Do Winners Win More from Transport Megaprojects? Evidence from the Great Seto Bridges in Japan

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【要旨】

経済学者たちは交通インフラ投資が経済活動に及ぼす異質な影響，特に“ストロー効果”---大規模な道路建設プロジェクトにより，すでに経済的に繁栄した中心都市がさらに恩恵を受ける一方で，周辺都市は経済的損失に直面するという現象--- に関心を高めている．我々は日本の瀬戸大橋が開通した場合にそのような効果が現れるかどうかを実証的に検証する．瀬戸大橋は1980年代から1990年代にかけて「日本列島改造論」の一環として実施された世界最大規模の公共投資である．近年開発された“recentered instrumental variable” を difference-in-differencesデザインに適用し，交通費用の大幅な低下とその低下が市場アクセスの水準に与える異質な影響を外生的変分として利用する．分析の結果，ストロー効果とは逆に，大規模な周辺都市が中心都市よりもプロジェクトからの恩恵を受けることを明らかにした．また，大規模な道路投資に起因する勝者と敗者の地理的分布は，既存の交通ネットワーク内において交通費用が減少する場所に依存することも示した．

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Evidence from the Great Seto Bridges in Japan

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Abstract

Economists are increasingly concerned with the heterogeneous impacts of transportation infrastructure investments on economic outcomes, particularly the phenomenon known as the “Straw Effect”: Core cities that were already in economic prosperity may gain more, and peripheral cities may lose, from large transportation projects. We empirically investigate whether such an effect manifests in the case of the Great Seto Bridges in Japan, a 70-billion-dollar project implemented as part of the “Building-a-new-Japan” initiative in the 1980s-1990s. We employ the recently developed recentered instrumental variable approach in the difference-in-differences design, exploiting the sharp decline in transport costs and its differential impacts on market access levels across cities of different economic prosperity as exogenous sources of variation. We find that, contrary to the straw effect, large peripheral cities gain more than core cities, rather than lose, from the megaproject. We also demonstrate that the distribution of winners and losers from the megaproject depends on where the associated cost reductions occur in the existing network structures.

JEL Codes: O18, R4, R11, R12

Keywords: Market Access, Transportation Investment, Core-Periphery Model, Economic Geography, Quantitative Spatial Model, Treatment Effect under Spatial Network

I. Introduction

Public transportation infrastructure is essential for economic growth and for efficient and equitable distribution of goods and services. However, economists are increasingly concerned about its heterogeneous impacts (Krugman, 1991; Krugman and Venables, 1995; Puga, 1999; Fujita et al., 1999; Fujita et al., 2001; Fujita and Thisse, 2002; Baldwin et al., 2003; Ottaviano and Thisse, 2004; Faber, 2014; Baum-Snow et al., 2020): "Core" cities may simply gain more from subsequent public transportation investments than "peripheral" ones. Or even worse, the peripheral cities may lose from such investments. This phenomenon is sometimes known as the *Straw Effect* in the literature (e.g., Ono and Asano, 2005; Kim and Han, 2016; Zheng et al., 2020), making an analogy from a plastic straw drawing water ("economic resources") away from a cup ("periphery").

Indeed, the Straw-effect phenomenon has a strong foundation in economic theory. Since Krugman (1991), economists have incorporated various economic mechanisms (e.g., agglomeration economies, endogenous labor migration, increasing returns to scale) into the theory of trade and economic geography, virtually all of which generally predict heterogeneous general equilibrium impacts of public transportation investments (Krugman, 1991; Krugman and Venables, 1995; Helpman, 1998; Ottaviano et al., 2002; Hanson, 2005). Therefore, the economic abundance some cities enjoy today may be the direct consequence of economic advantages they had for some historical, political, or geographic reasons rather than public transportation investments per se. This line of arguments can be easily adapted to recent advances in the quantitative spatial model (QSM) to demonstrate that under a variety of initial conditions, there are generally winners and losers from any given transportation investment in a given network of cities (see **Section II**).

This manuscript empirically investigates whether the Straw-effect phenomenon manifests in the case of the Great Seto Bridges in Japan during the 1980-1990s, a period marked by accelerated economic growth (See **Figure 3, Section III**). During the period, the Japanese government embarked on major highway constructions (often known as the "Building-a-new-Japan" initiative) in the western Japan region. The largest project was the construction of the three bridges that connect the isolated island region (Shikoku) to the main island of Japan (Honshu). The Bridges' construction lasted 21 years from 1978 to 1999, and its financial cost is estimated to be roughly 70 billion dollars. It is one of the most expensive transport megaprojects in Japan and worldwide (**Table 1, Section III**). There were concerns, even before construction began, regarding the economic impacts of the Bridges on the surrounding regions. While the project's intention was to promote the economic development of peripheral regions (Chugoku and Shikoku), the opponents of the project expressed serious concerns that the economic activities might be simply drawn from Shikoku to core cities in the main island such as Osaka (in the Kinki region) and Fukuoka (in the Kyushu region) or that the peripheral regions may simply end up with a large financial debt without much economic gain (*Asahi Newspaper*, 1987; 1998). For example, it is estimated that it would take at least 42 years, counting from 2008, to fully repay the debt for the project (*Mainichi Newspaper*, 2008).

Our primary objectives are, first, to quantify the heterogeneous causal effects of this transport megaproject on peripheral cities' economic outcomes (population, economic income, and employment), and second, to evaluate the distribution of winners and losers relative to their initial conditions (do winners tend to win while losers lose more?). By doing so, we also empirically evaluate the extent to which the Straw-effect phenomenon has (or has not) manifested in the Western Japan. Addressing these questions is highly policy-relevant, for a large sum of public investments are still being made on transportation infrastructures in low- and middle-income countries.[2]

Accomplishing these goals, however, is empirically quite challenging. Over the last few decades, a number of empirical studies has attempted to estimate the economic effect of public transportation investments on a variety of city-level economic variables (e.g., Chandra and Thompson, 2000; Baum-Snow, 2007; Duranton and Turner, 2011; Duranton and Turner, 2012; Duranton *et al.*, 2014; Faber, 2014; Storeygard, 2016; Donaldson and Hornbeck, 2016; Donaldson, 2018; Asher and Novosad, 2020; Banerjee *et al.*, 2020; Baum-Snow *et al.*, 2020). Three important challenges are identified in this line of literature. First, either the location or the timing or both of public transportation projects are likely endogenous, and causality may even run in the reverse direction: Transportation investments may occur in areas where either high or low economic growth is expected. To address this type of empirical challenges, the earlier literature often relies on quasi-experimental variation or the sharp discontinuity in either the location or the timing of the investment. For example, Donaldson and Hornbeck (2016) exploit the expansion of U.S. railroad networks during the 1870s-1890s as the source of exogenous variation for changes in market access. Faber (2014) uses the optimal least cost path of highways as an instrument for the non-random highway route placements while Baum-Snow (2007), Baum-Snow *et al.* (2020) and Duranton and Turner (2012) use planned highway or historical road network as an instrument for the interstate highway assignment. Furthermore, in a regression-discontinuity design, Asher and Novosad (2020) exploit the discrete cutoffs in village population size used to prioritize rural road construction in India.

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[2] The World Bank reports transport investment had $62.1 billion, which is 68% of total investments in 2022 (World Bank, 2022).

Second, the common concern in the earlier literature is that the general equilibrium mechanism may plausibly "contaminate" otherwise credible quasi-experimental identification and estimation strategies. Cities are connected, either directly or indirectly, through the construction of any given infrastructure in the transportation network of cities may (i) affect cities that are far apart and thus are not directly impacted ("spillover effect"), (ii) have heterogenous impacts on cities that depend, in a subtle way, on pre-treatment levels of economic development and transportation infrastructures ("stock effect"), and (iii) have "feedback effects" in the sense that its economic impact on one city affects other cities, which in turn affect the original city. All of these are known to create identification failures in the quasi-experimental research design. To address this type of problem, the literature often makes use of market access (MA) approach, in which the quasi-experimental variation in transport costs by a given transportation network is translated into the changes in the MA variable, a summary statistic grounded in the spatial general equilibrium model that embodies all of these nuisance effects (Donaldson and Hornbeck, 2016; Jaworski and Kitchens, 2019; Mori and Takeda, 2019; Baum-Snow et al., 2020; Jedwab and Storeygard, 2022).

Third, there is an emerging literature highlighting another source of identification threat to *both* types of empirical strategies (Borusyak and Hull, 2023; Borusyak, Jaravel, and Hull, 2023). In essence, the MA approach requires strictly exogenous (or "random") variation in the MA variable for identification of its causal impact because there is no "untreated" group in its general equilibrium framework. Borusyak and Hull (2023) have shown that even if public transportation projects are randomly assigned, either in location or in timing, the resulting change in the MA for a city depends on its intrinsic location in the structure of the given economic network. To see this, imagine a city located in the center of the economic network versus a city located at the edge of the network. Construction of a transportation project at *any* point in the network would have different effects on the MA levels of these cities. To address this fundamental problem, Borusyak and Hull (2023) proposes a recentered instrumental variable approach, which we also take in this paper and thus is outlined in detail below.

Our empirical strategy takes advantage of all these advances in this extremely rich empirical literature. First, we exploit the sharp decline in transport costs, induced by the construction of the Great Seto Bridges and other highways during the 1980s-1990s. Second, we construct and calculate the market access variable based on a version of the QSM (Allen and Arkolakis, 2014; Redding and Turner, 2015; Redding and Rossi-Hansberg, 2017; Redding, 2020). We then use the differential impacts of the Great Seto Bridges and other highway constructions on market access levels across cities of different economic prosperity as the source of exogenous variation. Third, we use this variation in the "recentered market access" (RMA) instrumental variable method recently developed by Borusyak and Hull (2023). Intuitively, the RMA extracts the purely exogenous variation from the observed MA, by purging out the influence of endogenous variation that comes from its geographic network characteristics --- some cities receive more transport projects and enjoy higher MAs precisely because they are located in geographically advantageous positions in the transportation network. By construction, the RMA is neither affected by the geographic location of the city nor by the non-random timing of the construction of the transportation network and satisfies the exclusion restriction because it has no direct effect on the economic outcomes. The RMA is also a relevant instrument for the observed MA because it is constructed from the MA variable.

Our IV estimates imply that a one-percentage increase in a city's measured market access leads to an increase in manufacturing output by 0.197%, in the city's population by 0.039%, and in employment (measured as the population in labor force) by 0.056%. These IV estimates are not only statistically significant at the conventional levels, but also larger in magnitude than OLS estimates. To put these numbers in context, we also calculate the predicated impact on the cities' economic growth in the region. Using the simulated QSM, we predict the highway expansion between 1985 and 1995, which includes the Central Seto Bridge resulted in the measured market access by 13.2% on average for cities in the Western Japan region. Combined with the IV estimates, this increase in market access translates, on average, into a 2.60% increase in the manufacturing output, a 0.51% increase in population, and a 0.74% increase in employment during the subsequent 10-year period. These relatively small economic gains, however, mask its highly heterogeneous impacts.

The heterogeneous economic impacts of the highway expansion are quantified in two ways. Our first approach is to use the IV estimates and predict the growth of economic outcomes (manufacturing output, population, and employment) during the 1995-2005 period for all cities in the study sample, and compare these outcome growths against the initial population size as of 1980 (i.e., prior to the highway expansion). The result indicates that *on average*, cities that had larger populations gained more, in all three outcomes, than those that had smaller populations, implying that winners tend to win more from the public transport projects while losers do not necessarily lose. We should *not* take this as a support for the Straw-effect hypothesis, however. Within each population quintile, there is substantial heterogeneity in economic gains, which with a closer examination, can be taken to refute the Straw effect at least in our empirical context. For example, large peripheral cities such as Hiroshima and Okayama gained more in all three outcomes than core cities such as Fukuoka and Osaka. Furthermore, Takamatsu and Matsuyama, relatively large peripheral cities in the Shikoku region, are also estimated to gain rather than lose from the transport projects.

Our second approach is to calculate the back-of-envelope estimates of the net benefits of the Central Seto bridge for all cities and compare them against the initial population size as of 1980. The problem with our first approach is that it does not account for the cost of highway construction. Hence, to account for the cost, we use the publicly available information on the cost expenditures for the Central Seto Bridge. To estimate the economic benefit, we take the difference in the predicted growth of manufacturing output between the two conditions: the observed condition with the Central Seto Bridge versus the counterfactual condition without the Central Seto Bridge. The results indicate that core cities are indeed estimated to *lose* from this transport megaproject while large peripheral cities are estimated to be the winners, with large gains in net benefit. Smaller peripheral cities are also estimated to lose from the project, but their loss is much smaller than the core cities. With these results, we conclude that the Straw effect did not quite occur at least in the way that the critics expected to be in the case of the Great Seto Bridge.

In our empirical framework, heterogeneous impacts occur in two pathways: the first is the heterogeneous impacts of the highway expansion on cities' market access levels, and the second is the heterogeneous impacts of the changes in market access levels on economic outcomes. Our market access approach naturally incorporates the first type of heterogeneity, since the MA variable is constructed through the QSM. In contrast, the second type of heterogeneous effects is not salient in our framework. In our base empirical specification, we assume a homogenous effect of MA on economic outcomes. This is consistent with the model prediction from the QSM. However, our MA variable excludes each city's own population size to avoid the endogeneity problem, and thus, some of the heterogenous effects are excluded by construction. We also estimate alternative specifications allowing for the heterogeneous effects of MA on economic outcomes. The results are reported in the Appendix E.

