as dependent variables along with the land price. This is because for the aggregate economy, locations with lower trade and search costs will have higher-performing firms, even if productivity is ex ante identical across all locations (Bernard et al. (2019)). Cities with firms that have higher productivity usually have higher wages (or income) in the city itself as well as in surrounding cities. In other words, a decrease in trade and search costs–in this study, due to market access—between two cities is likely to drive wages up in these two cities relative to those in other cities (Lin (2017)). [8] We also adjust income and income per capita using CPI, as same as we do in the land price.

3.2 Market Access Calculation

In this section, we explain the conceptual framework of market access and demonstrate how we calculate market access in an equation form. We aim to investigate the impact of market access growth–which is induced by HSR expansion– to economic development, addressing endogeneity issues in transportation infrastructure expansion. To do so, first, we calculate city-level market access, which is expressed as a potential demand of the market divided by the cost of getting passengers to the market.

Conceptually, market access indicates the market potential that each *city* faces given the geographical position of the *city* and other cites, which is widely used in transportation contexts (Redding and Venables (2004)) both in the freight (Donaldson and Hornbeck (2016)) and passenger transportation (Lin (2017)) contexts. Motivated by Donaldson and Hornbeck (2016) and Lin (2017), in this study, we calculate market access to represent the ability of a *city* to provide its residents with easy access to a large market. A *city*'s market access increases (1) when the travel time between cities are reduced, and (2) when the population of other cities increases; therefore, the market potentials around the *city* rise. In this study, HSR expansions reduce the traveling time.

We define the market access of origin city o as follows:

$$MA_{ot} = \sum_{d}^{o \neq d} \tau_{odt}^{-\theta} \times pop_{dt}, \tag{1}$$

where τ_{odt} is the travel time from origin city o to destination city d in year t, and pop_{dt}

[8] See Eaton and Kortum (2002) for theoretical details on how the labor cost equilibrium for the city is decided and see Lin (2017) for theoretical proofs on how the increase in the market access leads to an increase in wages.

is the population size in city d in year t. In other words, the market access of a certain city is a sum of connectivity with all other cities, and connectivity to each destination is expressed as the population size of the destination divided by traveling time to the θth power. Therefore, the market access of a city increases if people can travel to other cities with larger populations via means with shorter travel times. We use hours as the unit of measure for τ_{odt}.

As mentioned in Section 1, market access can capture the direct and indirect effects of HSR, which goes as follows:

Direct Impact. City o's market access directly increases when a new HSR station is built in the city o and connected with the existing HSR network. The direct connection can enhance the potential demand for access between city o and city d because the traveling time between the cities decreases (which is denoted by the reduction in τ_{odt} in Equation1).

Indirect Impact. City o's market access indirectly increases if new HSR stations are built or new HSR connections are established with destinations other than city o or d. This is because city o itself is not directly connected to the newly built HSR network, and people in city o can travel to another newly-connected city and then use the new HSR network to travel to city d. Thus, the market access of city o increases thanks to the reduction in travel time, which is equivalent to a reduction in τ_{odt}.

We provide an example of numerical interpretation for MA_{ot}. Suppose that there are two cities, o and d. If the minimum traveling time between o and d is 1 hour, one unit of the population in city d corresponds to one unit of the market access of city o. If an HSR expansion occurs and the travel time between o and d is reduced by half, one unit of the population in d will correspond to 2^{θ} units of market access in o.

The parameter θ is originally taken as trade elasticity, which represents how much trade cost affects trade flows (Donaldson and Hornbeck (2016)). In the context of passenger travel, θ is recognized as the elasticity of how much traveling cost affects passenger flows. While θ depends on the purpose of the calculation, we set $\theta = 3$ according to previous studies that have targeted passenger travel (Chang and Zheng (2022b), Lin (2017)). Therefore, a 50% reduction in travel time between the two cities of o and d causes an increase in the impact of the d's population on the market access of o by $2^3 = 8$ times.[9]

[9] The different values of θ are determined by how passengers are elastic towards travel time; previous works typically straddled the two extreme estimates of 1 to 26.83 (Chang and Zheng (2022b) and Donald-

To calculate market access based on Equation(1) in practice, we first estimate τ_{odt} for all combinations of 1741×1741 cities in Japan from 1983 to 2020 based on Chang and Zheng (2022b). We employ several assumptions about how people travel from the origin city to the destination city. The fundamental idea is that passengers choose the options with minimum travel time between cities. We prepare two options as follows:

Option 1 Travelling along the Euclidean distance at 60 km/h. We measure the Euclidean distance between the geographical gravity centers of city o and city d. Dividing the distance by 60 km/h, we derive the travel time for all cities by constructing all possible combinations of cities.

Option 2 All access are made through the HSR network. Figure 2 shows an example of traveling by HSR. First, people in city o travel from the geographical gravity center of city o (O1) to the nearest HSR station (S1). Using the HSR, they travel to another HSR station nearest to city d (S4). Finally, they travel from the station to the geographical gravity center of city d (D1). The assumption is that people travel at 60 km/h between the city center and the station and at 175 km/h along the HSR lines between stations.

We choose 60 km/h as a reasonable non-HSR commuting speed for two reasons. First, previous works and statistics from the Ministry of Transport of Japan show that the average travel speed of Japanese conventional passenger trains was 60 km/h (Koster et al. (2021), Hayakawa et al. (2021)), and the average driving speed of highways was 59 km/h (Ministry of Land, Infrastructure, Transport and Tourism (2013)).

Between these two options (Option 1 and 2), we assume that people adopt that with the shortest travel time, and the combination of the shortest travel time constructs a travel time matrix of 1741×1741 city-to-city connections.

Figure 3 describes the distribution of the evolution in market access from 1983 to 2020. The black line is the HSR network that already existed as of 1983. The green dotted line is the HSR network that was expanded between 1983 and 2020. The darker red colors in the map indicate greater market access growth. This map indicates that market access has increased for 38 years mainly in cities close to the HSR network, for both the areas already covered the 1980s and the areas where the HSR lines were expanded by 2020.

son and Hornbeck (2016)). In Supplementary Materials, we verify the robustness of our results to choosing alternative values for θ within (and even outside of) this range. Consequently, we do not find substantially different results estimates than estimates using $\theta = 3$.

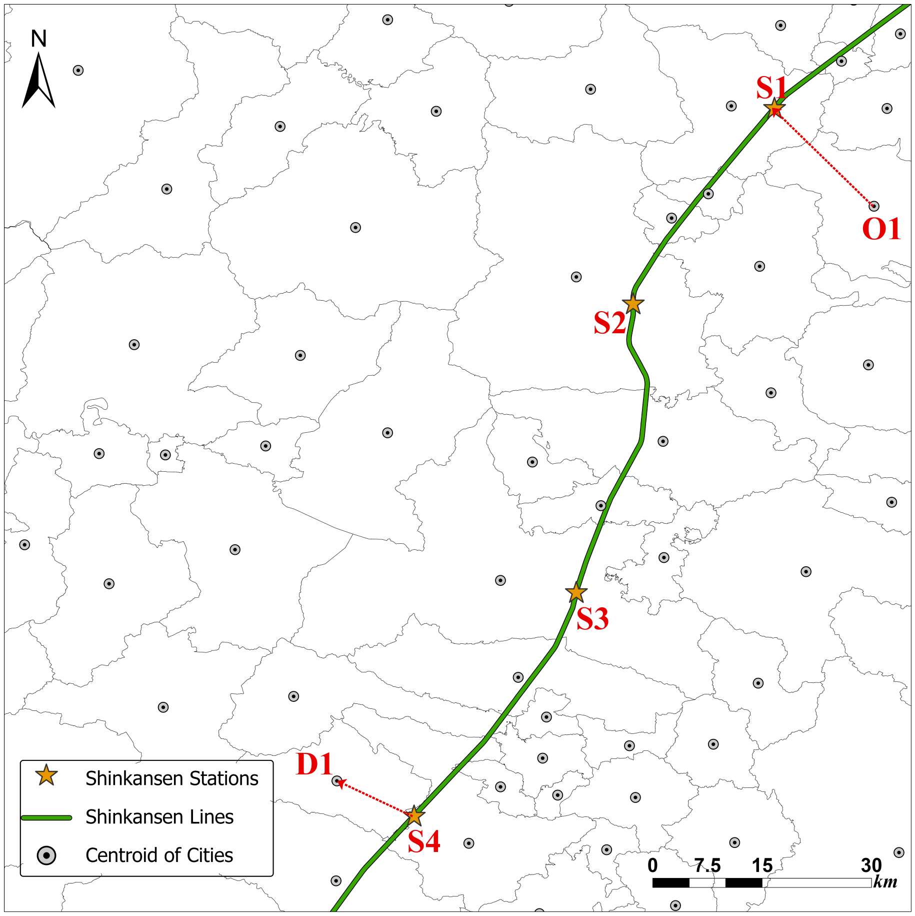

Figure 2: Basic Idea of Travel Time Matrix Calculation.