Our work closely complements the five strands of literature. To economize space, we only touch on each and defer more thorough discussions to **Appendix A**. First, it is most closely related to the studies that empirically investigate the impacts of transportation investments on disadvantaged communities (Chandra and Thompson, 2000; Storeygard, 2016; Asher and Novosad, 2020; Jedwab and Storeygard, 2022). Second, related to the first literature, there is an extremely rich literature that evaluates the economic impacts of public transportation investments (Baum-Snow, 2007; Duranton and Turner, 2011, 2012; Allen and Arkolakis, 2014; Duranton et al., 2014; Faber, 2014; Ghani et al., 2016; Donaldson and Hornbeck, 2016; Jedwab and Moradi, 2016; Storeygard, 2016; Donaldson, 2018; Jaworski and Kitchens, 2018; Mori and Takeda, 2019; Asher and Novosad, 2020; Baum-Snow et al., 2020; Banerjee et al., 2020; Jedwab and Storeygard, 2022). Third, ours builds on a large number of empirical studies that use the market-access approach (Davis and Weinstein, 2003; Hanson, 2005; Breinlich, 2006; Redding and Sturm, 2008; Nakajima, 2008; Head and Mayer, 2011; Donaldson and Hornbeck, 2016; Jaworski and Kitchens, 2018; Mori and Takeda, 2019; Jedwab and Storeygard, 2022). Fourth, ours is also related to the theoretical literature on quantitative spatial models (Redding and Turner, 2015; Redding and Rossi-Hansberg, 2017; Redding, 2020). Lastly, our paper has an important implication for the public finance literature studying how the burden of large public transport transportation investments should be shared among stakeholders (Anguera, 2006; Boardman et al., 2018).

This paper is organized as follows. Section II provides an intuitive explanation of the MA approach as well as the recentered instrumental variable approach using a stylized quantitative spatial model. It also demonstrates why conventional quasi-experimental identification strategies fail and why the recentered instrumental variable succeeds in such a setup. Section III discusses the institutional background and the data on highway constructions in Japan. Section IV discusses the estimation and identification strategies, and Section V presents the estimation results. Section VI conducts a counterfactual policy simulation and presents the results of our evaluation. Finally, Section VII concludes.

II. The Essence of the Empirical Problem and Its Solution

Before discussing our data and empirical setup in detail, we explain the essence of the empirical challenges and how our recentered market access approach might overcome the challenges in a canonical quantitative spatial model (QSM) (Redding and Turner, 2015; Redding and Rossi-Hansberg, 2017; Redding, 2020).

II-A. Market Access in a Stylized Quantitative Spatial Model

The QSM is a general equilibrium model of trade and migration across cities (with or without international trade) that explicitly accounts for economic geography over space. Here, we consider the model in a canonical form without international trade. We only describe the model in the nutshell. Those unfamiliar with QSM are encouraged to read the details of the model offered in **Appendix B**.

The model starts with a set of cities N with a structure of transportation, with bilateral iceberg trade costs τ_{ij} for each pair of cities (i, j). Consumers in each city i chooses where to live and work, and how much to consume each variety of goods, from which city. Firms are heterogeneous in productivity and produce a unique variety. Firms decide where to produce and how much (equivalently set the price) in monopolistic competition. The model is closed by assuming exogenous amenity, untradable good (e.g., floor space), and (aggregate) productivity for each city. The equilibrium quantities are solved by assuming the market clearing conditions for trade, migration, and the utility equalization across cities.

The key driver of the market equilibrium in virtually all QSMs is the equation that defines the *market access* (MA) for each city:

$$MA_i = \rho \sum_{j \in N} \tau_{ij}^{-\theta} MA_j^{-1} Y_j \, . \tag{1}$$

where τ_{ij} is the iceberg trade cost between cities i-j ($\tau_{ij} \geq 1$), and theoretically it is the trade costs taking into account natural and social geographical conditions. Y_j is the market size (we discuss this below), ρ is a constant, and θ is the trade elasticity ($\theta > 1$) (see **Appendix B** for derivation).

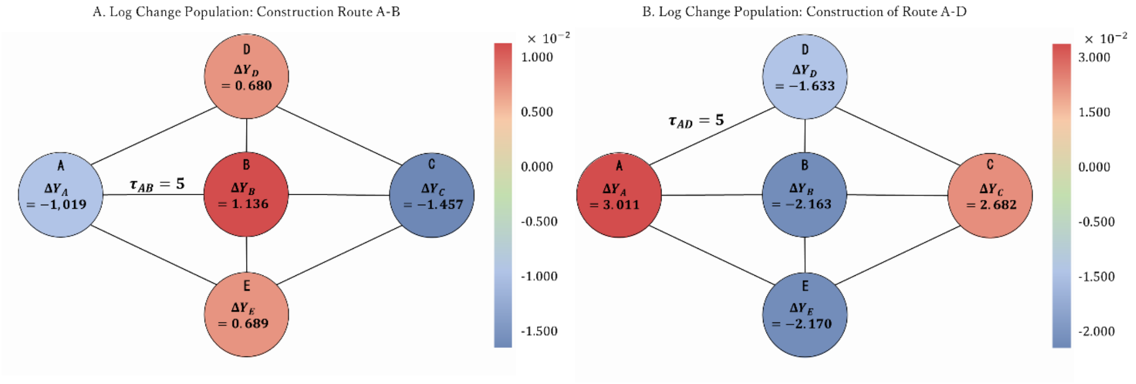
Intuitively speaking, MA_i represents how accessible the market is to the consumers and the firms in a city i. For consumers, MA indicates how many types of goods consumers can purchase and how reasonably priced they can purchase them. The larger the MA, the more attractive it is to consumers, which increases the labor supply (population) in that city through migration. On the other hand, a firm's MA indicates how much price competition a firm faces and how large a market it could be able to sell into. The larger the MA, the more attractive that city is to firms and the higher the demand for labor through increased production of goods in that city. MA for consumers is related to MA for firms in such a way that the former is determined by the latter for all cities and the latter is determined by the former for all cities. In other words, the MA is adjusted until the feedback loop of MAs for both consumers and firms in all cities is balanced. Thus, each city's market access is a measure that is determined by the spatial interactions among all cities.

II-B. An Illustrative Example: How Does the Empirical Problem Arise?

We now use a stylized version of this QSM with $N = 5$ to illustrate (i) how the empirical challenges emerge, (ii) how the MA approach overcomes the challenges, but only partially, and (iii) how the recentered MA might address them fully.

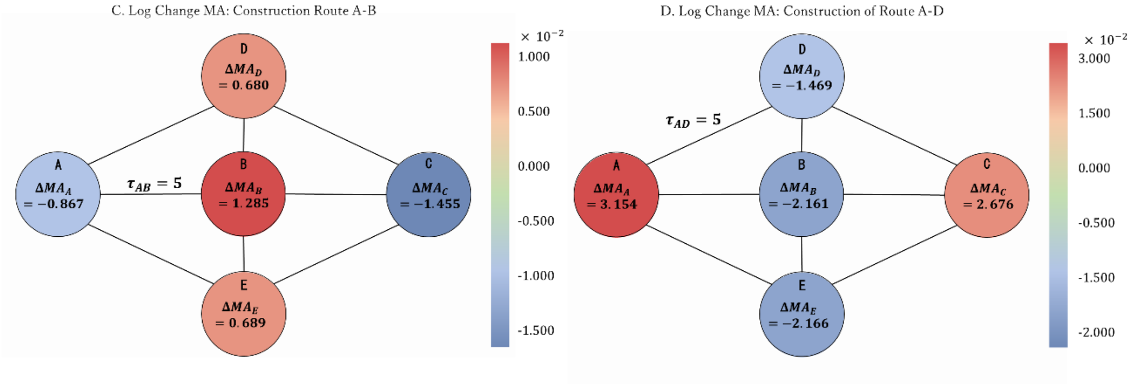
We impose a particular structure of transportation network connecting these cities. All cities are connected to three other cities, except city B, which is connected to all other cities. We assume cities are connected to each other, with equal symmetric trade costs: $\tau_{ij} = 10$ for all i, j. We also assume that cities A and C have a population size of 1,000 while the other cities have a population size of 500. These initial distributions of trade costs and population sizes are meant to capture the intrinsic structure of network arising from the natural or social geographic conditions that are purely exogenous. Cities are homogenous in all other aspects. Of course, we can consider thousands of different initial configurations that are equally reasonable. The following explanations do not depend on the specific configuration we consider here. As a thought experiment, we consider two types of public transportation investment. The first is to construct a highway that would lower the trade cost between cities A and B from $\tau_{AB} = 10$ to $\tau_{AB} = 5$. The second is to construct a highway that would lower the trade cost between cities A and D from $\tau_{AD} = 10$ to $\tau_{AD} = 5$. **Figure 1** describes the resulting distribution of populations in terms of log changes in populations (top panels) and MAs (bottom panels).

Figure 1. The General-Equilibrium Effects of Public Transportation Investment



A. Log Change Population: Construction Route A-B

B. Log Change Population: Construction of Route A-D



C. Log Change MA: Construction Route A-B

D. Log Change MA: Construction of Route A-D

Notes: Initial conditions are such that $\tau_{ij} = 10$ for all i, j, $Y_A = Y_C = 1000, Y_B = Y_D = Y_E = 500$. Panels A and B show the (log) changes in population. Panel A is for the case that trade costs decrease between cities A and B whereas panel B is the case that that trade costs decrease between cities A and D. Panels C and D show the (log) changes in MA. Panel C is for the case that trade costs decrease between cities A and B whereas panel D is the case that that trade costs decrease between cities A and D.

This illustrative example demonstrates the empirical challenges we wish to address in our empirical study. Note, first, that by construction, the public transportation investment, the *treatment*, is related to any economic variables of the model, and thus, is endogenous in the econometric sense. Hence, in this example, we assume away the kind of empirical challenges researchers often face in a real empirical context (which we do address later), allowing us to focus on other kinds of challenges. In the difference-in-differences or similar research design, we compare the outcome trends of the treated cities versus the "untreated" cities.[3] In this setup, the "untreated" cities would be cities C, D, and E in Panel A (B, C, E in Panel B). Hence, our estimand and sample analogue of interest would be:

$$E[Y_i(1) - Y_i(0)|i \in N_T] = \frac{\sum_{i \in N_T} \Delta Y_i}{N_T} - \frac{\sum_{i \in N_U} \Delta Y_i}{N_U}. \tag{2}$$

where we abuse the notation and define N_T as both the number and the set of treated cities, and N_U as both the number and the set of "untreated" cities.

Clearly, this estimation strategy does not work in this context because the "untreated" cities are not really untreated. The construction of the route does change these cities' population sizes, and hence, they cannot be used as the valid counterfactual. Another problem with (2) is that there are winners and losers in both the treated and the comparison groups, as seen in Figure 1. In Panel A, city B ("treated") and cities D and E ("untreated") experience gains in population whereas city A ("treated") and C ("untreated") lose. Similar comments apply to Panel B. The problem here is that there seems no systematic way in which to account for such heterogeneity in the difference-in-differences framework since it is theoretically impossible to know a priori which cities are affected and by how much, and whether the effect is negative or positive when trade costs change.

In contrast, the MA approach accounts for all the general equilibrium effects that arise from the construction of a transportation infrastructure. In Panel C, MA increases in cities B, D, and E whereas it decreases in cities A and C. In response to these MA changes, the population sizes of cities B, D, and E increase while those of cities A and C decrease. Similar comments apply to Panel D. Our estimand and sample analogue of interest is, thus, the expected value of the gradient:

$$E\left[\frac{\partial Y}{\partial MA}\right] = \frac{\sum_{i \in N} \Delta Y_i}{\sum_{i \in N} \Delta MA_i} \tag{3}$$

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[3] Note that the public transportation investment, the *treatment*, is often related to all economic variables of the model, and thus, is endogenous in the econometric sense. In this example, we assume away the kind of empirical challenges researchers often face in a real empirical context (which we do address later), allowing us to focus on other kinds of challenges.

We estimate this gradient typically by regressing changes in the outcome of interest against the changes in market access. This estimation strategy should work, in principle, as long as the changes in MA are purely exogenous (i.e., random or as good as random). Hence, we are tempted to make an argument that this strategy should also work if the changes in trade costs, which cause the changes in MA, are random.

Borusyak and Hull (2023) clarifies, unfortunately, that this argument is not correct. That is, *even if an assignment of transportation investments is random*, changes in MA may not be random. Figure 1 indeed demonstrates why this is the case. The changes in MA for *each city* depend clearly on not only where the cost shocks occur but also where each city is located in a given network. In other words, the same (random) cost shock can generate different changes in MA, and the economic mechanism that induces this difference is correlated with changes in the outcome variable, leading to a heterogeneity term that works as the omitted variable. This is the essential endogeneity that arises from the intrinsic network structure. Furthermore, this also implies that the conventional IV approach that relies on historical, planned, or inconsequential transportation routes is unlikely to work well because all these variables are plausibly correlated with the intrinsic network structure. We elaborate on this point further in the next subsection.

II-C. How the Recentered Market Access Address the Empirical Problem

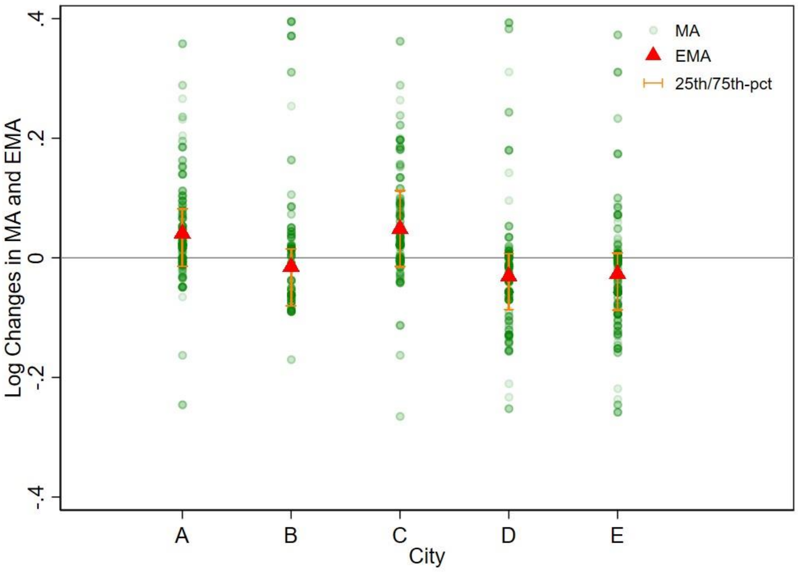
As an alternative, Borusyak and Hull proposes a recentered instrumental variable approach. In the current setup, the approach “recenters” the MA variable, and is henceforth called a recentered market access (RMA) approach. The approach proceeds in three steps. First, we generate a sequence of S random draws of public transportation investments, or equivalently, draws of a vector $\{\boldsymbol{\tau}^s\}_{s\in S}$. Second, we calculate a sample analogue of the expected value of MA (EMA) that follow from this sequence of random draws: $\mu_i \equiv E_s[MA_i|\boldsymbol{\tau}^s] \approx \frac{1}{\#S}\sum_{s\in S} MA_i(\boldsymbol{\tau}^s)$. Third, we create a recentered instrument by calculating the difference between the observed and the expected MA for each realized vector of $\boldsymbol{\tau}^s$: $RMA_i(\boldsymbol{\tau}^s) \equiv MA_i(\boldsymbol{\tau}^s) - \mu_i$.

By construction, this recentered MA changes must be correlated with the observed changes in MA (relevance) and must be orthogonal to any non-random components that are related to the changes in MA (exogeneity). Simply put, the approach essentially purges out the “pure shock”, which originates from the “as-good-as-random” assignment of public transportation investments, from the observed changes in the market access level, which arises in a complex manner from the non-random exposure of cities in a given network structure to the “as-good-as-random” assignment.

Figure 2 illustrates the intuition for why and how this method works. Using the same stylized transportation network in **Figure 1**, we take 300 random draws of transport costs $\boldsymbol{\tau}^s$. To operationalize the randomization, we assume each draw represents a reduction in the transport cost on the single connected route, or the pair of cities, (i, j). There are a total of eight possible route connections. Hence, we randomly select a city pair and take a random draw τ_{ij}^s from a uniform distribution on (1.5, 9.5).

Figure 2 plots the results of this exercise. For each city, the realized changes in MA are shown as dots while the expected change in MA in logs are shown as triangles. All values are in logged changes relative to the status quo. The figure demonstrates that each city has a unique distribution of the realized MA changes and the distributions are not centered around zero, despite that we take fully randomized draws of transport costs. Cities A and C tend to receive positive MA growths more frequently while cities D and E tend to receive negative growths more frequently. As a result, the expected MA growths are positive for cities A and C whereas negative for cities D and E. This illustrates Borusyak-Hull's point that cities' *exposure* to shocks may not be random even if shocks are purely random. This point is particularly important to secure identification in our later empirical setup. In the meantime, by "re-centering" (i.e., subtracting the expected MA growth), we obtain the distributions of pure MA shocks that are orthogonal to the non-random component with zero expected means. purging out this structural dependency.

Figure 2. An Illustrative Visualization of RMA Approach



Notes: This figure plots the outcomes of simulations drawing 300 random transport cost shocks using the stylized city network depicted in Figure 1. For each city, the circles represent the realized MA changes and the triangle denotes the expected MA change in logs.

III. Background and Data

III-A. Background

Our study area covers the western Japan region, which consists of 23 prefectures with 615 municipalities. The western Japan is separated by the Seto Inland Sea into three major islands the main island (called Honshu), the Shikoku Island, and the Kyushu Island (see **Figure 3**). The region has two well-known metropolitan areas: the Kinki area and the Kitakyushu area. The Kinki area consists of three major cities: Kyoto, Osaka and Kobe. The Kitakyushu area consists of two major cities: Kitakyushu and Fukuoka. These five cities are labeled "Core" cities (blue triangles) in **Figure 3**. The region also hosts several large cities along the Seto Inland Sea, which served as a waterway for transporting large industrial materials such as petroleum and iron ore. These relatively large regional cities are labeled "Large Peripheral Cities" (blue circles) in **Figure 3**.[4]

The highway construction began in the 1950s in Japan. By the early 1980s, major highways connecting the core cities were completed, including an important connection between Fukuoka, the largest city in the Kyushu Island, and the main island by 1973. Our study focuses on the period of public transportation investments that are designed to connect peripheral cities to core cities in the late 1980s-1990s. The purpose of these investments was to "disperse economic and manufacturing activities", which have been concentrated in core cities, to other surrounding areas (Ministry of Land, Infrastructure, Transport and Tourism (MLIT), 1969).

The largest of these investments during this period was the construction of the Great Seto Bridges, which are designed to connect the Shikoku Island to the main island. Historically, the Shikoku region was separated from the main island by the Inland Sea. Before the construction of the Bridges, commuting and goods transport were done by maritime routes. The Great Seto Bridges consist of three bridges: the Central-Seto Bridge, the East-Seto Bridge, and the West-Seto Bridge (see **Figure 3**). The Central-Seto Bridge, completed in 1988, connects Kagawa in the Shikoku region to Okayama in the Chugoku region. The East-Seto Bridge, finished in 1998, and links Tokushima in the Shikoku, the Awaji Island, and Hyogo in the Kinki region. Lastly, the West-Seto Bridge, completed in 1999, joins Ehime in the Shikoku to Hiroshima in the Chugoku.

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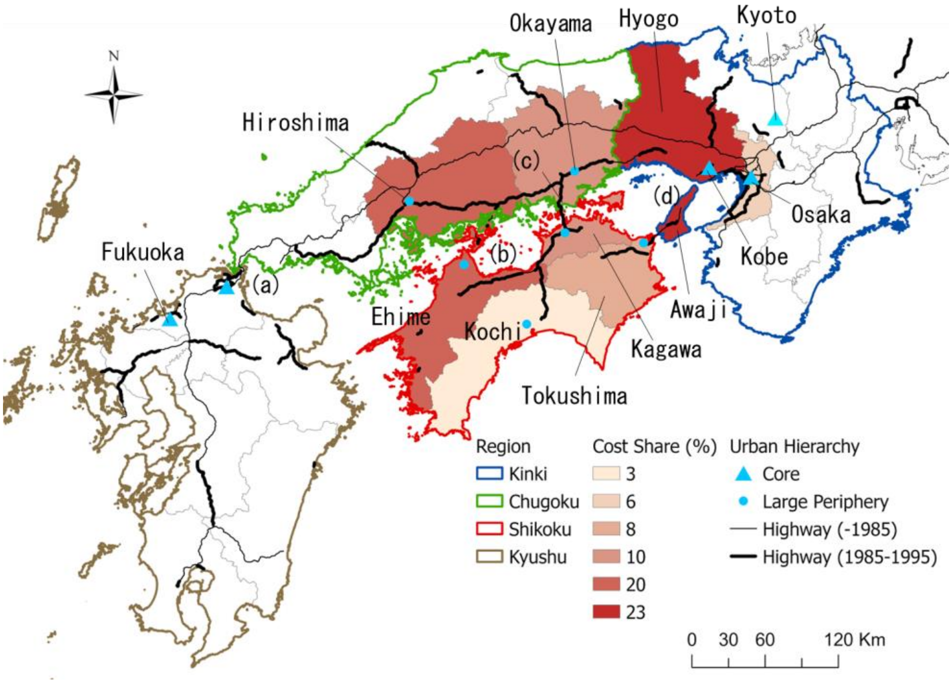
[4] These core cities had a population size of 500,000 or more prior to 1980. The large peripheral cities had a population size of 200,000 or more before 1980. In the official language, cities with populations exceeding 500,000 are called ordinance-designated cities, and cities with populations exceeding 200,000 are called central cities in Japan (The Ministry of Internal Affairs and Communications (MIC), 2021; 2023).

Figure 3. Major Highway Routes and the Great Seto Bridges in Western Japan



Notes: Area surrounded by blue is the Kinki region, green is the Chugoku region, red is the Shikoku Island, and light brown is the Kyushu Island. The Kinki and Chugoku regions lie on Honshu Island. The prefectures in red are those that directly bear the construction costs of the Great Seto Bridges. Five transport megaprojects are also labeled: (a) the Kanmon Bridge (opening in 1973), (b) the West-Seto Bridge (opening in 1999), (c) the Central-Seto Bridge (opening in 1988), and (d) the East-Seto Bridge (opening in 1998).

Figure 4 shows the estimated impacts of bridges have on transport costs. Here we define transport costs as the sum of travel time costs and transport user fees between all cities (a more detailed explanation of the costs is offered in **Subsection III-B**).[5] The figure plots the changes between 1985 and 1995 in logged values of transport costs. As shown, the largest reduction in transport cost occurred in the Shikoku region, and the next largest was in the inner main island, implying that the construction of the Great Seto Bridges is critical in explaining the changes in transport costs during this period.

From its inception, the construction of the Bridges was highly contentious for several reasons. First, the construction of the Bridges was one of the largest transport megaprojects in Japan and worldwide (see **Table 1**). The total construction cost was estimated to be around 70 billion dollars, and the construction of the three bridges took roughly 20 years. The cost per kilometer is the highest compared to other large-scale public investments in the world,

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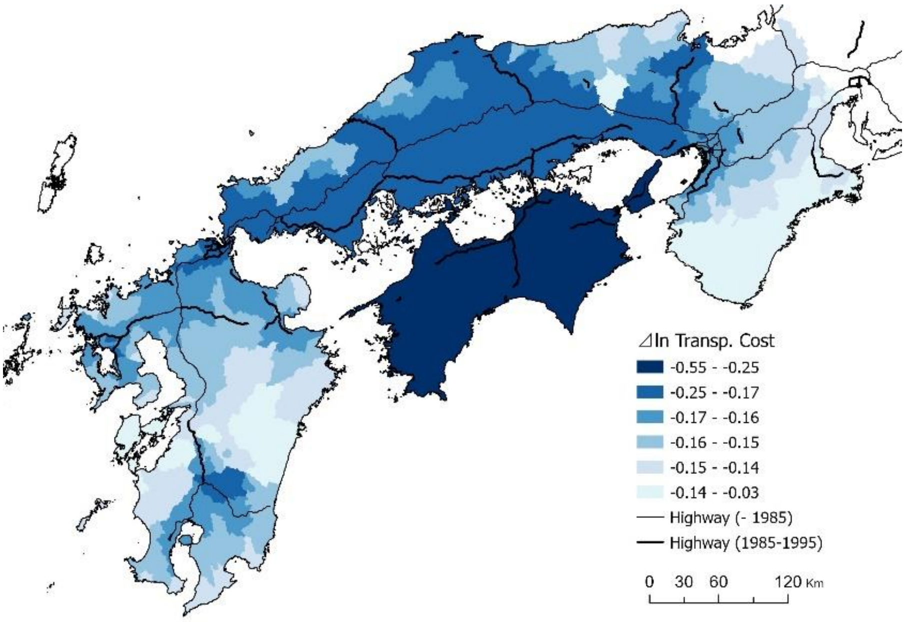
[5] We use the term "transport costs" instead of "trade costs" in our analysis because transport costs are often the dominant factor in determining inter-city trade and migration (e.g., Duranton and Turner, 2012; Redding, 2020).

and is approximately 5.8 times the cost of the Channel Tunnel connecting the U.K. and France. Due to the huge financial burden, there was a debate as to whether the project would be profitable and which prefectures should bear the cost and how much (*Asahi Newspaper*, 1985; *Nikkei Newspaper*, 1985).

Figure 4. Transport Cost Reductions during the 1985-1995



Notes: This figure shows the change (in logarithm) in transport costs from 1985 to 1995. The thin line represents highways built before 1985, and the thick line represents highways built between 1985 and 1995. Transport costs are defined as the sum of time costs and transport user fees required to travel between cities, added together across all cities.

Second, critics raised concerns about the *Straw effect* in the project. The *Straw effect* is the phenomenon that economic activity in peripheral cities in the Shikoku region would be swallowed by the core cities such as Osaka (Ihara *et al.*, 2015). Such a concern is not unrealistic, and is indeed rooted in economic theory. Since Krugman (1991), economists have long developed the theory of how cities grow. It is easy to construct an example in the stylized spatial model where the core cities simply gain more, and the peripheral cities lose from a transportation project (as illustrated in Panel B, **Figure 1**).

The realization, and economic gains from the project and its distribution over space are quite important from the public finance standpoint. Currently, eight prefectures unevenly bear the burden of the construction costs, but after 30 years of construction, these prefectures have not been able to fully pay the debt. The cost shares of eight prefectures are also shown in **Figure 3** as shaded areas, with darker red colors indicating higher cost shares. Comparing **Figure 3** and **Figure 4**, we see that the geographic distribution of the cost shares does not match that of the transport cost reductions. This highlights the importance of our question: Does it match the distribution of economic gains?

Table 1. Construction Costs of Transportation Mega-Projects

Country	Project	Approximate Cost (USD Bil. in 2015)	Total Length (km)	Unit Cost (USD Mil. in 2015/km)
Japan	Honshu-Shikoku Bridge Project	69.46	25	2734.82
UK and France	Channel Tunnel (Railway Tunnel)	23.66	50	468.81
Switzerland	Gotthard Base Tunnel (Railway Tunnel)	10.81	57	189.57
United States	Interstate Highway System	502.36	78,465	6.40
China	National Trunk Highway System	38.05	161,000	0.24
Germany	Unification Transport Projects (VDE)	40.46	1,900	21.30
Spain	High-speed railway network (AVE)	44.85	3,622	12.38
	International Space Station	173.85	400	434.63

Source: Board of Audit of Japan, 1998; Veditz, Leslie Allen, 1993; Thomas Müller and Isidor Baumann, 2016; Al Neuharth, 2006; Faber, 2014; Bundesministerium für Verkehr, Bau und Stadtentwicklung, 2012; Ian Mount, 2014; Richard Hollingham, 2015.

III-B. Data

We make use of three sets of data for our empirical analysis.