For the construction of Figure 2, we refer to Chang and Zheng (2022b).

3.3 Categorization of Regions

One of the main objectives of this study is to examine whether regional disparities exist in terms of the impacts of the HSR expansion on economic development. To accomplish this, we adopt the classification of regional categories officially defined by the Japanese government, which categorize the prefectures by population, the level of economic development (i.e, GDP), and urbanization. Table 1 shows the classification of the areas that we use for subsample regression analysis.

Nationwide The first category is nationwide, which includes all prefectures of Japan. By focusing on all prefectures, we can estimate the overall impact of the HSR expansion on economic development in Japan.

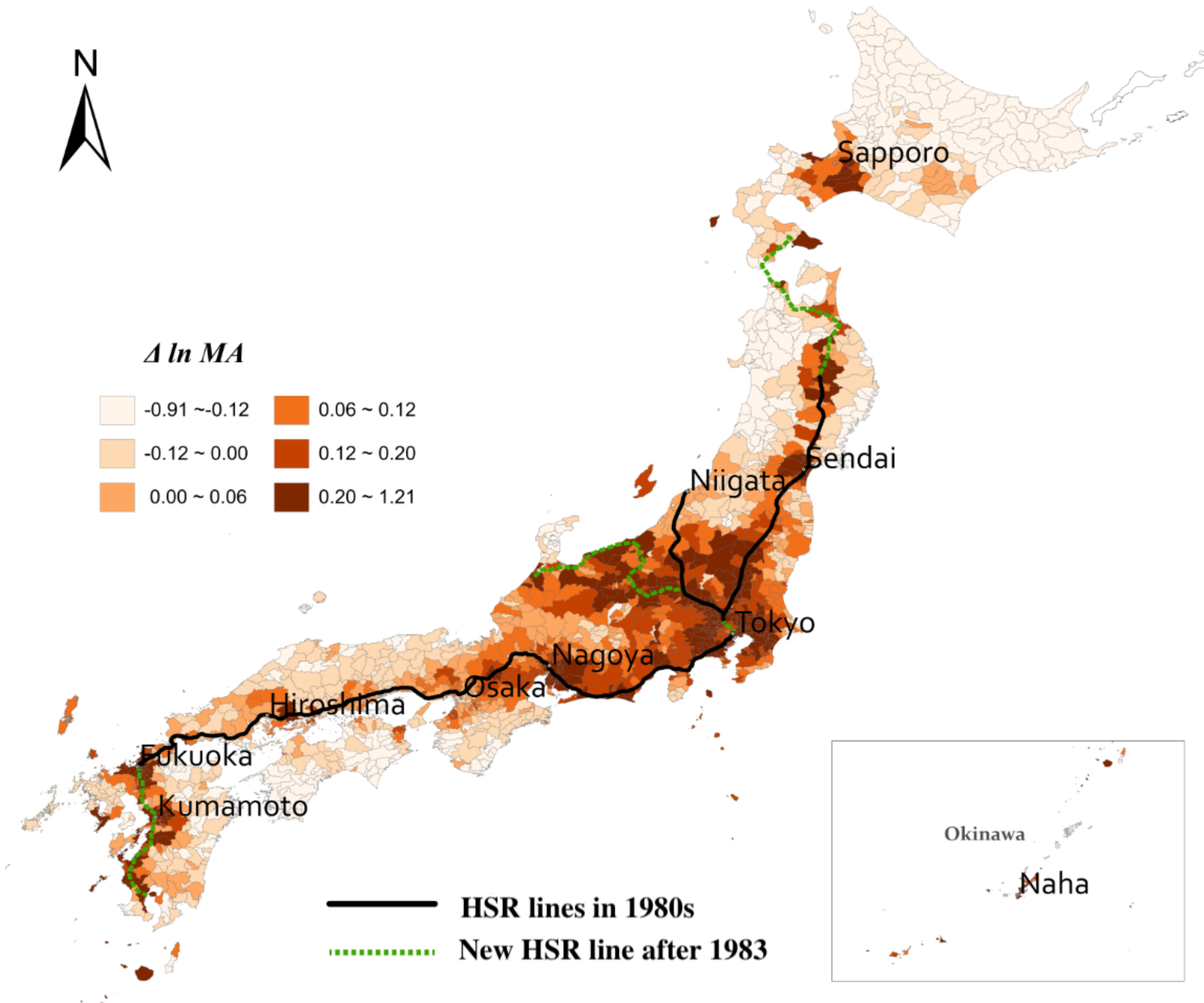

Figure 3: Market Access Evolution in Japan

Tokyo The second category, Tokyo, consists only of Tokyo prefecture. Tokyo is the center of economy, industry and politics, as it has the largest population of any area in Japan. In addition, the Japanese HSR network is shaped such that all lines are spread from Tokyo as the center toward the major cities of each region.

Megacities The third category is Megacities, including the prefectures that form the three largest metropolitan areas in Japan: the Tokyo area, Osaka area, and Nagoya area. This can be regarded as the second-largest regional category with respect to economic level.

Regional cores The fourth category, Regional cores, consists of the prefectures where the four local central cities, Sapporo, Sendai, Hiroshima, and Fukuoka, are located. These cities are called Regional cores and are recognized as the center of the economy in each region of Japan, having important roles in the economy, industry, politics, and population in that region (Ministry of Land, Infrastructure, Transport and Tourism (2014)).

Local cities Finally, Local cities is composed of the prefectures that are not included in the categories mentioned above. Figure 4 shows a map that is color-coded by the regional classification defined above.

Table 1: Definition of Regional Category

Regional Categories (R)	**Included Prefecture**
Nationwide	All
Tokyo	Tokyo
Megacities	Tokyo, Kanagawa, Saitama, Chiba, Aichi, Kyoto, Osaka, Hyogo
Regional cores	Hokkaido, Miyagi, Hiroshima, Fukuoka
Local cities	All other prefectures which are not included in above categories.

Table 2 shows the mean and standard deviation of the variables through the target period by regional category. In terms of the main economic variables, land price, income, and income per capita show the highest value for Tokyo and the second highest for Megacities. The economic variables for Regional cores and Local cities show a similar level. While the average land price is higher for Local cities than for Regional cores, average income and income per capita are higher in the latter. The mean value of market access is the highest in Tokyo, followed by Megacities, Local cities, and Regional cores. As

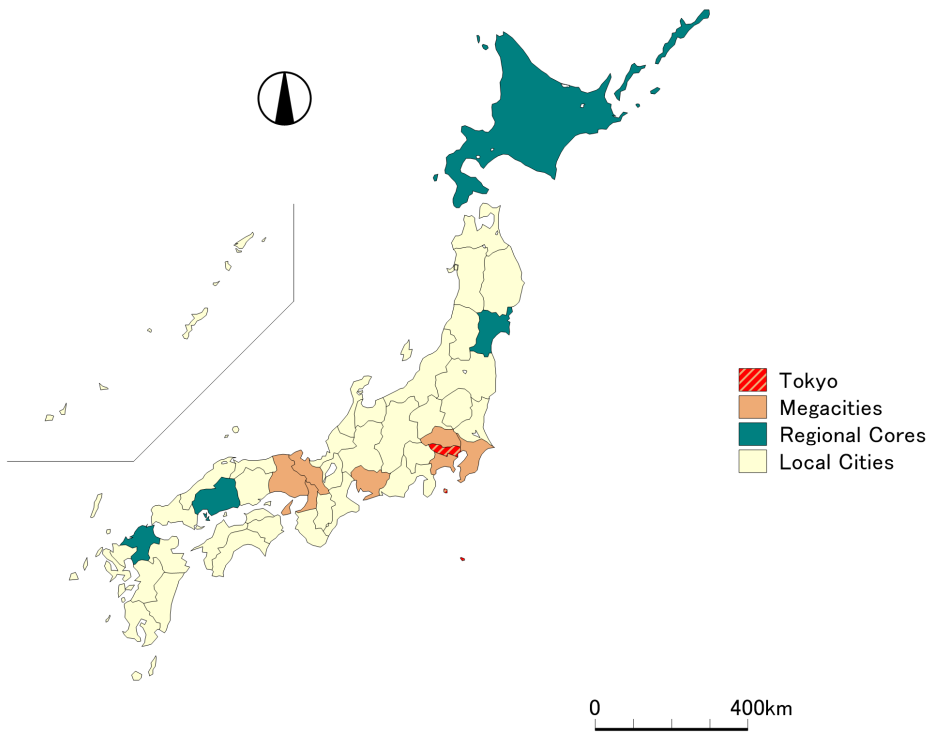

Figure 4: Regional Category

a whole, the average yearly growth in market access is 0.4% in Japan. By region, market access in Tokyo shows the highest growth (0.6%), followed by that in Megacities (0.5%), Regional cores (0.4%), and Local cities (0.3%).

Table 2: Mean and Standard Deviation of Variables

	Nationwide	Tokyo	Megacities	Regional cores	Local cities
Land Price	130.0	992.2	297.3	59.7	64.5
	(495.7)	(2005.2)	(899.7)	(142.6)	(53.0)
Income	101.0	403.0	253.0	64.7	58.3
	(293.0)	(429.0)	(534.0)	(237.0)	(115.0)
Income per capita	2940.2	4092.3	3513.4	2836.1	2767.2
	(622.2)	(1137.9)	(747.9)	(404.1)	(489.6)
Population	72.2	201.8	153.3	53.0	49.0
	(178.5)	(201.6)	(308.1)	(172.4)	(85.4)
Market Access	306.1	3252.6	1118.7	66.2	86.3
	(872.3)	(2623.1)	(1599.9)	(128.9)	(191.1)
Annual Market Access Growth	0.4%	0.6%	0.5%	0.4%	0.3%
	(0.004)	(0.005)	(0.003)	(0.005)	(0.004)
Number of Cities	1,739	62	376	295	1,068

Unit: Land Price: 1,000 JPY; Income: 1 billion JPY; Income per capita: 1,000 JPY / person; Population: 1,000 person; Market Access: 1 million person / $hour^3$. Market Access Growth: %.

3.4 Baseline Estimation

We regress the log value of economic outcomes in city o in year t on log value of Market Access for each city (MA_{ot}) , a prefecture-by-year fixed effect (δ_{it}), a city fixed effect (δ_o), and a cubic polynomial in city latitude and longitude interacted with year effects ($f(x_o, y_o)\delta_t$), referring to Donaldson and Hornbeck (2016):

$$\ln V_{ot} = \beta_R I_{o \in R} \ln(MA_{ot}) + \delta_{it} + \delta_o + f(x_o, y_o)\delta_t + \epsilon_{ot}. \tag{2}$$

To see the heterogeneous impact of market access on economic outcomes by the size of a region, we allow the coefficient of interest β_R to differ by the type of region (R) to which a city belongs. Note that for $R =$ *nationwide*, which includes entire prefectures, our specification is equivalent to Donaldson and Hornbeck (2016). The mapping from prefecture to region is defined in Table 1 and visualized in Figure 4. ϵ_{ot} is the error term.

4 Result

4.1 Main Result

Table 3 presents the results of our baseline regression result from Equation 2, taking log land price (Panel A), log income (Panel B) and log income per capita (Panel C) as dependent variables. Each column of the table presents the results for one region category. For example, the first column of Panel A shows the nationwide estimation result of Equation 2, taking land price as a dependent variable. Likewise, the second column of Panel B represents the estimation result of Equation 2 for Tokyo, taking income as a dependent variable.

We begin by explaining the impact of the HSR on the land price (presented in Panel A). Overall, the increase in market access leads to the growth of the land price. Nationwide, market access is estimated to have a statistically significant impact on land price: First, a 1% increase in market access increases land price by approximately 0.176% (Column (1)). Increases in land price due to the market access increase will be highest in Regional cores (0.469%), followed by Tokyo (0.408%) and Megacities (0.332%). We do not see any land price increases in cities in the Local cities category, as the estimated coefficient for it is statistically insignificant and close to zero (-0.030), indicating regional disparity, as not all regions experience economic growth due to market access enhancement.

We then explain the results for income in Panel B of Table 3, which presents the results on the impact of market access increase on income. Similar to increases in land price, market access growth increases income. A 1% increase in market access increases the national average for income by 0.425%. The estimated elasticity is larger for Tokyo (of 1.230%) and Megacities (of 1.116%) than for Regional cores (0.827%), and Local cities (0.179%). While all positive, the results show that the differences in the coefficients across regions exist, as Tokyo's coefficient is more than six times higher than that for cities in the Local cities category.[10]

From the results above, it seems evident that the HSR expansion induces both economic growth and regional disparities. Such a conclusion becomes more evident when we examine the impact of market access expansion on income per capita, as it is the indicator that shows the standard of living and quality of life of the population. The results in Panel C (income per capita) suggest the regional disparity across the city categories, particularly because Regional cores do not benefit from the market access expansion, and Local cities even demonstrate negative coefficients (-0.020). In contrast, income per capita increases by 0.023% if market access increases by 1% nationwide, by 0.327% in Tokyo and by 0.269% in Megacities.

4.2 Endogeneity in HSR Expansion

The baseline specification controls the important endogeneity concern that the Shinkansen network expansion might have been intended to promote specific regions' economic growth. In our specification, the prefecture-year fixed effect term in Equation(2) would capture relative increases in economic outcomes driven by prefecture-specific shocks, and city fixed effects control the time-invariant characteristics of each city, which affects HSR network expansion.

There are remaining endogeneity concerns that our baseline specification cannot resolve. The route connection between stations is correlated with population distribution, which can be correlated with economic outcomes such as land price.

To address this concern, we incorporate an 'exogenous' hypothetical HSR network

[10]Additionally, the increase in income due to the market access expansion might be associated with population growth and specialization patterns. While examining the causal relationship between population and income (per capita), and specialization pattern and income (per capita) is beyond the scope of our research, we check whether market access expansion affects population growths and specialization patterns to indirectly conjecture the reason behind the income growths. Data and results on population and specialization patterns are presented in Section A2.

Table 3: Impact of Market Expansion on Economic Outcomes

Panel A: Land Price	(1) Nationwide	(2) Tokyo	(3) Megacities	(4) Regional cores	(5) Local cities
ln(Market Access)	0.176***	0.408**	0.332***	0.469***	-0.030
	(0.036)	(0.193)	(0.079)	(0.078)	(0.040)
R-squared	0.998	0.993	0.998	0.998	0.998
N	60,861	2,170	13,159	10,325	37,377
Panel B: Income	**Nationwide**	**Tokyo**	**Megacities**	**Regional cores**	**Local cities**
ln(Market Access)	0.425***	1.230***	1.116***	0.827***	0.179***
	(0.017)	(0.094)	(0.046)	(0.039)	(0.012)
R-squared	0.998	0.993	0.998	0.998	0.998
N	60,861	2,170	13,159	10,325	37,377
Panel C: Income per capita	**Nationwide**	**Tokyo**	**Megacities**	**Regional cores**	**Local cities**
ln(Market Access)	0.023***	0.327***	0.269***	-0.012	-0.020***
	(0.004)	(0.007)	(0.025)	(0.010)	(0.003)
R-squared	0.977	0.959	0.963	0.962	0.975
N	60,861	2,170	13,159	10,325	37,377

Note: Standard errors in parentheses. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.
Estimated coefficients in Table 3 are weighted by the population in 1983. For example, the results in Panel A are estimated after weighting the population from 1983, following Donaldson and Hornbeck (2016). Prefectures by year fixed effects, city fixed effects, and cubic-polynomial fixed effects are included in all models.

as an instrument for the realized network. Specifically, we calculate the HSR network with the lowest construction cost that connects all incumbent stations on the actual network using the least-cost path (LCP) spanning tree algorithm. The results from the LCP algorithm correspond to the question of how HSR expansion might have been done if construction cost minimization was the only concern. Thus, we construct a hypothetical LCP spanning tree network using land-cover and geographical traits (i.e., size of the ocean area and elevations of the mountains) data and following Faber (2014)'s optimal route algorithm to compute the least costly construction paths between any bilateral pair of targeted nodes.[11] Note that the network generated by the LCP method is not correlated with population distribution according to the definition of LCP but is still correlated with the baseline market access, which suffices as a proper IV.

Then, we use the calculated construction cost between stations, and identify the routes that connect all nodes of stations that minimizes the construction costs, referring to Kruskal (1956). These processes allow us to calculate the hypothetical market access

[11] The land cover data are retrieved from JAXA ALOS Hgih-Resolution Land Use and Land Cover Map Products: https://www.eorc.jaxa.jp/ALOS/en/dataset/lulc_e.htm; the digital elevation data are retrieved from JAXA ALOS Global Digital Surface Model "ALOS World 3D - 30m (AW3D30)": https://www.eorc.jaxa.jp/ALOS/en/dataset/aw3d30/aw3d30_e.htm"

based on the network generated by the LCP method. We present our LCP network and actual HSR network in Figure 5.