Transport Cost and Market Access Variables: We define the transport costs as the sum of the travel time cost and the user fee between cities. Prior to the construction of the Bridges, transportation in our study area and period heavily relied on local roads and ferries for the transport of goods and people. Hence, to calculate travel time costs, we use transportation network data from the following sources: local road network data (ESRI Japan, 2021), highway road data (MLIT, 2020), and ferry route data (MLIT, 2012). We adjust the travel time on the road for road widths and road types (local vs. highway), accounting for differences in travel speeds. For this, we use the General Traffic Volume Survey Results of the National Road and Street Traffic Situation Survey by MLIT (2015). We then multiply the travel time by the official estimate of the time value of 3,060 JPY per hour (MLIT, 2008). For user fees, we use toll rates by NEXCO West Japan and ferry fares for different ferry routes.

As a measure of the market size in equation (1), we use the population size of each city, following Donaldson and Hornbeck (2016), and Borusyak and Hull (2023). Our population data come from the Statistics Bureau of the Ministry of Internal Affairs and Communications. As we explain in the next section, we use 5-year lagged population sizes to avoid the endogeneity problem.

Outcome Variables: As our outcome variables of interest, we consider three variables: manufacturing output, population, and employment. We use these as our outcomes not only because all of these variables have been used in previous studies (e.g., Duranton and Turner, 2012; Faber, 2014; Baum-Snow *et al.*, 2020; Jedwab and Storeygard, 2022; Borusyak and Hull, 2023) but also because they are the primary indicators when the critics express their concerns about the Straw effect. A city's manufacturing output is obtained the value of manufactured product shipment from Industrial Statistics Survey (METI, 1980-2010). For both population and employment, the data come from the Statistics Bureau of the Ministry of Internal Affairs and Communications. We use the population in the labor force as a proxy for the employment level of each city. Arguably, this is an inaccurate measure of employment in each city because people might commute across cities and some people may be unemployed. Nonetheless, we believe it is still a good proxy because the residential choices of people in the labor force are highly correlated with employment demand in cities.

Control Variables: Our control variables include both the physical geographic characteristics ("first nature") and the sociodemographic characteristics ("second nature") aggregated at the city level as of 1980 as our controls. These are known as the primary drivers of economic growth (see Krugman (1993) and the quantitative spatial model in Appendix B). As the variables that capture the first nature, we follow Faber (2014), and use the average slope, the average elevation, the percentage of land areas suitable for building, the percentage of water areas, and the percentage of wetland areas before 1980. All these variables use data from the National Land Numerical Information Download Service (MLIT, 1981; 1976). For the sociodemographic characteristics, we use the percentage of elderly residents, the percentage of employees in the manufacturing sector, and the manufactured product shipment value as of 1980. The data for these variables come from the Census Statistics (MIC, 1980) or Industrial Statistics Survey (METI, 1980).

III-C. Descriptive Statistics

We report the descriptive statistics on key variables used in our empirical analysis in **Table 2**. The first two columns in **Table 2** report the means and standard deviations using all samples whereas the remaining columns report these for by city size as of 1980: small, large peripheral, and core cities (see **Figure 3** and **Section Ⅲ-A**).

Table 2. Descriptive Statistics

			The Size of Economy									
			Small Periphery									
	Overall		Lower		Middle		Upper		Large Periphery		Core	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Panel A: Transport Cost and MA												
⊿ln Transport Cost	-0.47	(0.28)	-0.48	(0.31)	-0.46	(0.28)	-0.47	(0.26)	-0.48	(0.25)	-0.38	(0.01)
⊿ln MA	0.13	(0.23)	0.10	(0.20)	0.11	(0.18)	0.19	(0.29)	0.19	(0.25)	0.18	(0.12)
⊿EMA	0.08	(0.14)	0.08	(0.15)	0.08	(0.14)	0.10	(0.15)	0.07	(0.09)	0.14	(0.13)
Panel B: Outcpme Variables												
i) 1995												
Manufacturing Output (Bn.)	176	(441)	22.3	(45.7)	72.2	(108)	208	(204)	939	(733)	3110	(2139)
Population (K)	76.8	(178)	9.5	(5.0)	29.5	(10.3)	86.6	(41.2)	418	(181)	1556	(607)
Employment (K)	37.8	(124)	4.2	(2.4)	12.7	(4.8)	38.9	(20.6)	198	(101)	1058	(800)
ii) 2005												
Manufacturing Output (Bn.)	173	(397)	29.1	(77.8)	80.3	(150)	210	(242)	910	(855)	2262	(1241)
Population (K)	76.8	(182)	9.1	(5.3)	29.2	(12.4)	85.7	(42.9)	421	(186)	1591	(598)
Employment (K)	35.8	(111)	4.0	(2.6)	12.3	(5.5)	37.3	(20.0)	189	(98.0)	960	(649)
Panel C: Control Variables												
i) Geographical Conditions												
Average Elevation	238	(191)	317	(242)	225	(167)	196	(139)	125	(83.4)	158	(136)
Average Land Steepness	12.8	(7.0)	15.4	(7.9)	12.7	(6.6)	11.4	(5.7)	8.3	(4.7)	8.8	(6.3)
Share of Water Area	0.10	(0.09)	0.08	(0.09)	0.09	(0.08)	0.11	(0.10)	0.13	(0.07)	0.11	(0.07)
Share of Wetland Area	0.010	(0.05)	0.008	(0.040)	0.007	(0.027)	0.017	(0.067)	0.009	(0.035)	0.005	(0.008)
Share of Building Area	0.22	(0.19)	0.15	(0.15)	0.20	(0.16)	0.26	(0.20)	0.41	(0.24)	0.43	(0.24)
ii) Socioeconomic Conditions												
Manufacturing Output (Bn.)	131	(418)	12.6	(38.4)	39.0	(67.4)	140	(156)	797	(767)	2884	(2315)
Share of Manuf. Labor	0.08	(0.05)	0.07	(0.07)	0.08	(0.05)	0.09	(0.05)	0.08	(0.04)	0.09	(0.03)
Share of Elderly	0.12	(0.03)	0.14	(0.03)	0.13	(0.03)	0.11	(0.03)	0.08	(0.02)	0.09	(0.01)
Observations	615		191		191		191		37		5	

Notes: This table shows the means and variances of the variables by city size. This classification is defined based on the 1980 population and the urban hierarchy criteria in Japan: Core is over 500,000 or more, Large Periphery is below 500,000 and over 200,000, and Small Periphery is below 200,000. The small periphery is subdivided into three groups: Lower is below the 33rd quantile, Middle is over the 33rd and below the 66th quantile, and Upper is over the 66th quantile. Panel A shows the change in the MA variable from 1985 to 1995. Panel C shows the control variables as of 1980.

Panel A displays the changes in logged transport costs, market access (MA), and expected market access (EMA) between 1985 and 1995 (see the next section on how the MA and EMA variables are calculated). We see a substantial decline in transport costs, by about 47% on average, and an associated increase in MA, by 13% on average. Importantly, the decline in transport costs is larger in smaller cities whereas the increase in the MA is more pronounced in larger cities. This weak correlation between the two variables signifies the importance of our empirical approach.

Panel B reports the means and standard deviations of our outcome variables in 1995 and 2005, the beginning and ending years of the ten-year period we use to evaluate the economic impact. In 1995, our sample had the mean manufacturing output of approximately 176 billion yen, the population size of roughly 77,000, and the population in labor force of 36,000 per city. Overall, cities in the Western Japan region are on a declining trend during this period. Interestingly, however, larger cities tend to lose manufacturing output while gaining population; on the other hand, smaller cities tend to gain manufacturing output while losing population.

Panel C presents the means and standard deviations of our control variables as of 1980, the pre-treatment period. The table indicates that larger cities were typically located in more favorable terrain, with suitable land for building and accessible water resources. These factors are positively correlated with changes in the MA variable, leading to bias in the estimates if not controlled for. However, these control variables show little correlation with both changes in transport costs and the outcome variables.

IV. Empirical Strategy

IV-A. The Recentered Market Access Approach

Our goal is to quantify the causal effect of the Great Seto Bridges on the economic growth of cities in the western Japan. As discussed in the previous sections, we are particularly interested in its heterogeneous impacts: which cities gain (or lose) more, and why? The essential problem, as demonstrated in Section II, is that not just cities directly connected by the Bridges but *all* cities are treated via the general equilibrium effects by this transportation investment. Hence, the usual quasi-experimental methods, such as difference-in-differences or regression-discontinuity methods, are unlikely to work well in our context. Instead, we start by the structural market access equation. This type of structural equation can be derived from the quantitative spatial model (Donaldson and Hornbeck, 2016; Redding, 2020; Jedwab and Storeygard, 2022):

$$\ln Y_{i,t} = \beta \ln MA_{i,t} + W_{i,t}\gamma + \xi_i + \eta_{i,t} + \epsilon_{i,t}. \tag{4}$$

where $Y_{i,t}$ is a variable that measures the economic size of city i in year t, $MA_{i,t}$ is a market access variable, $W_{i,t}$ denotes a vector of controls, ξ_i is time-invariant unobservables, $\eta_{i,t}$ is time-varying observables, and $\epsilon_{i,t}$ is pure i.i.d. errors.

The literature has identified a number of empirical issues in estimating this equation, but the bottom line is that to obtain an unbiased estimate of β, we need exogenous variation in the MA variable that is uncorrelated with uncontrolled unobservables. To ensure it, we combine the following set of strategies.

The first strategy is to apply the conventional wisdom from the panel-data methods. First, we follow Donaldson and Hornbeck (2016) and Jedwab and Storeygard (2022), and define the MA variable for city i at time t by taking the first-order approximation to equation (1):

$$MA_{i,t} \approx \sum_{j \neq i} \tau_{ij,t}^{-\theta} POP_{j,t-1}. \tag{5}$$

where $POP_{j,t}$ is the city j's population size in year t and we set the value of trade elasticity to $\theta = 4.0$ following Simonovska and Waugh (2014).[6] Note that in this expression, the value of city i's own outcome $Y_{i,t}$ does not enter the value of $MA_{i,t}$. Second, we take the first-difference of equation (4) to eliminate the time-invariant unobservable term ξ_i. Third, we run the regression in lags, i.e., $\Delta(\ln Y_{i,t})$ are regressed on $\Delta(\ln MA_{i,t-1})$. This ensures that the MA variable does not depend on the contemporaneous values of the outcome. In general, the economic benefits of a transportation megaproject take quite some time to materialize after its construction. In our case, the government documents report that the effects were observed several years after the construction of the Bridges (MLIT, 2019; Honshu-Shikoku Bridge Expressway Company Limited, 2023). Forth, regarding the MA variable in equation (5), we take a time delay between transport cost and the size of the economy, i.e., $POP_{j,t-1}$ relative to $\tau_{ij,t}$, to avoid endogeneity problems coming from simultaneous changes in these. Fifth, we include controls to absorb the remaining terms, $\Delta W_{i,t}\gamma$ and $\Delta\eta_{i,t}$. We explain the final estimating equation in detail below.

Our second strategy is to exploit the quasi-experimental variation in transport costs induced by the construction of the Great Seto Bridges (and other highway constructions during the same period). As shown in **Figure 4**, the construction of the Central-Seto Bridge dramatically reduced the transport costs for not only the connected but all cities. This gives us the exogenous source of variation in the MA variable. Furthermore, much of this transport cost reduction occurred in the late 1980s and in the Shikoku region, bringing the region's transport costs down to the same level as the other areas (**Figure 5-A**). Recall that only the Central-Seto Bridge was constructed in 1988, and the other two bridges were not completed until 1998. **Figure 5-A** reveals that the construction of the Central Seto bridge caused the sharp transport

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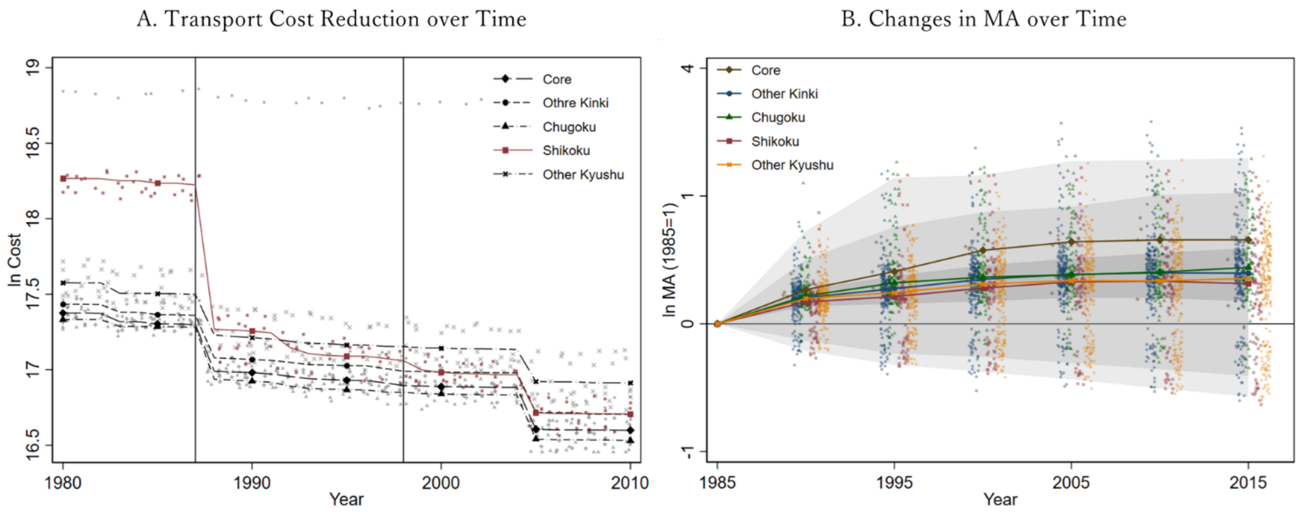
[6] We also report the results of our estimation using alternative trade elasticities in Appendix D. Intuitively speaking, smaller values of θ assign more weights to transport costs while higher values assign more weights to the population size. The trade elasticity of $\theta = 4.0$ appears to hit the right balance as discussed in the appendix as well as in Simonovska and Waugh (2014).

cost decline in cities surrounding the Seto bridges in the Chugoku and the Shikoku regions in the late 1980s while the other two bridges in the late 1990s led to relatively small transport cost reductions and their magnitudes were similar across regions.