We use LCP-based marker access as an instrument of the market access in each city used in the baseline specification. In other words, we employ a two-step least squares (2SLS) approach in Equation 2 by using LCP-based market access as an instrument for the actual market access of cities. In what follows, we present and explain our IV regression results which takes land price as a dependent variable.[12]

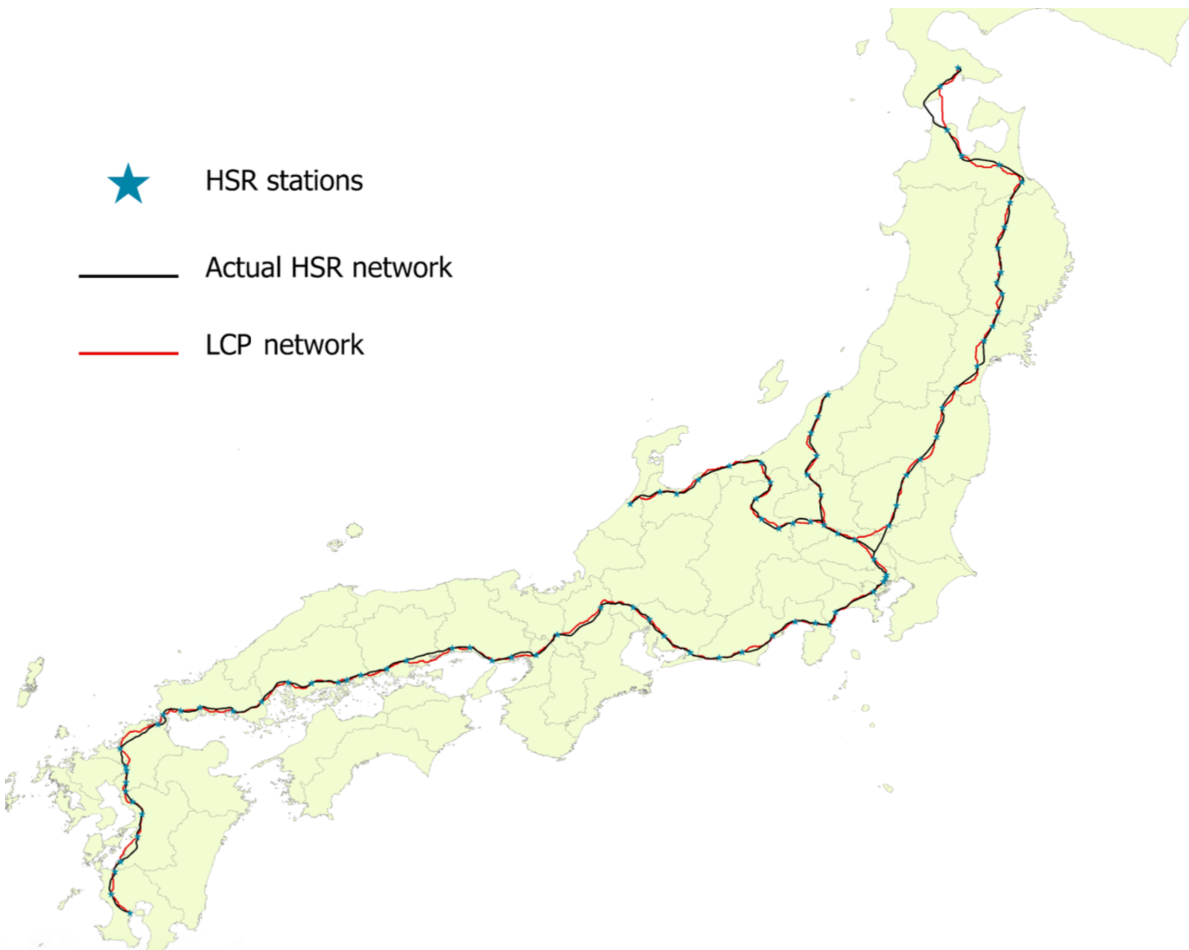

Figure 5: LCP network and actual HSR network

Table 4 reports the estimation results of each city after instrumenting actual market access with hypothetical market access. First, Column (1) reports that cities with greater LCP market access experienced higher market access from 1983 to 2020. Next, most of

[12]Results on income and income per capita are presented in Supplementary Materials, and we do not find qualitatively different results from them to the results from land price.

our results imply that the cities with greater LCP market access in each year experienced increases in land price (Column (2)). Column (3) reports the implied instrumental variable estimates; the implied impact of market access on land price is larger than the baseline estimate (Column (4)). Most of the results imply that the coefficients of IV estimates are slightly larger than the baseline parameters.

Overall, similar to the results in Section 4.1, while we observe that most of the estimated coefficients in Column (3) display positive coefficients, the results show evidence of regional disparities. In particular, Local cities in Panel E do not experience an increase in land price, even if we instrument market access to LCP market access.

The IV estimates do not reject a considerable impact of market access on economic outcomes. Thus, the results with IVs reaffirms that our baseline specification controls endogeneity concern and therefore is robust. Therefore, we employ the baseline estimates to counterfactual simulations from the next sections.

5 Counterfactual Simulations

Using the estimated parameters, we now conduct a series of counterfactual simulations. First, we reconfirm the economic impacts of HSR by assuming that the railroads did not exist after 1983. Next, we conduct a policy simulation for Japan's future HSR development policy.

5.1 Impact of the Absence of Railroads

Based on our estimation results, we confirm that HSR facilitates economic growth and aggravates regional disparity at the same time. However, what would happen if there was no HSR in the first place? Would the opposite result–a decline in economic outcomes and the alleviation of regional disparities— happen? To answer this question, we first construct a counterfactual scenario that assumes the absence of HSR networks.

We proceed by recalculating the travel time matrix to construct a counterfactual without HSR networks. Specifically, we need to calculate the lowest travel time under the assumption that people are not using HSR. The process is as follows:

1. **Step 1. Calculate the lowest travel time**: We calculate the Euclidean distance with a travel speed of 60 km/h from the gravity centers of the origin city to destination

Table 4: Impact of Market Access on Land Price: Instrumented

	Panel A: National			
Land Price (1983 to 2020)	ln(Market Access) (1983-2020)	Land Price (1983 to 2020)		
	Model (1)	Model (2)	Model (3)	Model (4)
	OLS	OLS	2SLS	OLS
ln(Market Access)			0.210***	0.176***
			(0.037)	(0.036)
ln(LCP	1.028***	0.215***		
Market Access)	(0.006)	(0.039)		
N	42,440	42,440	42,440	42,440
R-sq	0.999	0.979	0.979	0.979
	Panel B: Tokyo			
	Model (1)	Model (2)	Model (3)	Model (4)
	OLS	OLS	2SLS	OLS
ln(Market Access)			0.423**	0.408**
			(0.191)	(0.193)
ln(LCP	0.991***	0.418***		
Market Access)	(0.005)	(0.189)		
N	2,079	2,078	2,079	2,079
R-sq	0.999	0.981	0.981	0.981
	Panel C: Megacities			
	Model (1)	Model (2)	Model (3)	Model (4)
	OLS	OLS	2SLS	OLS
ln(Market Access)			0.336***	0.332***
			(0.09)	(0.08)
Log LCP	0.931***	0.310***		
Market Access)	(0.030)	(0.085)		
N	12,065	12,065	12,065	12,065
R-sq	0.999	0.979	0.979	0.979
	Panel D: Regional cores			
	Model (1)	Model (2)	Model (3)	Model (4)
	OLS	OLS	2SLS	OLS
ln(Market Access)			0.506***	0.469***
			(0.084)	(0.078)
ln(LCP	1.047***	0.533***		
Market Access)	(0.088)	(0.006)		
N	6,146	6,146	6,146	6,146
R-sq	0.999	0.970	0.970	0.970
	Panel E: Local cities			
	Model (1)	Model (2)	Model (3)	Model (4)
	OLS	OLS	2SLS	OLS
ln(Market Access)			-0.0193	-0.0300
			(0.041)	(0.040)
ln(LCP	1.042***	-0.020		
Market Access)	(0.003)	(0.043)		
N	24,229	24,229	24,229	24,229
R-sq	0.999	0.955	0.955	0.955

Note: Standard errors in parentheses. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Estimated coefficients in Table 4 are weighted by the population in 1983. For example, the results in Panel A are estimated after weighting the population from 1983, following Donaldson and Hornbeck (2016). Prefectures by year fixed effects, city fixed effects, and cubic-polynomial fixed effects are included in all models.

city, as mentioned in Section 3, using ArcGIS. We use 40–80 km/h for the robustness checks and present the results in the Supplementary Materials.

2. **Step 2. Check the validity of the calculated lowest travel time:** Highway can stand as an alternative of long-distance travel by HSR (Baum-Snow et al. (2017)). We

therefore proceed the validation of **Step 1** by comparing (1) the length of actual highways to (2) the Euclidean distance (calculated through **Step 1**), between major cities in Japan (Tokyo, Osaka, and Nagoya). We refer to Chang and Zheng (2022b) for this process. The ratio of (1) divided by (2) is approximately 1.2-1.3, which is acceptable and close to Chang and Zheng (2022b). Thus, we confirm that the calculated travel time in **Step 1** is a valid proxy of travel time for non-HSR travel mode.

We begin our estimations by assuming that the the total number of population is held fixed at 2020 levels but follow the respective city's population distribution of 1983 and try other assumptions later, referring to Donaldson and Hornbeck (2016). This is because we assume that, for example, if accessibility would not have increased in the absence of HSR, the population distribution in 2020 would have been different from the actual population distribution in 2020. We also use the population distribution in 2000 and 2020 for the robustness checks.

To this end, we calculate the impact of market access expansion on economic outcomes under the assumption that HSR did not exist. Mathematically, this can be expressed as:

$$\%\overline{\Delta V}_R = \hat{\beta}_R \times \%\overline{\Delta MA'}_R, \tag{3}$$

where $\%\overline{\Delta V}_R$ is the averaged percentage change in the economic outcomes V_{ot} in region R, and $\%\overline{\Delta MA'}_R$ is the weighted mean of the percentage change in the market access in region R under the assumed absence of all HSR lines, which is calculated as:

$$\%\overline{\Delta MA'}_R = \frac{\sum_{o \in R}(w_o \times \%\Delta MA'_o)}{\sum_{o \in R} w_o}, \tag{4}$$

where $\%\Delta MA'_o$ is the difference between newly calculated market access without HSR and market access with HSR in city o in 2020, and w_0 is the weight for each city o. We use the population of city o in 2020 as the weight. The change in market access for each city, $\%\Delta MA'_o$, is calculated as follows:

$$\%\Delta MA'_o = \frac{(MA^*_{ot} - MA_{ot})}{MA_{ot}} \times 100, \tag{5}$$

where MA^*_{ot} is a newly calculated market access assuming the absence of the HSR in year t (this case, $t = 2020$). We use this type of calculation method for further counterfactual simulations by substituting the counterfactual values of MA'_{ot} for the newly calculated market access reflecting each policy scenario s and then calculate the difference between

MA_{ot} to estimate the changes in the economic outcomes. We further discuss this issue in Section 5.2.

Based on the calculation from equations 4 and 5, without HSR networks, market access in Japan would fall by 13.14% from that with HSR; it would fall by 6.70% in Tokyo, 8.23% in Megacities, 15.57% in Regional cores, and 18.41% in Local cities.

We present our results in Table 5, with the population level fixed at the year 2020 level, but we follow the population distribution levels in 1983 (Column 1), 2000 (Column 2) and 2020 (Column 3). The results in Table 5 refer to the changes of the value of each economic outcome compared to the situation where we have HSR (in year 2020), assuming that there was no HSR in the first place, thus from 1983. For example, the first column of Panel A refers to the changes in the nationwide land price; if there were no HSR, the land price would fall by 2.730%.

Our results are straightforward. First, the absence of HSR networks leads to a reduction in national economic outcomes. As seen in Panel A, the land price falls approximately by 2.730%, followed by income (6.592%) and income per capita (0.357%). Second, however, in some sense, the absence of HSR alleviates regional disparity by increasing the economic outcomes of Local cities by 0.416%. Furthermore, the highest economic loss would be in Tokyo, which would experience a fall in land price by 8.193%, in income by 24.7%, and in income per capita by 6.567% without HSR, which further implies that the economic benefits of HSR construction have not been equally distributed. Overall, the effect of the absence of HSR is more significant in Column (1) than in Column (2) and in Column (2) than in Column (3).

5.2 Policy Evaluation

In this section, using the estimation results from Section 4, we perform a series of counterfactual simulations to evaluate future HSR-related policies in Japan. Because our results in Section 4 imply that HSR would boost economic developments while worsening regional disparity, evaluating whether future HSR schemes in Japan are also going to continue the same implications is our main interest. Thus, our counterfactual exercises would answer our research question: Is HSR double-edged?

Table 5: Impact of the Absence of Shinkansen Networks

		Difference (%)		
		(1)	(2)	(3)
		Population Distribution		
		1983	2000	2020
Panel A: Nationwide	Land price	-2.730	-2.603	-2.312
	Income	-6.592	-6.285	-5.583
	Income per capita	-0.357	-0.340	-0.302
Panel B: Tokyo	Land price	-8.193	-6.930	-2.735
	Income	-24.700	-20.891	-8.245
	Income per capita	-6.567	-5.554	-2.192
Panel C: Megacities	Land price	-5.755	-5.092	-2.734
	Income	-19.345	-17.117	-9.189
	Income per capita	-4.663	-4.126	-2.215
Panel D: Regional cores	Land price	-6.356	-6.011	-7.303
	Income	-11.207	-10.600	-12.878
	Income per capita	0.163	0.154	0.187
Panel E: Local cities	Land price	0.416	0.442	0.552
	Income	-2.484	-2.636	-3.295
	Income per capita	0.278	0.295	0.368

Note: Taking the year 2020 with HSR as a benchmark, 'Difference' refers to the change in economic outcomes when we assume there was no HSR.

5.2.1 Constructing Policy Evaluation Counterfactuals

The Japanese government, seeking to achieve economic development and regional development, announced two plans for future HSR expansions, as presented in Table 6. The first plan is to develop a linear train, the Linear Shinkansen (also known as Chuo Shinkansen), which is being built between Tokyo and Nagoya with the intention to further extend it to Osaka. Linear Shinkansen is projected to connect Tokyo and Nagoya in 40 minutes (which takes 2 hours of traveling time by Shinkansen in 2022) and Tokyo and Osaka in 67 minutes (which takes 3 hours of traveling time by Shinkansen in 2022), with a top speed of 500 km/h (314 mph). On May 27, 2011, the Japanese government authorized the beginning of the construction. The connection between Tokyo and the Nagoya stretch of the Linear Shinkansen is projected to open in 2027.[13]

The second plan is to connect the regional Shinkansen stations–in this context, other than Tokyo and Megacities–to the existing mainstream line, thus enhancing the acces-

[13] The Nagoya–Osaka extension is estimated to open in 2037.

sibility between Local cities and developed areas (Tokyo and Megacities). The plan includes the Hokuriku, Kyushu and Hokkaido regions, with detailed plans to build 15 new stations. This plan will also reduce the travel time between regional stations and Tokyo; for example, as of 2021, the travel time between Tokyo and Sapporo was approximately 8 hours, and once construction is completed, travel times between Tokyo and Sapporo could fall to approximately 4 hours.

Ultimately, the Japanese government aims to achieve both plans–stages of completion for the Linear Shinkansen are planned for 2027 (Tokyo-Nagoya line) and 2037 (Tokyo-Osaka line), and the regional expansion is planned to be completed in 2031. Thus, we set 2031 as the benchmark year for our counterfactual simulations which evaluates the future policies mentioned above for two reasons. First, while the expected locations of soon-to-be-constructed stations between Tokyo and Nagoya (planned to be completed in 2027) were announced as of 2022, allowing us to construct our counterfactual based on the actual locations of stations, the locations of new stations between Nagoya and Osaka (planned to be completed in 2037) are not yet decided. Second, because the regional expansion would finish in 2031, we set 2031 as the benchmark to maintain the consistency of the two scenarios. Figure 6 presents how the HSR networks of Japan will be extended in 2031; the upper panel shows the HSR networks in 2020, and the lower panel displays HSR networks will be, once the linear HSR and regional expansions are completed in 2031.

While it is generally agreed that HSR brings economic benefits, there are massive construction costs before such benefits are realized. For example, the total projected cost of the Linear Shinkansen from Tokyo to Osaka is approximately 9 trillion JPY (approximately $75.83 billion). From Tokyo to Nagoya, the construction costs are expected to balloon by 1.5 trillion JPY (about $13.7 billion) above the initial estimate of 5.5 trillion JPY (approximately $47.35 billion) because of construction challenges, according to JR Tokai and the Japanese government.[14]

On the other hand, regional expansion is also a costly decision, and the estimated cost for regional expansion is around 3.97 trillion JPY ($34.18 billion); the construction costs are projected to be approximately 1.67 trillion JPY (approximately $14.5 billion) for the Hokkaido expansion alone, 1.68 trillion JPY (about $14.5 billion) for the Hokuriku expansion, and 0.6 trillion JPY (approximately $5.17 billion) for the Kyushu expansion.[15] Such

[14]The information of construction cost of the Linear Shinkansen is retrieved from: https://www.sankei.com/article/20210427-UBP3RRFOARJ5NAWR4KPL3PP2WU/

[15]The information of construction cost is retrieved from the reports of the Ministry of Land, Infras-

tremendous anticipated costs prompt policy evaluations of whether the economic benefits will compensate for the construction costs. Furthermore, because of the literature gap regarding whether HSR expansions provide economic growth equally to all regions, we are also interested in examining whether economic growth is focused in the center area and isolates lagging cities, thus causing regional disparities.

To this end, our counterfactual scenario answers the following questions:

1. Will the Linear Shinkansen and regional expansion plans (and both together) boost economic development, thus compensating for the construction costs?