Figure 5. Transport Cost Reductions and Changes in MA over Time


A. Transport Cost Reduction over Time

B. Changes in MA over Time

Notes: Panel A shows that transport cost reduction. Each line represents the median for the region. The Kinki and Kyushu regions use averages excluding the core cities. Small dots are the medians for the prefectures. Panel B shows that changes in the MA variable. Gray shaded areas represent the 1st to 99th percentile, 5th to 95th percentile, and 25the to 75th percentile of all observers, in order from lightest to darkest color. Each line represents the median for each region. Dots represent the raw values for cities.

In Panel B, we visually present the changes in logged MA relative to the values in 1985 as a result of the reduction in transport costs. The gray shaded areas, ranging from lightest to darkest, denote the 1st to 99th percentile, 5th to 95th percentile, and 25th to 75th percentile of all observations, respectively. Lines with markers represent the median values for five representative regions while dots represent the values for individual cities. The figure delivers several key messages that echo the points we made in **Section II**. First, there is no one-to-one relationship between the changes in transport costs and those in the MA variable. Although the magnitude of the transport costs reduction is far more pronounced in the Shikoku region, there are winners and losers of MA in all regions. The correlation between the decline in transport costs and the growth in MA variable is not uniform, particularly in the Shikoku region, where we see both increase and decrease in MA. Second, the transport cost reductions have persistent impacts on the MA variable. We see a substantial increase in MA not only in 1990 following the sharp decline in transport costs in 1988, but also in 1995 in the Chugoku and Shikoku regions. The MA growth levels off only after 2000, with some changes during

1995-2005. Third, the median values indicate that core cities have a higher growth of the MA possibly due to their original advantages of geographic and economic networks. This suggests that pre-existing network dynamics play a significant role in determining the endogenous impacts of transportation cost reductions, as discussed in **Section II-C**.

This leads us to use the following estimation equation.

$$\Delta(\ln Y_i)_{95-05} = \beta\Delta(\ln MA_i)_{85-95} + g(X_{i,80}) + \Delta\epsilon_{i,95-05}. \tag{6}$$

where $g(X_{i,80})$ is the term that controls for the influence of the observables $\Delta W_{i,t}$ and the unobserbales $\Delta\eta_{i,t}$. We use socioeconomic and geographic variables in 1980 as pre-treatment controls. Note that this specification is similar to that of Duranton and Turner (2012) or Faber (2014), but differs from them in that we don't use the difference-in-difference(DID) design directly in the estimating equation and that we instead use the DID design only as the source of variation in our MA variable. In the nutshell, this equation compares the outcome trends of cities that experience larger (or positive) shocks in MA against those of cities with smaller (or negative) shocks, controlling for other economic factors.

Our third strategy is to apply the recentered instrumental variable approach (Borusyak and Hull, 2023) in equation (6) to address the fundamental endogeneity problem. Economists are increasingly concerned with the endogeneity of the MA variable, even after taking all the steps and the quasi-experimental variation above, that may arise from reverse causality or selection bias. That is, public infrastructure investments are made in cities where higher (or lower) economic growth is expected. This kind of endogeneity is hard to address because the selection hinges on the *future* expectation, and as a result, the reverse causality might still exist even if we take long lags in regression analysis. In the earlier literature, economists have used an instrumental variable (IV) approach, relying on three types of instruments: planned route IV (e.g., Baum-Snow, 2007), historical route IV (e.g., Duranton and Turner, 2012), and optimal least cost path IV (Faber, 2014). However, economists have long been concerned with the validity of such instruments.

Fortunately, Borusyak and Hull (2023) also offered a possible solution, called the recentered instrumental variable approach. The fundamental problem for the earlier literature is that a city's location in the intrinsic structure of economic network is inherently endogenous, so any variable constructed from the network structure, whether it is based on the far past, the first-nature, or the optimization algorithm, cannot be plausibly exogenous. Borusyak and Hull (2023) convincingly shows why this is the case, clarifying the nature source of bias.

We operationalize Borusyak-Hull's RMA approach discussed in Section II-C as follows. We first randomly select the location and timing of transportation investments in the western

Japan, and calculate the corresponding changes in transport costs and MA variable.[7] We then calculate the expected MA growth for each city as the average of the 10-year growth of realized pre-treatment MAs in log:

$$\Delta EMA_{i,85-95} \equiv E[\Delta(\ln MA_i)_{85-95}] = \frac{1}{\#S}\sum_{s\in S}\left[\ln \widetilde{MA}^{s}_{i,95} - \ln MA_{i,85}\right] \tag{7}$$

where $\widetilde{MA}^{s}_{i,95}$ is city i's counterfactual MA (simulated for year 1995) from each random draw s, and $MA_{i,85}$ is city i's observed MA before treatment in 1985. We then define the recentered market access (RMA) growth as the difference between the observed changes in MA and EMA growth:

$$\Delta RMA_{i,85-95} \equiv \Delta(\ln MA_i)_{85-95} - \Delta EMA_{i,85-95}. \tag{8}$$

From the way it is constructed, it is clear that ΔRMA_i is the *exogenous component of the observed variation in MA* that is realized from the actual public infrastructure investments. We can make use of this RMA growth variable as a valid instrument for MA because it must be correlated with MA (relevance) and is uncorrelated with the unobserved error (exogeneity). On the latter, note that the RMA growth instrument has an intuitive appeal for empirical economists who are concerned concerns about bias arising from reverse causality or selection --- the government agencies may decide when and where to make public transportation investments forecasting the excepted growth of cities in different areas, but ΔRMA_i purges out that expected growth component from the MA variable. Some may wonder if this argument holds, then we may actually use ΔEMA_i as a control in the OLS regression so as to absorb the expected growth component. Indeed, Borusyak and Hull (2023) shows that the OLS regression with EMA growth as a control and the IV regression with RMA growth as an instrument generally lead to similar estimates. In Section V, we show that this is indeed the case with ours too.

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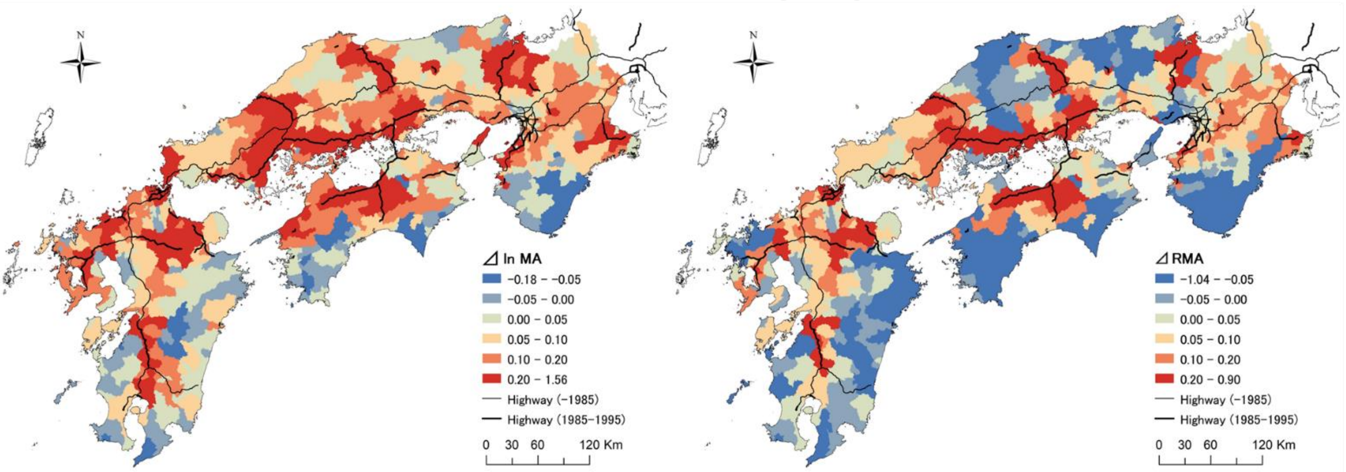
[7] We use the population size of each city as of 1980 in calculating the MA for each draw. In each draw, we randomly select a highway segment from the set of highway segments that were built between 1985 and 2015 with a 50% probability. Due to high computational burden, we only repeat 100 times of random draws.

IV-B. The Instrument Validity

This section discusses the spatial as well as temporal distribution of both the MA growth and the RMA growth variables in our study's context. **Figure 6** shows the changes in logged values of MA (Panel A) and in logged values of RMA (Panel B) over the period of 1985-1995.

First, the spatial distribution of changes in market access (**Figure 6-A**) does not necessarily coincide with that of transport costs (**Figure 4**). There is an indication that MA variable increase significantly in cities where highways were constructed. For instance, we see substantial increases in the MA variable in cities near the Great Seto Bridges. However, some cities (e.g., northeastern Kyushu) increase their market access levels even though no highways were built during this period while some other cities (e.g., cities near Osaka) decrease their market access even though highways were built. Furthermore, cities in the southern Shikoku region lost market access despite that transport costs for these cities substantially declined. This reinforces the importance of accounting for the general equilibrium effects of public infrastructure investments discussed in Section II.

Figure 6. Spatial Variation in Raw and Recentered Market Access



A. Log Changes in Market Access, 1985-1995

B. Log Changes in Recentered Market Access, 1985-1995

Notes: Panel A shows the logarithm changes in MA variable over 1985-1995: we use lagged values of population to construct the MA variable based on equation (5). For Panel B, we construct the logarithm changes in RMA by using the population as of 1980 for the changes in EMA based on equations (7) and (8).

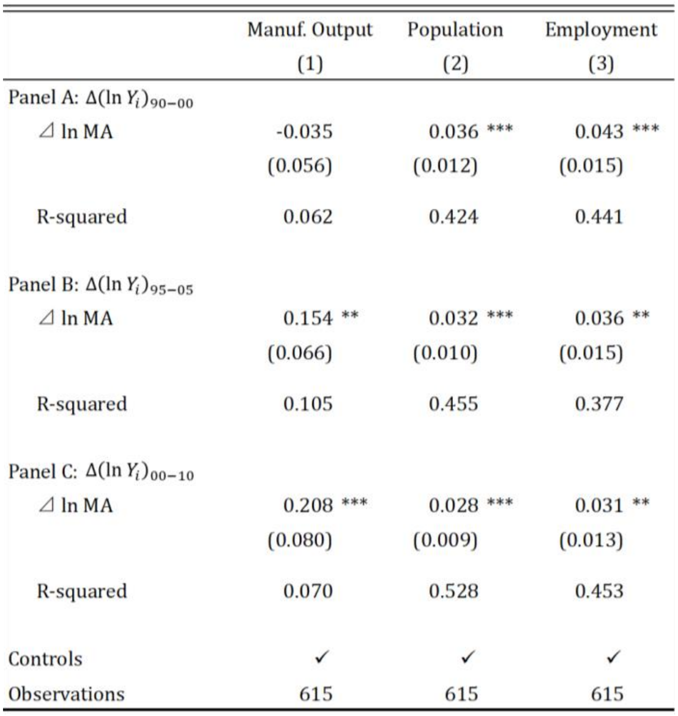
Second, **Figure 6-B** indicates that the spatial distribution of changes in MA matches that of changes in RMA, implying these are spatially highly correlated and that RMA growth is indeed a relevant instrument for changes in MA variable. However, the figure also illustrates that some of these changes in market access are *unexpected*, in the sense that the changes exceed (or fall short of) the expected growth of market access for some cities. For example, the northern Shikoku and the southern Chugoku regions experienced larger changes in RMA growth than others, implying that the market access growth due to the construction of the Great Seto Bridges is not something we expect from the intrinsic structure of the economic geography. On the other hand, the core cities, such as Osaka, received the negative shock in market access after netting out the expected growth. These cities, with large economic size, tended to grow faster than others, however, the actual growth arising from the construction of the Bridges and other highways during the period fell short of that expectation. This implies that the observed variation in MA due to the construction of the Great Seto Bridges and other highways during the period indeed has unexpected, exogenous variation in MA, which we can exploit in the identification of its economic impact. We report the results of the first stage in two-stage least squares regression in **Appendix C**.

V. Estimation Results

V-A. OLS Regression

We first present the results on the OLS regression of equation (6) in **Table 3**. We use three outcome variables, manufacturing output (the first column), population size (the second column), and employment (the third column), to gauge the extent of the impact on city-level economic growth. We also use the following city-level variables as of 1980 as controls: the average land steepness, average elevation, percentage of building areas, percentage of water areas, percentage of wetlands, and percentage of elderly and manufacturing labors, and measures of economic size as of 1980. These are meant to capture the influence of city-level unobservables on the economic growth trends. To allow for the possibility that the impulse responses may vary over time, we also run the same regressions varying the time periods to measure the economic impact: $\Delta(\ln Y_i)_{90-00}$ (Panel A), $\Delta(\ln Y_i)_{95-05}$ (Panel B), and $\Delta(\ln Y_i)_{00-10}$ (Panel C). Our preferred specification is the one with $\Delta(\ln Y_i)_{95-05}$ in Panel B, for reasons we outlined in **Section IV**. All regressions use full controls (see the table footnotes for details).

Table 3. OLS Regression Results



	Manuf. Output (1)	Population (2)	Employment (3)
Panel A: $\Delta(\ln Y_i)_{90-00}$			
⊿ ln MA	-0.035	0.036 ***	0.043 ***
	(0.056)	(0.012)	(0.015)
R-squared	0.062	0.424	0.441
Panel B: $\Delta(\ln Y_i)_{95-05}$			
⊿ ln MA	0.154 **	0.032 ***	0.036 **
	(0.066)	(0.010)	(0.015)
R-squared	0.105	0.455	0.377
Panel C: $\Delta(\ln Y_i)_{00-10}$			
⊿ ln MA	0.208 ***	0.028 ***	0.031 **
	(0.080)	(0.009)	(0.013)
R-squared	0.070	0.528	0.453
Controls	✓	✓	✓
Observations	615	615	615

Notes: All regressions use the following city-level variables as of 1980 as controls: average steepness, average elevation, percentage of building areas, percentage of water areas, percentage of wetlands, percentage of elderly, percentage of manufacturing employees, manufacturing output and population size as of 1980. *** 1%, ** 5%, * 10% significance levels and parentheses denote cluster robust standard errors, clustered at the city level.