2. Will the Linear Shinkansen and regional expansion alleviate regional disparities?

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tructure, Transport and Tourism: Hokkaido Shinkansen: https://www.mlit.go.jp/common/000207256.pdf; Hokuriku Shinkansen: https://www.mlit.go.jp/report/press/content/001397617.pdf; Kyushu Shinkansen: https://www.mlit.go.jp/common/001229421.pdf

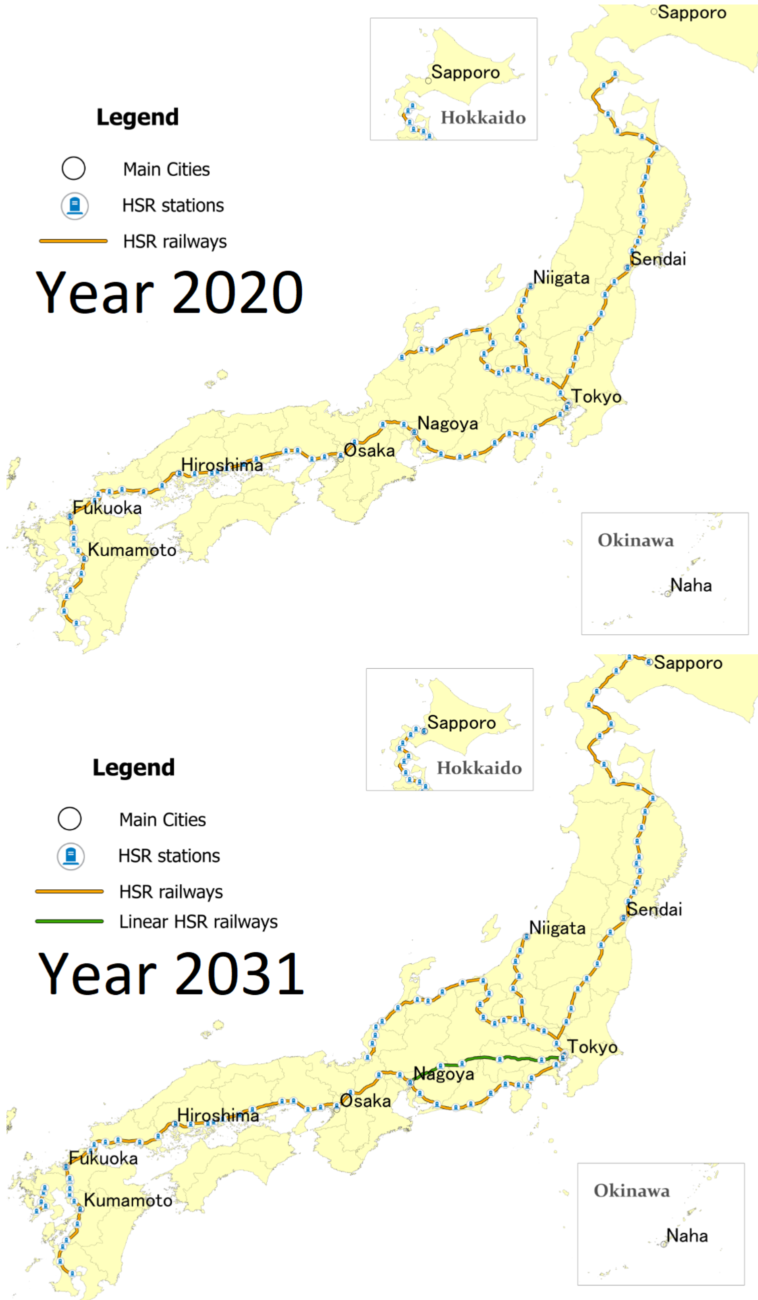

Figure 6: HSR networks for counterfactual simulations

To isolate the pure impact of each policy, we first simulate a no-policy counterfactual in which the Shinkansen network was maintained at the prepolicy level until 2016.[16] The quantification of each policy's economic impacts is reported relative to this no-policy counterfactual. We do this because we need a benchmark against each policy's economic

[16] Recall that there was no further construction of HSR stations between 2016 and 2022.

outcomes.

Then, we run three sets of counterfactual simulations. The first is called the Linear Shinkansen policy, which assumes that *only* the Linear Shinkansen was constructed. The second is the regional expansion policy, which assumes that *only* regional expansion takes place. Then, we run both scenarios, which assumes that linear and regional expansion policies are implemented simultaneously. Table 6 provides a snapshot of the simulation exercises according to each scenario.

Figure 7 presents the change in the newly calculated market access of each scenario compared to the no-policy scenario (market access as of 2020), and darker colors indicate higher market access growth. Installing Linear Shinkansen will drastically improve the market access in Tokyo and Megacities areas. In contrast, the increase in market access would seem to be less significant in other areas. On the other hand, while market access does not substantially increase in Tokyo and Megacities in the Regional Expansion Scenario, market access grows rapidly in other areas, particularly in Hokkaido and the northern part of the Kyushu area. Implementing both scenarios shows increased market access value, which ranges on a relatively average value of the Linear Shinkansen and Regional Expansion Scenario.

Table 6: Scenario Descriptions

Scenario	**Descriptions**
Linear Shinkansen	Connect Megacities with extremely high-speed linear train
Regional Expansion	Connect Kyushu Hokkaido, and Hokuriku to the Megacities
Both	Linear Only + Regional Expansion
No Policy	Baseline: No Linear, No Regional Expansion

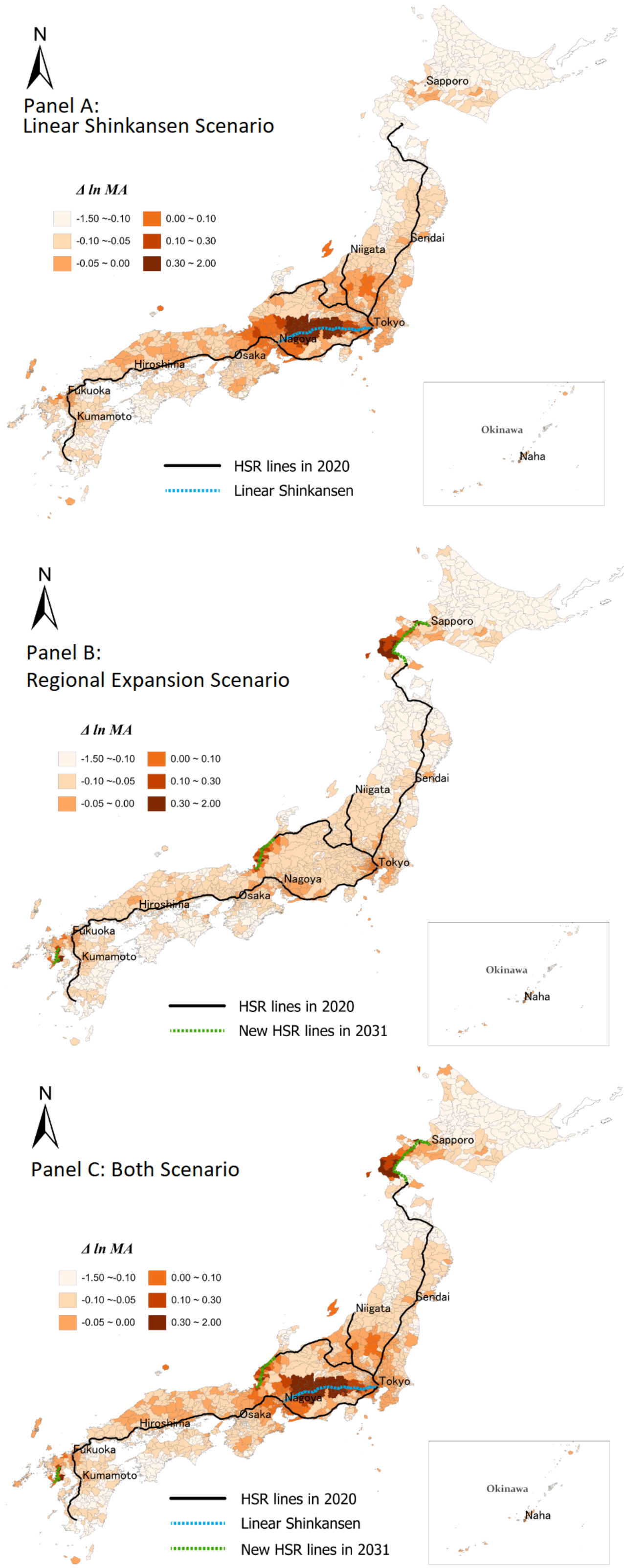

Figure 7: Market Access Change in Each Scenario

5.2.2 Result Interpretations from Policy Evaluation

We present our counterfactual simulation results in Table 7, which displays the changes in each economic outcome (land price, income, and income per capita). The five panels in Table 7 represent the simulation results of each region category of the corresponding scenario, which is presented in each column.[17] For example, in Panel A of Table 7, under the Linear Shinkansen scenario, land price would increase by 0.743% over that of the no policy scenario. Similarly, the results in the second column correspond to the Regional Expansion Scenario, indicating that the land price increases by approximately 0.121% nationwide over that under the no policy scenario. In the following paragraphs, we discuss the results by scenario.