We have two important take-aways from **Table 3**. First, the changes in MA during the 1985-95 period have statistically significant, yet economically small impacts on economic outcomes. With our preferred specifications using 1995-2005 as the outcome period (Panel B), the point estimates are 0.154, 0.032, and a 0.036, respectively, for manufacturing output, population, and employment. Standard errors are larger for regressions on manufacturing output than on population or employment. Using the mean values reported in **Table 2**, these estimates imply that the highway construction during this period lead to, on average, 2.03%, 0.42%, and 0.48% changes in manufacturing output, population, and employment during the same period. Second, the estimated impulse responses are roughly consistent across different periods, except for the manufacturing output using 1990-2000 as the outcome period. As shown in **Figure 5-B**, the changes in MA are serially correlated in somewhat unpredictable ways due to persistency and feedback loops of the transport-cost impacts. The outcomes in the 1990-2000 period may be responding to the changes in MA in the periods other than 1985-1995 that are not used as our treatment variable. Even with our clean identification strategy, we cannot completely eliminate such intertemporal correlations. This supports our rational for using 1995-2005 as our preferred outcome period since it is the period when the influence of other periods' MA changes is expected to be the smallest.

V-B. Recentered Market Access Approach

Next, we present the results of the RMA approach in **Table 4**, using the same set of outcome variables and controls as in **Table 3**. We make use of the RMA approach in two ways, a la Borusyak and Hull (2023): (a) using ΔEMA as an additional control and (b) using ΔRMA as an instrument for $\Delta \ln MA$. If the approach works, we expect the estimates would be similar. For each outcome, the first column displays the OLS results with a full set of controls and ΔEMA, and the second column shows with ones and ΔRMA as an instrument. As shown, our results are consistent with Borusyak and Hull (2023) in that our IV results with RMA growth are quantitatively quite similar to the OLS results with EMA growth as an additional control. Hence, we discuss our results mainly using the estimates from the RMA-IV regression.

Our results indicate that the use of the RMA approach tends to increase the magnitude of the estimates, without changing their signs, reinforcing the impacts of transportation investments. With our preferred specifications using 1995-2005 as the outcome period, our point estimates are 0.197, 0.039, and 0.056, respectively, for manufacturing output, population, and employment. Using the mean values reported in **Table 2**, these estimates imply that the highway construction during this period lead to, on average, 2.60%, 0.51%, and 0.74% changes in manufacturing output, population, and employment, respectively, during the 1995-2005 period. For all regressions, the IV estimates are larger in magnitude than the OLS estimates, implying the existence of a downward bias on the OLS estimates. This is somewhat unexpected, but is indeed consistent with econometric theory.[8] The sign of the coefficient on EMA growth is negative. This implies that the non-random exposure in the current setup induces non-random structural errors in equation (6) that are negatively correlated with EMA growth. Hence, if uncontrolled, this causes a downward bias in the estimates.

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[8] Borusyak and Hull (2023) use Chinese high-speed rail expansion as an application. Their IV estimates on the market access variable are generally smaller in magnitude than the OLS estimates, but their coefficients on EMA growth are positive.

Table 4. The Results of the Recentered Market Access Approach

	Manuf. Output		Population		Employment	
	EMA-OLS	RMA-IV	EMA-OLS	RMA-IV	EMA-OLS	RMA-IV
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: $\Delta(\ln Y_i)_{90-00}$						
⊿ ln MA	-0.180 **	-0.162 **	0.054 ***	0.052 ***	0.065 ***	0.062 ***
	(0.081)	(0.079)	(0.016)	(0.015)	(0.022)	(0.020)
⊿ EMA	0.376 **		-0.049 **		-0.056	
	(0.178)		(0.024)		(0.045)	
R-squared	0.070	0.057	0.426	0.422	0.443	0.440
Panel B: $\Delta(\ln Y_i)_{95-05}$						
⊿ ln MA	0.203 **	0.197 **	0.040 ***	0.039 ***	0.059 ***	0.056 ***
	(0.093)	(0.087)	(0.012)	(0.012)	(0.021)	(0.019)
⊿ EMA	-0.126		-0.022		-0.059	
	(0.214)		(0.019)		(0.042)	
R-squared	0.106	0.104	0.456	0.455	0.379	0.375
Panel C: $\Delta(\ln Y_i)_{00-10}$						
⊿ ln MA	0.358 ***	0.340 ***	0.036 ***	0.035 ***	0.057 ***	0.054 ***
	(0.100)	(0.102)	(0.011)	(0.010)	(0.016)	(0.016)
⊿ EMA	-0.390 **		-0.020		-0.068 **	
	(0.155)		(0.018)		(0.028)	
R-squared	0.077	0.067	0.529	0.528	0.457	0.451
First-Stage F-Stat.		126		126		126
Controls	✓	✓	✓	✓	✓	✓
Observations	615	615	615	615	615	615

Notes: For each outcome, the first column presents the results of OLS regression with ΔEMA, and the second column reports the results of 2SLS with ΔRMA as the instrument. We use the same set of controls as in Table 3. *** 1%, ** 5%, * 10% significance levels and parentheses denote cluster robust standard errors, clustered at the city level.

V-C. Heterogeneity and Robustness

The regression equation (6) estimates the *average* elasticity of a city's economic size with respect to the market access over cities. This is fine if the elasticity is homogenous or the heterogeneity is uncorrelated with changes in MA. However, there is another source of concern. To calculate our MA variable in estimating equation (6), we use equation (5), which excludes city i's own population whereas the true MA variable in equation (1) is defined recursively using i's own population. This is done to avoid the direct influence of the city's own economic outcome on the MA variable, which would cause another endogeneity issue.[9] Yet, such omission may create unobserved heterogeneity in economic impacts that may be correlated with the changes in MA. To address such a concern, we estimate a version of equation (6) allowing for the heterogeneous effects of MA：

$$\Delta(\ln Y_i)_{05-95} = \sum_r \beta_r \mathbb{I}[i \in G_r]\Delta(\ln MA_i)_{85-95} + g(X_{i,80}) + \Delta\epsilon_{i,95-05}. \tag{9}$$

where $\mathbb{I}[\cdot]$ is an indicator, which equals one if city i belongs to a group G_r. We classify cities into three groups (heterogeneity dummies) using the following three alternatives: the tertiles of manufacturing output as of 1980, and population size as of 1980. Estimating these regressions using the IV approach requires the same number of instruments as the number of dummies accounting for the heterogeneity. We could potentially interact the RMA with these dummies. Such a strategy is known to result in implausible estimates in practice. Therefore, we instead use the EMA as a control in equation (9).

Table E2 presents the results of estimating equation (9) using the RMA approach. The table also reports the p-values of the joint hypothesis test of the null that there is no interaction effect. We have several take-aways from the results. First, the p-values are sufficiently small for population and employment, leading to rejection of the null hypothesis. This suggests the possibility of heterogeneous effects on these two outcomes. On the other hand, for manufacturing output, our concerns about interaction effects are small. Second, the second and the third tertiles tend to have larger, statistically more significant effects than the first tertile for all outcomes. This implies that cities that enjoy economic abundance prior to the transportation investment tend to gain more from a given increase in MA. Interestingly, in some specifications, the second tertile has larger effects than the third tertile on some economic outcomes. The cities in the second tertile tend to be large peripheral cities. Hence, the results are consistent with the analysis in the next section, which reveals that large peripheral cities gain more from the megaproject. With these, we conclude that although there

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[9] Donaldson and Hornbeck (2016) investigate the extent of such bias by estimating the same regressions using equation (1) versus equation (5). In **Table E1** of **Appendix E**, we present the OLS regression results using equation (1), but using the lagged values of population, following Donaldson and Hornbeck (2016). All estimates become positive, larger in magnitude, and more statistically significant, most likely capturing the spurious correlation via each city's own population size between the recursively calculated MA and the outcome variables.

may be a concern for existence of heterogenous treatment effects, the concern about manufacturing output, which is utilized in the subsequent analysis, is not too serious, and hence, we continue to use the estimates from regression (6).

VI. The Economic Impact of the Great Seto Bridges and Its Spatial Distribution

We now turn to the main question of the paper: Do winners win more (losers gain less or even lose) from the transport megaproject? We approach this question in two ways.

The first approach is to simply plot the predicted changes in the cities' economic outcomes over the 1995-2005 period against the cities' population sizes as of 1980. For this, we simply make use of the RMA-IV regression results from columns 2, 4, and 6 in **Table 4**. This approach simply tells us how the estimated impacts on cities' economic outcomes are distributed relative to their initial population sizes, and hence, gives us a quantitative answer to questions like "Do larger cities tend to grow more with transport projects?". This approach is arguably too simplistic for three reasons: the estimated changes include the effects of all highways constructed during the 1985-1995 period, are not in comparison with the counterfactual in the absence of the megaproject, and do not account for the costs of construction.

Our second approach thus attempts to estimate the net benefit of the transport megaproject for each city relative to the counterfactual in the absence of the Great Seto Bridge. To do so, we proceed in four steps. First, we re-calculate the transport costs, removing the Central Seto Bridge, which is the only bridge constructed during the 1985-1995 period. Second, we make use of the properties of the QSM and simulate the resulting changes in the market access levels for all cities in our sample that would occur during the post-construction (1995-2005) period. Third, we make use of the estimates from the RMA-IV regression in Table 4 and estimate the outcome changes in response to changes in market access in two states of the world: the observed state with the construction of the Central Seto Bridge and the counterfactual state without the Bridge. Lastly, we apply our estimates of the cost shares of the Central Seto Bridge to arrive at the estimates of the net benefit for each city.

VI-A. Distribution of Economic Impacts of Highway Construction

Figure 7 displays the results of the first approach, for each of the three outcomes.[10] The figure shows a clear sign of the agglomeration benefits: larger cities, prior to the transportation

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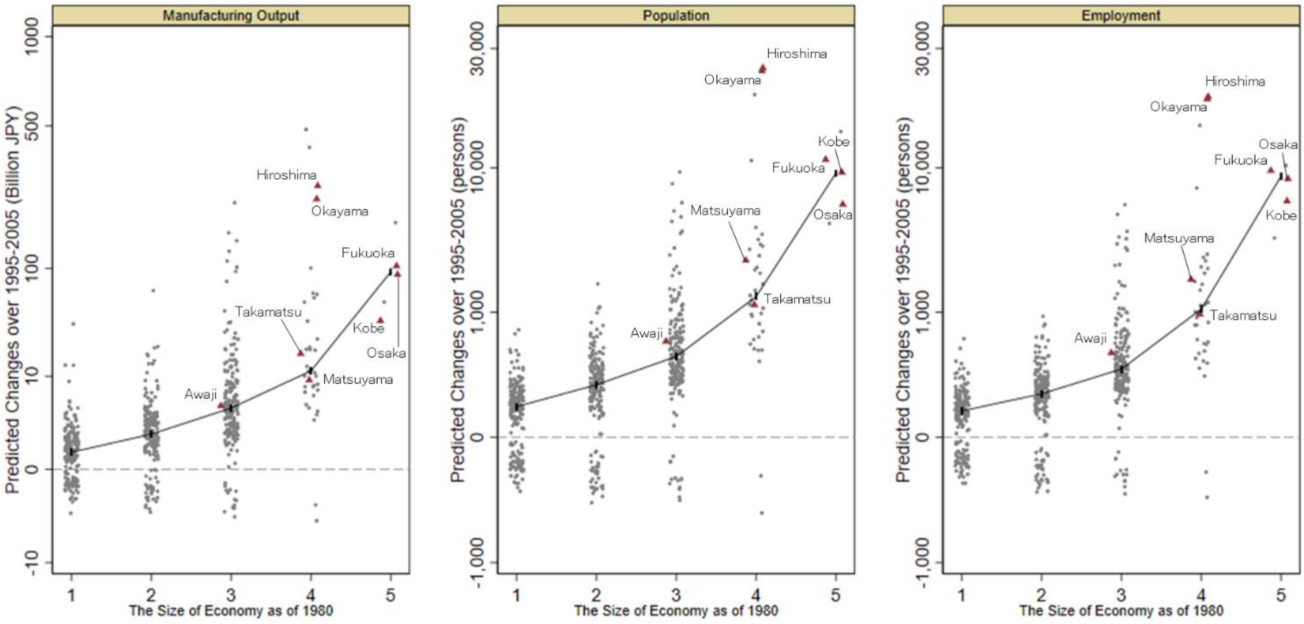
[10] In calculating the market access levels, we use the *observed* values of population in 1980 and 1990 in **Figure 7**. We provide the results using the pre-treatment values as of 1980 in **Appendix F**.

projects, tend to attract more economic activity than smaller cities. The magnitude of this effect seems economically large. At the median, the largest cities (the fifth category) gain roughly 9.5 billion yen in manufacturing output, 9,400 persons in population size, and 9,000 persons in labor force over the 1995-2005 period. The magnitude of these impacts gradually diminishes for smaller cities, yet even the smallest cities show gains, albeit modest: at the median, these cities gain 63 million yen in manufacturing output, 15 persons in population, and 9 persons in labor force. Hence, from the first exercise, we conclude that the highway construction during the 1985-1995 period had positive impacts for *all* cities, yet the impacts are distributed more toward larger cities than smaller cities.