Linear Shinkansen Scenario The economic benefits from installing Linear Shinkansen are concentrated in Tokyo and Megacities, although there are nationwide (as in Panel A) benefits such as increasing land price, income, and income per capita by 0.743%, by 1.794%, and by 0.097%, respectively. Putting aside that the national economic outcomes benefitted by the Linear Shinkansen, separately looking into each region provides clear images of the impact of the Linear Shinkansen scenario. First, in Tokyo (presented in Panel B), the land price grows by 1.342%, followed by a 4.047% increase in income and a 1.076% increase in income per capita. Likewise, in Megacities (shown in Panel C), installing Linear Shinkansen increases the land price by 1.066%, accompanied by 3.582% and 0.863% increases in income and income per capita.

The economic benefits of Linear Shinkansen would be diluted in Regional cores (Panel D), as we do not witness an increase in income per capita in Regional cores–while we do nationwide and in Tokyo and Megacities. Nevertheless, we can still argue that the Linear Shinkansen benefits Regional cores, as the land price and income there increase by 0.324% and 0.571%. [18]

The regional disparities become evident for Local cities (Panel E). In Local cities, installing the Linear Shinkansen decreases the land price by 0.197%. Meanwhile, while in-

[17] Here, we use a coefficient that differs according to our region categories, following our main model presented in Table 3. We also calculate counterfactual simulation estimates using only nationwide coefficients, following Donaldson and Hornbeck (2016), and present the results in Supplementary Materials. Doing so allows us to look into the changes in economic outcomes using nationwide trends. However, since the study focuses on regional differences in economic outcomes, we take the results calculated based on the coefficients that differ across regions as the main estimation results.

[18] In the case of income per capita results in Regional cores, even though there are negative coefficients, the results are close to zero; therefore, we argue that the income per capita would not change significantly across scenarios.

come grows by 1.178%, income per capita falls by 0.132% if the Linear Shinkansen is established. As expected, therefore, we conclude that the benefits of constructing the Linear Shinkansen will be focused to developed areas such as Tokyo and Megacities, leaving Local cities left behind and aggravating the regional disparities.

Regional Expansion Scenario Regional expansion boosts the nationwide and regional core economic outcomes, and its impact does not benefit or harm Tokyo or Megacities. Nationwide (Panel A), the land price increases by 0.121%, and income and income per capita increase by 0.293% and 0.016%, respectively. For Tokyo (Panel B), the estimated land price increase per market access increase under the regional expansion plan are 0.0005% and 0.0007% in Megacities (presented in Panel C).

The results from Panel D suggest that most of the economic benefits occur in the Regional cores. For example, the increase in market access under the Regional Expansion Scenario increases the land price by 0.900% and income by 1.588%. The impact of regional expansion on the increase in income per capita is not significant and is close to zero (-0.022%).

Local cities (Panel E) are likely to experience a decline in economic outcomes under the Regional Expansion Scenario, as they do in the Linear Shinkansen scenario. Under the Regional Expansion Scenario, their land price and income per capita fall by 0.035% and 0.023%, respectively. These results all suggest regional disparities.

Both Implementing both Linear Shinkansen and Regional Expansion Scenarios fosters the economic benefits of most of the developed cities while simultaneously worsening regional disparities. For example, the nationwide land price increases by 0.857%, which is greater than the increases in the Linear Shinkansen scenario (0.743%) and the Regional Expansion Scenario (0.121%). At the same time, Local cities are likely to experience a fall in land price even greater (by 0.229%) than that in the two other scenarios. Tokyo and Megacities demonstrate similar economic outcome growth as in the Linear Shinkansen scenario, as their economic gains under regional expansion are close to zero. The Regional cores, which gain from both scenarios but more so from regional expansion, demonstrate an increase in land price and income, while the changes in income per capita are less significant, as they are close to zero (-0.031).

Table 7: Counterfactual Simulation Result (Increase from the Baseline (%))

	Linear Shinkansen	Regional Expansion	Both
(A) Nationwide			
Land price	0.743	0.121	0.857
Income	1.794	0.293	2.070
Income per capita	0.097	0.016	0.112
(B) Tokyo			
Land price	1.342	0.0005	1.342
Income	4.047	0.0015	4.047
Income per capita	1.076	0.0004	1.076
(C) Megacities			
Land price	1.066	0.0007	1.066
Income	3.582	0.0023	3.582
Income per capita	0.863	0.0006	0.863
(D) Regional cores			
Land price	0.324	0.900	1.233
Income	0.571	1.588	2.175
Income per capita	-0.008	-0.022	-0.031
(E) Local cities			
Land price	-0.197	-0.035	-0.229
Income	1.178	0.208	1.364
Income per capita	-0.132	-0.023	-0.152

Note: We use the predicted population for 2031 from National Institute of Population and Social Security Research (https://www.ipss.go.jp/pp-shicyoson/j/shicyoson18/t-page.asp) to calculate the market access for each scenario.
Note: For more information on how the land price of each prefecture responds to the increase in the market access, please refer to the supplementary materials.

5.2.3 Policy Implications from Counterfactual Analysis

To derive policy implications from our counterfactual analysis, we calculate the economic benefits from each scenario, referring to the estimation results of the nationwide land price. [19]

We choose land price from among all economic indicators (i.e., income and income per capita), as land price best reflects the impact of transportation infrastructure, as mentioned in Section 5. We refer to the previous works that examine the impact of the transportation infrastructure through land price, such as Donaldson and Hornbeck (2016) and Banerjee et al. (2020). These works demonstrate that the transportation infrastructure benefits the land price of the region, which experiences enhanced accessibility.

[19] While it would have been ideal to use city-level economic outcomes, we chose nationwide land price due to data availability, as we are not able to obtain data on the city-level construction costs of each scenario. For example, while we have estimated construction cost data for the nationwide level, we do not have estimated construction cost data for a city in the Tokyo category.

We calculate the estimated benefit of land price by multiplying the average national land price with the percentage increase in land price in each scenario. In mathematical form, the estimated benefit of land price can be written as follows:

$$Benefit_s = \overline{V}_{Nationwide,2020} \times \%\overline{\Delta V}_{Nationwide,s} \times A, \tag{6}$$

where $Benefit_s$ is the estimated benefit of increasing land price under scenario s, $\overline{V}_{Nationwide,2020}$ denotes the average land price nationwide in 2020, $\%\overline{\Delta V}_{Nationwide,s}$ represents the percent change in the average land price nationwide under scenario s, and A refers to the total residential area in Japan, which was 19,700km^2 as of 2019. [20] [21]

The results are presented in Table 8, which shows the estimated land price increase (denoted as (A) in Table 8) in each scenario (displayed in each column), estimated construction cost in 2022 (denoted as (B)), and the difference between the land price increase and the estimated construction costs ((A)-(B)), which, finally, shows the economic gains under each scenario.

In the Linear Shinkansen scenario, the estimated increase in the land price is 11.47 trillion JPY (approximately \$99.4 billion). Thus the construction costs (around 7 trillion JPY for the line from Tokyo to Nagoya) of the Linear Shinkansen will be compensated for by the expected rise in the land price by around 4.47 trillion JPY (around \$38.48 billion). Next, the land price rise due to the Regional Expansion Scenario will be approximately 1.90 trillion JPY (approximately \$16.40 billion). This estimate is not sufficient to compensate for the construction costs of the regional expansion of the HSR; the construction cost of such expansion would be approximately 3.95 trillion JPY (around \$34.21 billion); therefore, the regional expansion would result in economic loss. Finally, for both scenarios, the estimated land price increase is 13.46 trillion JPY (approximately \$115.76 billion), and the estimated costs are 10.95 trillion JPY (around \$94.18 billion), resulting in an economic benefit of 2.51 trillion JPY (approximately \$21.58 billion). The benefits from constructing the Linear Shinkansen contribute most of the economic gains, probably compensating for the economic loss of the regional expansion.

Our results reveal that the fundamental regional disparity, which incorporates the

[20]The information is provided by the Ministry of Land, Infrastructure, Transport and Tourism (`https://www.mlit.go.jp/kokudoseisaku/kokudoseisaku_fr3_000033.html`).

[21]We also test whether the variations in the land price increase and estimated construction costs reduce the estimated economic benefits of the Linear Shinkansen in Supplementary Materials, and we confirm such trends. Nonetheless, note that the increase in market access in our study is based on the potential increase in ridership rather than the actual increase/decrease in ridership. Thus, more attention should be paid to the baseline scenario result.

Table 8: National Level Cost–Benefit Analysis

	Linear Shinkansen	**Regional Expansion**	**Both**
(A): Land Price Increase (trillion JPY)	11.47	1.90	13.46
(B): Estimated Construction Costs (trillion JPY)	7	3.95	10.95
(A)-(B): Estimated Economic Benefits (trillion JPY)	4.47	-2.05	2.51

economic lagging of the Local cities, is not resolved in any of the scenarios. The Linear Shinkansen construction will induce nationwide-level economic growth, and such gains are most likely to be focused in Tokyo and Megacities. On the other hand, the Linear Shinkansen aggravates regional disparity, as the economic gains of Regional cores are lower than those of Tokyo and Megacities, and Local cities experience economic loss. The results under the Regional Expansion Scenario presents national economic growth, and the economic outcomes of the Regional cores are improved. However, the benefits from the regional expansion cannot compensate for the construction costs, resulting in overall economic loss.

Against this backdrop, a natural question is what the economic outcomes of implementing both scenarios would be, because the Japanese government will realize both plans by 2031. Our results indicate that implementing both plans will boost economic outcomes mainly in and relatively equally across Tokyo, Megacities, and Regional cores, while the other areas will fall behind and regional disparities will be exacerbated, as Local cities will experience a decrease in the economic outcomes. Therefore, we conclude that future HSR plans in Japan are a double-edged sword. Choosing economic development or the alleviation of regional disparities is left to the hands of policymakers, and we call for policies that aid these regional disparities, particularly in cities outside developed areas.

6 Conclusion

This study clarifies how transportation infrastructure boosts economic development by examining the causal relationship between market access expansion and economic development. The results from an analysis on the Shinkansen, the oldest HSR in the world, from the 1980s, suggest that HSR expansion increases land price, income and per capita income. Such effects are significant in Tokyo and Megacities but are weaker or negative in Local cities. Inspired by the estimation results, we conduct counterfactual scenarios that evaluate future policy schemes in Japan. Our simulation results suggest that while economic development would take place to the policy target areas, regional disparities would be exacerbated, as Local cities would lag behind.

While we provide clear evidence on the impact of the HSR expansion and economic outcomes, future studies can explain the mechanism behind our results. Specifically, future studies may examine how the industry structure is reallocated through transportation infrastructure. For example, service industries that require more human interaction will find more customers around new stations (Glaeser and Gottlieb (2009)), and increased market access may lead to the agglomerations of service industries around the newly developed stations. Exploring such increases in specific industries around areas with enhanced accessibility requires detailed subdivisions of each industry to explain how quality workers–with higher income levels–move according to accessibility improvements. For example, categorizing the service industry into specific subindustries (i.e., tourism) will show how the workers employed in these industries migrate following the HSR expansion. Unfortunately, we could not conduct such analyses due to data availability. Such work is crucial, as it can help generalize our findings, and we leave it for future research.

Appendix

In this section, we present the entire list of opening dates and regions of Shinkansen, and present the result of the market access expansion to population and specialization patterns.

A1 List of Opening Dates and Regions

Table A1 presents the list of the opening dates and regions of the Shinkansen line.

Table A1: Detailed Descriptions of HSR openings

Line	Area	Opening Date
Tokaido Shinkansen	Tokyo-Shin Osaka	1964/10/01
Sanyo Shinkansen	Shin-Osaka-Okayama	1972/03/15
	Okayama-Hakata	1975/03/10
Tohoku Shinkansen	Omiya-Morioka	1982/06/23
	Ueno-Omiya	1985/03/14
	Tokyo-Ueno	1991/06/20
	Morioka-Hachinohe	2002/12/01
	Hachinohe-Shin Aomori	2010/12/04
Joetsu Shinkansen	Omiya-Niigata	1982/11/15
Yamagata Shinkansen	Fukushima-Yamagata	1992/07/01
	Yamagata-Shinjo	1999/12/04
Akita Shinkansen	Morioka-Akita	1997/03/22
Hokuriku Shinkansen	Takasaki-Nagano	1997/10/01
	Nagano-Kanazawa	2015/03/14
Kyushu Shinkansen	Shin-Yatsushiro - Kagoshima Chuo	2004/03/13
	Hakata - Shin-Yatsushiro	2011/03/12
Hokkaido Shinkansen	Shin-Aomori - Shin-Hakodate Hokuto	2016/03/26

A2 Population and Specialization Patterns

In this section, we conduct additional analysis on the impact of market access on population growth and that of HSR expansion on the labor allocation pattern.

To this end, from the SSDS, we retrieve the data of the number of employees according to three industry categories: agriculture,[22] heavy industry, and service industry. The

[22]To be precise, the agricultural sector includes the agricultural and forestry sectors and fisheries. For

number of employees of each industry is reported every 5 years from 1981 to 2006, and again in 2009 and 2014. We estimate the annual number of employees by industry by conducting a linear interpolation. Then, we calculate the share of employees in each industry by dividing them to the total number of employees. Table A2 shows the mean and standard deviation of the share of employees through the target period by regional category.

Table A2: Mean and Standard Deviation of Variables

	Nationwide	Tokyo	Megacities	Regional cores	Local cities
Agriculture Sector	2.0	0.2	0.5	4.0	2.0
	(3.5)	(0.6)	(1.0)	(5.0)	(3.4)
Heavy-Industry Sector	33.0	22.3	31.4	28.8	34.7
	(12.7)	(10.8)	(13.2)	(11.0)	(12.7)
Service Sector	65.0	77.4	68.0	67.2	63.3
	(12.7)	(10.8)	(13.2)	(11.1)	(12.6)

Unit: Agriculture, Heavy-Industry, and Service Sector: %.

We present our results in Table A3, which shows the estimation results of Equation 2, using population (Panel A), the proportion of workers in the agricultural sector (Panel B), the proportion of workers in the heavy industry sector (Panel C), and the proportion of workers in the service sector (Panel D). In this analysis, all dependent variables are logarithmically transformed. The estimated coefficients are weighted by the population as of 1983, following the specification of Donaldson and Hornbeck (2016). Each column in table A3 presents the results of each region category. Below, we explain the results in each panel.

Population A 1% increase in market access will increase the population by 0.480% nationwide. Specifically, if market access rises by 1%, the population will increase by 1.079% in Tokyo, by 0.802% in Megacities, by 0.929% in Regional cores, and by 0.270% in the remaining areas. Note that our results do not imply that the population will increase continuously; that is, cities experience a decrease in market access due to population reductions in neighboring cities. Thus, even though a positive effect on the population is estimated, this result does not simply lead to a continuous increase in Japan's total population.

simplicity, we use the term *agricultural sector* to represent these industries.

Agricultural Sector Next, Panel B presents the changes in the proportion of employees in the agriculture sector. Overall, we witness a reduction in the proportion of workers in the agricultural sector. A 1% increase in market access will reduce this proportion by 0.008% nationwide, by 0.001% in Tokyo, by 0.006% in Megacities, by 0.011% in Regional cores, and by 0.009% in the remaining cities.

Heavy Industry Sector While the coefficients in Panel B show overall reductions, we witness differences in the results in Panel C: While the 1% increase in market access increases the proportion of heavy industry workers by 0.014% nationwide, by 0.042% in Regional cores and by 0.012% in Local cities, we witness a rapid reduction in Tokyo by 0.147%, which is more than nine times larger than that of the absolute value of the nationwide results.

Service Sector The market access increase will reduce the proportion of service workers nationwide (by 0.018%), while increasing the proportion in Tokyo (0.142%).

Table A3: Population and labor reallocation result

Panel A: Population	**Nationwide**	**Tokyo Area**	**Megacities**	**Regional cores**	**Local cities**
ln(Market Access)	0.480***	1.079***	0.802***	0.929***	0.270***
	(0.016)	(0.068)	(0.032)	(0.033)	(0.014)
R-squared	0.998	0.997	0.999	0.998	0.995
N	66,082	2,356	14,288	11,210	40,584
Panel B: Agriculture Sector	**Nationwide**	**Tokyo Area**	**Megacities**	**Regional cores**	**Local cities**
ln(Market Access)	-0.008***	-0.001*	-0.006***	-0.011***	-0.009***
	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)
R-squared	0.745	0.723	0.756	0.862	0.631
N	64,902	2,242	13,870	11,134	39,898
Panel C: Heavy-Industry Sector	**Nationwide**	**Tokyo Area**	**Megacities**	**Regional cores**	**Local cities**
ln(Market Access)	0.014***	-0.147***	-0.008	0.042***	0.012***
	(0.002)	(0.019)	(0.011)	(0.004)	(0.002)
R-squared	0.970	0.959	0.969	0.965	0.969
N	64,902	2,242	13,870	11,134	39,898
Panel D: Service Sector	**Nationwide**	**Tokyo Area**	**Megacities**	**Regional cores**	**Local cities**
ln(Market Access)	-0.018***	0.142***	-0.007	-0.042***	-0.012***
	(0.002)	(0.015)	(0.010)	(0.003)	(0.002)
R-squared	0.962	0.944	0.962	0.961	0.958
N	64,902	2,242	13,870	11,134	39,898

Note: Standard errors in parentheses. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

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Contributions

Sunbin YOO: Conceptualization, methodology, formal analysis, writing (original draft, review and editing); Junya KUMAGAI: Methodology, formal analysis, writing (review and editing); Kohei KAWASAKI: Methodology, formal analysis, writing (original draft); Sungwan HONG: Writing (original draft), methodology; Binqi ZHANG: methodology, resources; Takuya SHIMAMURA: methodology; Shunsuke MANAGI: Resources and supervision.