Figure 7. Distribution of Economic Impacts across Cities of Different Population Sizes



Notes: The figure classifies cities based on their population sizes as of 1980 as follows: Cities with population size of 500,000 or more (size 5), cities with 200,000 or more (size 4), and tertiles of small peripheral cities (size 1-3). This classification follows the MIC guideline. Each point represents the estimated impacts over the 1995-2005 period. The black line shows the median of each the size of the economy.

There is another important take-away from this exercise. In the figure, the impacts on four large peripheral cities (Hiroshima, Okayama, Matsuyama, and Takamatsu) as well as on three core cities (Osaka, Kobe, and Fukuoka) are labeled with triangles. The large peripheral cities are the cities that are of critical importance to the regional economy, and the critics of the Great Seto Bridge are particularly concerned with the straw effect on these cities: the economic activity may be drawn from these central peripheral cities to the core cities. The figure demonstrates that this concern *did not* materialize. In fact, these peripheral cities are among the largest gainers from highway construction during this period. The impacts on these cities manufacturing output are 290 billion, 240 billion, 19 billion and 11 billion yen, respectively, for Hiroshima, Okayama, Takamatsu, and Matsuyama. Several reasons explain this. First, these peripheral cities are sufficiently large prior to the highway construction, and hence, they enjoy the gains from agglomeration forces just like other large cities. Second, these cities are located near the Central Seto Bridge, and thus, are likely to be the direct beneficiaries of the Bridge. Arguably, this approach is overly simplistic as discussed above.

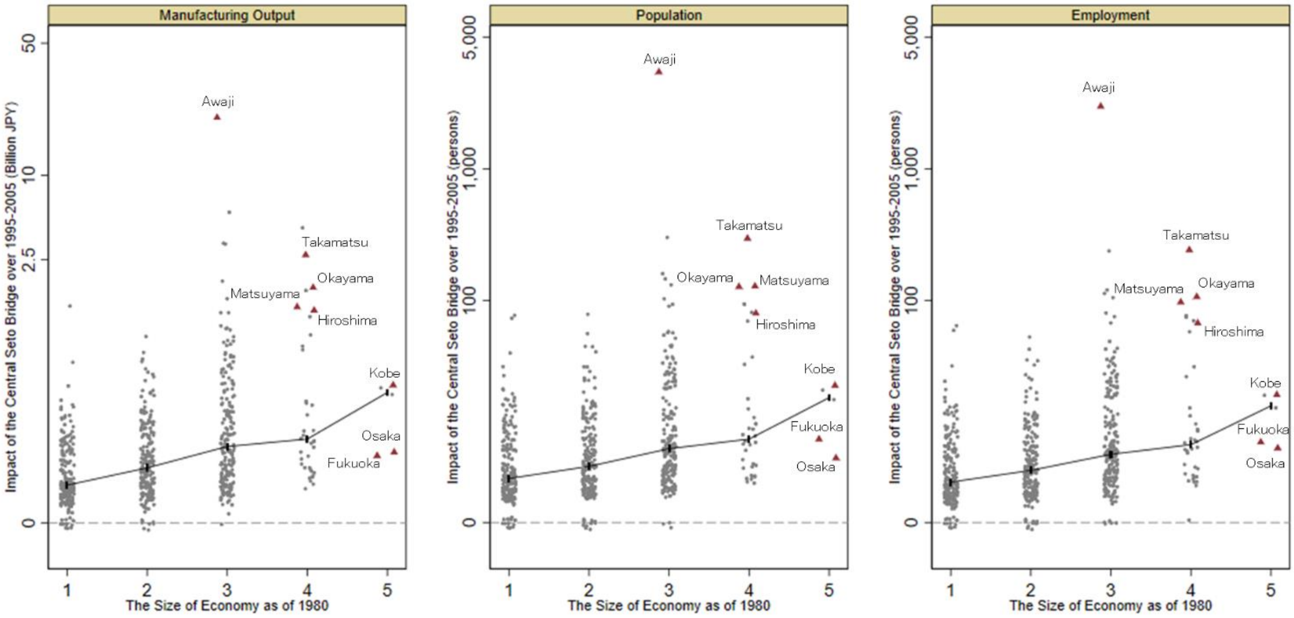
VI-B. Distribution of Net Benefits of the Central Seto Bridge

In this section, we attempt to estimate the net benefits of the Central-Seto Bridge for all cities in the sample, and compare the distribution of the net benefits against the initial population sizes of these cities. Recall that only the Central Seto Bridge was completed by 1988, the other two bridges were not completed until the late 1990s, and hence, we assume away the effect of the other bridges in this exercise.

As the first step, **Figure 8** plots the estimated impacts of the Central Seto Bridge alone on three outcomes: (a) manufacturing output, (b) population, and (c) employment, for each population size as of 1980, in a manner analogous to **Figure 7**. To recap, as explained above, these impacts are obtained by re-calculating the transport costs without the construction of the Central Seto Bridge, simulating the market access using the QSM, applying the RMA-IV estimates from **Table 4**, and taking the difference between the outcomes predicted at this counterfactual state versus those predicted at the observed state for the period of 1995-2005.

Three important observations arise from **Figure 8**. First, the magnitudes of the estimated impacts are much smaller in **Figure 8** than in **Figure 7**, implying that the *pure* effect of the Central Seto Bridge is small and that much of the effects in **Figure 7** come from the *combined* effect of the other highways and the Central Seto Bridge. This also signifies the importance of our approach in accounting for the general equilibrium impacts. Second, the estimated impacts are not necessarily monotonically increasing in initial population size (see Panel A. manufacturing output), though there is a tendency for the impacts are larger for larger cities. Third, major beneficiaries of the Central Seto Bridge are the cities located near the Bridge in the Seto Inland Sea region, in particular, the Awaji Island and major peripheral cities within the Shikoku region. The difference between **Figure 7** and **8** suggests that the construction of the Central Seto Bridge has a relatively large impact on these areas, and that its construction substantially contributes to their economic growth.

Figure 8. Counterfactual Impacts of the Central Seto Bridge
Across Cities of Different Population Sizes



Notes: The figure uses the same classification of population size as in **Figure 7**. Each point represents the counterfactual impact of the construction of the Central Seto Bridge over 1995-2005. The black line shows the median of each the size of the economy.

Our next step is to convert these counterfactual impacts into monetary values in net benefits. To do so, we apply the following simplifying accounting rules. First, on the cost side, we make use of the publicly available information on the construction cost of the Central Seto Bridge and its cost shares by prefectures from MLIT (2010). It is estimated that the Central Seto Bridge alone costs about 1.13 trillion yen in 1988 JPY. Unfortunately, we do not have the cost burden at the city level. However, the construction cost burden born by each prefecture is eventually collected through taxes from each resident within the prefecture. Hence, for simplicity, we assume the cost burden is shared in proportion to each city's population size as of 1985. Second, on the benefit side, we assume that the primary benefit of the project arises in the form of the value of the goods and services produced within the city's boundary that is purely attributable to the project. Hence, we make direct use of the estimated impacts on cities' manufacturing output, and assume away other kinds of (non-pecuniary) benefits. This is arguably a simplifying assumption. But when discussing the benefit of this kind of transport megaprojects, the city governor's interest often lies in increasing the city's tax base, for which the value of total economic output is a good measure.

There is one subtle issue, in making use of our regression/simulation results, however. On one hand, the Bridge has a useful life of 100 years (MLIT, 2004). Hence, ideally, we would like to do the cost-benefit analysis, estimating the benefit flows over the entire life years of the Bridge. On the other hand, our preferred estimates get at the counterfactual impacts of the Central Seto Bridge over the period of 1995-2005 only. Extending the estimated effect beyond this period is spurious, for reasons similar to why we chose this period as the impulse response window in our main regression. As a compromise, we estimate the net benefit for the period of 1995-2005, assuming that construction costs should be paid equally over the 100 years of useful life,[11] and applying the social discount rate of 4% per year following Circular-4 guideline (which is the same as the social discount rate used in Japan). To be precise, the net present value of the Bridge for city i prorated for the 1995-2005 period is calculated as:

$$NB_{i,88-05} = \sum_{t=1988}^{2005} \left(\frac{1}{1+\rho}\right)^{t-1988} \left[B_{i,t} - C_{i,t}\right] \tag{10a}$$

$$B_{i,t} \cong \begin{cases} (\hat{Y}_{i,95-05})/10 & \text{for } t > 1995 \\ 0 & \text{for } t \leq 1995 \end{cases} \tag{10b}$$

$$C_{i,t} \cong \hat{C}_i/100 \qquad \text{for } \forall\, t \tag{10c}$$

where ρ is the social discount rate, $\hat{C}_i$ is the estimated cost burden for city i in 1988 JPY, and $\Delta\hat{Y}_{i,95-05}$ is the estimated impact of the Bridge on city i's manufacturing output over the period of 1995-2005. In principle, this accounting method should yield roughly the same result as that of applying the same benefit flow over the entire life of the Bridge against the one-time construction cost.

Figure 9 plots the estimated net benefits for cities against their population size as of 1980, in a manner analogous to **Figures 7** and **8**. There are three striking messages from the figure. First, surprisingly, core cities become net losers despite that they were expected to be winners from the Bridge. This occurs because these core cities incur larger cost burdens compared to other peripheral cities due to their disproportionately large population sizes. Second, large peripheral cities along the Seto Inland Sea region, namely, Awaji, Hiroshima, Matsuyama, Okayama, and Takamatsu, stand out as clear winners. While these cities also bear significant cost burdens, the economic benefits that they reap from the Bridge are substantially greater than other cities (see **Figure 8**). Finally, smaller peripheral cities face low-cost burdens but also experience small economic gains, leading to slightly negative net benefits on average. Hence, our findings suggest that contrary to some critics' expectations, the Straw-effect

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[11] This is equivalent to applying the depreciation rate of 1% per year.

phenomenon did not quite occur, and instead, the large peripheral cities were net winners when cost burdens are accounted for. Our results thus signify a more complex picture of the distribution of economic benefits arising from a transport megaproject.

Figure 9. Distribution of Net Benefits Across Cities of Different Population Sizes

Notes: The figure uses the same classification of population size as in **Figure 7**. Each point represents the counterfactual impact of the construction of the Central Seto Bridge over 1995-2005. The black line shows the median of each the size of the economy.

To elaborate on this point, we also provide three additional maps in **Appendix G** showing the geographic distribution of net benefits (Panel A, **Figure G1**), total costs (Panel B), and total benefits (Panel C) across cities in the Western region. The maps indicate that the benefits mostly fall on cities around the Inland Sea region while the costs are distributed across all cities. As a result, cities enjoying positive net benefits are geographically concentrated in the Inland Sea region. The geographic distribution of benefits is closely linked to the network structures reflecting both natural and socio-geographic factors prior to the construction of the Central-Seto Bridge: pre-existing transport costs, agglomeration forces due to city size, and proximity to the Bridge.

Lastly, let us touch on the impact on the aggregate welfare. Our back-of-envelope estimates indicate that the Central-Seto Bridge generates an aggregate net benefit of approximately 12.5 billion yen for the Western Japan region over the analysis period of 1988-2005. Thus, the winners' net gains (such as Awaji, Matsuyama, Okayama, and Takamatsu) outweigh the losers' net losses (such as for Fukuoka, Hiroshima, Kobe, and Osaka) despite the facts that it had prohibitively large construction costs and that many cities are net losers of the project. However, there are two things to note about our results. First, the benefits may be under-estimated because we only used the estimated impact on manufacturing output over the 1995-2005 period. Arguably, the Bridge may stimulate growth of cities over a much longer time horizon and may also bring other pecuniary and non-pecuniary benefits to the cities. On the other hand, the net benefits may be over-estimated because we only consider the construction costs, ignoring other kinds of costs such as a potential increase in transport-related air pollution. Nonetheless, our findings cast an important question for public finance economists: How should design and finance a transport megaproject when there are clear winners and losers from the project. This question is important not only for low- and middle-income economies but also maturing economies expected to face a rapid demographic transition.

VII. Conclusion

We empirically examine the phenomenon known as the Straw effect, in the unique historical context during the rapid motorization period in Japan. That is, core cities may gain more from large transportation investments than peripheral cities do, or even worse, the peripheral cities may even lose from such investments. As a first step, we estimate the heterogenous causal effects of a large public transportation project, using the construction of the Great Seto Bridge, one of the largest transport megaprojects around the world, as the source of exogenous variation in transport costs and also employing the newly developed recentered instrumental variable method in the market access approach. The estimated impacts are used to evaluate the empirical distribution of winners and losers from the Bridge construction and to gauge the extent of the Straw effect.

Our results indicate that virtually *all* cities, nor just large cities or cities nearby the Bridge, experience positive growth in manufacturing output, population, and employment. But the growth rate is higher for cities that were larger (in population size) before the construction of the Bridge and other highways, suggesting the existence of agglomeration bonus. This result is consistent with the economy theory, and also in some sense, the Straw-effect hypothesis. We do not find, however, that the Straw effect occurs in the original form claimed by some critics. Some of the large peripheral cities are estimated to experience *higher* economic growth purely attributable to the Bridge construction than core cities. More importantly, when the cost burdens of the Bridge were considered, core cities are estimated to lose from the Bridge construction while these large peripheral cities are estimated to gain substantially. Although the aggregate net benefit for the Western Japan region is positive, a large number of cities are estimated to be net losers, with large parts of net benefits concentrated in a much smaller number of cities. This implies that the financing scheme should have been more carefully designed. How to optimize a public transportation project and its cost sharing rule when their economic benefits are heterogenous is an important public finance question. Due to space and data limitations, we do not explore this question and it is hence left for future research.

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Appendix A. Related Literature

This paper is related to five major strands of literature.

The first studies focus on the heterogeneous effects of transportation constructions on economic activity. It is most closely related to investigating impact on disadvantaged communities (Chandra and Thompson, 2000, Faber, 2014; Storeygard, 2016; Asher and Novosad, 2020; Baum-Snow et al., 2020; Jedwab and Storeygard, 2022). Theoretically, starting with Krugman's Core-Periphery model (1991), it is shown that lower trade costs have a positive impact on core cities, while hurting peripheral cities. Empirically, based on this theoretical background, Jadwab and Storeygard (2022), which analyze peripheral cities in Africa, finds a larger positive impact for peripheral cities, while Asher and Novosad (2020), who analyze peripheral cities in India, indicates that road construction has little effect on population growth. Contrary to these, Faber (2014) and Baum-Snow et al. (2020) show a larger positive impact on core cities through transportation constructions. In western Japan, we focus on, we can use the structure of the core cities and the peripheral cities, at the same time, the timing of highway construction connecting them, and the non-marginal quasi-experimental variation of bridge construction. We investigate whether the straw-effect phenomenon, which is a heterogeneous effect on economic activity, appears or not.

Second, it is related to studies, which is extremely rich literature, that empirically evaluate the construction of transportation infrastructure on economic activity (Baum-Snow, 2007; Duranton and Turner, 2012; Duranton et al., 2014; Faber, 2014; Ghani et al., 2015; Donaldson and Hornbeck, 2016; Jedwab and Moradi, 2016; Storeygard, 2016; Donaldson, 2018; Jaworski and Kitchens, 2018; Mori and Takeda, 2019; Asher and Novosad, 2020; Baum-Snow et al., 2020; Banerjee et al., 2020; Jedwab and Storeygard, 2022). Baum-Snow (2007) investigates the effects of inter-state highway on suburbanization in the U.S., Duranton et al. (2014) indicates inter-state highway has a large effect on the weight of city exports in the U.S., and Donaldson (2018) shows the effects of railroad construction on inter-city trade and market integration in India. Duranton and Turner (2012), Ghani et al. (2015), Banerjee et al. (2020), and other literature above analyze the impact on city economic growth. These papers use continental countries such as the U.S., China, and India as their study area, unlike Japan. Since we use a quasi-experimental variation that takes advantage of the geographical uniqueness of land division by inland seas, it could lead to a substantial reduction in transport costs.

Third, it relates to literature that use the market access (MA) approach (Davis and Weinstein, 2003; Hanson, 2005; Breinlich, 2006; Redding and Sturm, 2008; Nakajima, 2008; Head and Mayer, 2011; Donaldson and Hornbeck, 2016; Jaworski and Kitchens, 2018; Mori and Takeda, 2019; Jedwab and Storeygard, 2022). For example, Redding and Sturm (2008) uses an exogenous change in the unification of East and West Germany, and Nakajima (2008) uses an exogenous change in the economic separation of Japan and Korea to show the importance of market access. Donaldson and Hornbeck (2016), and Jedwab and Storeygard (2022) analyze the impact of changes in market access through transportation network construction. However, these papers may not address endogenous bias due to MA variable. We address this issue by estimating unbiased causal effects by using the instrumental variable proposed in Borusyak and Hull (2023).

Fourth, it is also related to the theoretical literature on quantitative spatial models (QSE) (Allen and Arkolakis, 2014; Redding and Turner, 2015; Redding and Rossi-Hansberg, 2017; Redding, 2020). The model is based on gravity equations for goods and population flows, allowing for empirical analysis of general equilibrium effects. Theoretical studies of new economic geography (e.g., Fujita et al. 1999; Fujita and Thisse, 2002; Baldwin et al. 2003) show that the love of variety, increasing return to scale, and transport costs lead to heterogeneous geographic distribution of economic activity. However, this theoretical model is complex and thus diverges from empirical estimation. QSM is an approach that solves such empirical problems. Redding and Turner (2015) show that the general equilibrium effects of transportation infrastructure development on wages, population, trade, and industry composition based on Krugman (1991). Allen and Arkolakis (2014), on the other hand, base its model on a perfect competition Armington with differentiated varieties rather than the homogeneous tradable goods and monopolistically competitive market assumed in Krugman (1991). Redding and Rossi-Hansberg (2017), and Redding (2020) review these series of studies.

Lastly, it relates to studies that investigate how the burden of large public transport transportation investments should be shared among stakeholders (Anguera, 2006; Boardman et al., 2018). To the best of our knowledge, little research exists that describes which parties should bear the burden of public investment costs and debt, and to what extent. Moreover, many of these studies show the validity of ex-post evaluation of public megaprojects by using engineering methods, not economic methods. For example, Anguera (2006) provides a cost-benefit evaluation of the construction of the Channel Tunnel connecting the U.K. and France. However, its total funding burden in the U.K. was less than the estimated total benefits, suggesting that the overall U.K. economy would be better off without its construction. Boardman et al. (2018) provide a case study of a cost-benefit analysis of a mining development project in British Columbia, Canada. The primary beneficiaries of the project are the Canadian National Railway and the federal government.

Appendix B. Quantitative Spatial Model and Market Access

B.1. A Brief Summary of Quantitative Spatial Model

The Quantitative Spatial Model (QSM) offers a comprehensive framework for understanding the spatial dynamics of economic activities, considering both first-nature and second-nature geographical factors. First-nature geography includes physical characteristics such as terrain and climate, while second-nature geography contains human-made elements like politics and policy. These aspects play an important role in shaping the spatial interaction of economic activities across cities. In the QSM, economic activities are influenced by both agglomeration forces and dispersion forces. This interaction determines the spatial distribution of economic activities across locations.

In the model, an economy consists of locations, $i, n \in N$, all locations connected by transportation networks. Each location has a worker, and there are L workers (consumers) in the overall economy. These consumers have a "love of variety" preference and consume both tradable and non-tradable goods. They are perfectly geographically mobile. Producers produce tradable goods under conditions of monopolistic competition with one industry and increasing returns to scale. Productivity, amenity, bilateral trade costs, and supply of floor space (non-tradable goods) are given exogenously.

A consumer has a utility function:

$$U_n = \left(\frac{C_n}{\alpha}\right)^{\alpha} \left(\frac{H_n}{1-\alpha}\right)^{1-\alpha} B_n,$$

where $C_n = \left[\sum_{i \in N} \int_0^{M_i} c_{ni}(\psi)^{\frac{\sigma-1}{\sigma}} d\psi\right]^{\frac{\sigma}{\sigma-1}}$ is the consumption of tradable goods in location n, M_i is the number of variety produced in location i, H_n is the consumption of non-tradable good, and B_n is amenity (e.g., quality, safety). The indirect utility function is derived as follows[12]:

$$V_n = \frac{B_n v_n}{P_n^{\alpha} Q_n^{1-\alpha}}, \tag{B.1}$$

where $P_n = \left[\sum_{i \in N} \int_0^{M_i} p_{ni}(\psi)^{1-\sigma} d\psi\right]^{\frac{1}{1-\sigma}} \equiv CMA_n^{\frac{1}{1-\sigma}}$ is price index, ψ is a variety and σ is an elasticity of substitution, and Q_n is the price of non-tradable good.

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[12] The budget constraint for consumer is given by $v_n = P_n C_n + Q_n H_n$.

Next, based on the consumer's partial utility maximization problem, a consumer consumes the following amount of tradable goods:

$$c_{ni}(\psi) = \frac{p_{ni}(\psi)^{-\sigma}}{P_n^{-\sigma}} \frac{\alpha v_n}{P_n} = \left(\frac{p_{ni}(\psi)}{P_n}\right)^{-\sigma} C_n. \tag{B.2}$$

Consumers increase (decrease) their consumption of a variety ψ when the relative price of variety ψ is low (higher). Based on equation (B.2), we can get the optimal price by solving the producer's profit maximization problem:

$$p_{ni}(\bar{\psi}) = p_{ni} = \frac{\sigma}{\sigma - 1} \frac{w_i \tau_{ni}}{A_i}. \tag{B.3}$$

We can derive the equilibrium wage from the equilibrium condition of tradable goods[13]:

$$w_i = \xi A_i^{\frac{\sigma-1}{\sigma}} (FMA_i)^{\frac{1}{\sigma}}, \tag{B.4}$$

where $FMA_i \equiv \sum_{n \in N} (w_n L_n) \tau_{ni}^{1-\sigma} P_n^{\sigma-1}$, and ξ is constant defined as $\xi \equiv \sigma^{-1}(\sigma - 1)(F(\sigma - 1))^{-\frac{1}{\sigma}}$.

The general equilibrium of QSM can be obtained by solving for three endogenous variables: bilateral trade flows, population share, and wages. First, the gravity equation is shown as follows:

$$\Gamma_{ni} = \frac{L_i (\tau_{ni} w_i / A_i)^{1-\sigma}}{\sum_{k \in N} L_k (\tau_{nk} w_k / A_k)^{1-\sigma}}. \tag{B.5}$$

It implies the share of expenditures in location n on goods exported from location i. Second, we can obtain the population share from the population mobility condition[14]:

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[13] From equations (B.2) and (B.3), and the zero-profit condition with free entry and exit, the output of the tradable goods in supply location i can be shown as $x_i = A_i F(\sigma - 1)$. The location n's demand of the tradable goods produced in location i is $x_{ni} = \left(\frac{\sigma}{\sigma-1} \frac{\tau_{ni} w_i}{A_i}\right)^{-\sigma} \frac{(\alpha v_n L_n)}{P_n^{1-\sigma}}$. Then, the equilibrium condition is $x_i = \sum_{n \in N} x_{ni} \tau_{ni}$.

[14] The population mobility condition is $L_n = \left[\frac{A_n^{\alpha} B_n H_n^{1-\alpha} (\Gamma_{nn})^{-\frac{\alpha}{\sigma-1}}}{\bar{V} \alpha \left(\frac{\sigma}{\sigma-1}\right)^{\alpha} \left(\frac{1}{F\sigma}\right)^{\frac{\alpha}{1-\sigma}} \left(\frac{1-\alpha}{\alpha}\right)^{1-\alpha}}\right]^{\frac{\sigma-1}{\sigma(1-\alpha)-1}}$ derived by using equations (B.1) to (B.5).

$$\lambda_n = \frac{L_n}{L} = \frac{\left[A_n^{\alpha} B_n H_n^{1-\alpha} (\Gamma_{nn})^{-\frac{\alpha}{\sigma-1}}\right]^{\frac{\sigma-1}{\sigma(1-\alpha)-1}}}{\sum_{k\in N}\left[A_k^{\alpha} B_k H_k^{1-\alpha} (\Gamma_{kk})^{-\frac{\alpha}{\sigma-1}}\right]^{\frac{\sigma-1}{\sigma(1-\alpha)-1}}}.$$

Finally, the market clearing condition in the goods market is:

$$w_i \lambda_i = \sum_{n\in N} \Gamma_{ni} w_n \lambda_n .$$

We can obtain the endogenously determined population by solving a system of equations.

B.2. What is Market Access?

There are two indicators of market access: firm (FMA) and consumer (CMA). FMA increases where price competition is less intense and where firms trade with larger economies. CMA, on the other hand, increases when firms face strict price competition. From the consumer's perspective, this competition leads to lower prices, which makes them access to a greater variety of goods.

We can derive the MA defined in equation (1) by using the FMA and CMA. First, we can rewrite the FMA by using the relationship between the price index P_n and CMA_n:

$$FMA_i = \sum_{n\in N} (w_n L_n) \tau_{ni}^{1-\sigma} (CMA_n)^{-1}.$$

Second, since the price index P_n can be rewritten in equilibrium,

$$P_n^{1-\sigma} = CMA_n = \sum_{i\in N} \frac{L_i}{F\sigma}\left(\frac{\sigma}{\sigma-1}\frac{\tau_{ni} w_i}{A_i}\right)^{1-\sigma} \tag{B.6}$$

, we can derive the trade flow from location n to location i:

$$\begin{aligned} X_{ni} &= (w_n L_n) \times \Gamma_{ni} \\ &= \frac{L_i}{F\sigma}\left(\frac{\sigma}{\sigma-1}\frac{w_i}{A_i}\right)^{1-\sigma} \tau_{ni}^{1-\sigma} (w_n L_n)(CMA_n)^{-1}. \end{aligned} \tag{B.7}$$

In equilibrium, labor income $w_i L_i$ and total expenditures on trade goods are equal, then the following relationship holds:

$$w_i L_i = \sum_{n \in N} X_{ni}\,. \tag{B.8}$$

We can derive the relationship between CMA and FMA by using equations (B.6), (B.7), and (B.8):

$$CMA_n = \sum_{i \in N} \frac{L_i}{F\sigma} \left(\frac{\sigma}{\sigma - 1} \frac{\tau_{ni} w_i}{A_i} \right)^{1-\sigma} = \sum_{i \in N} \tau_{ni}^{1-\sigma} (w_i L_i) FMA_i^{-1}.$$

Since it is known that $MA_i \equiv FMA_i = \rho CMA_i$ when trade costs are symmetric, $\tau_{ij} = \tau_{ji}$ (e.g., Donaldson and Hornbeck, 2016; Redding, 2020), We can define MA as follows:

$$MA_i = \rho \sum_{n \in N} Y_n \tau_{ni}^{-\theta} MA_n^{-1},$$

where $Y_n = w_n L_n, \theta = 1 - \sigma$. The MA, derived by integrating both FMA and CMA, measures the market potential in each location by considering both the potential opportunity to sell goods for firms and an availability of variety under their budget constraint for consumers.

Appendix C.
The Results of First Stage in Two-Stage Least Squares Regression

We show the results of the first-stage estimation in 2SLS regression in **Table C1**. This stage is crucial as it tests the validity of our chosen instrumental variable, the recentered market access (RMA) growth. The main result in Column (1) indicates a statistically significant and positive impact on the change in the MA variable, with a coefficient of 1.05. This finding is not only statistically significant but also aligns with the patterns we observed in **Figure 5**, thus satisfying the "relevance condition" for our instrumental variable.

To further validate these results, we varied the trade elasticity parameter θ, as detailed in Columns (2) to (5). Across these different specifications, we consistently observed a strong positive relationship between the instrumental variable and the change in the MA variable. This consistency supports the robustness of our first-stage estimation and reinforces the reliability of the RMA growth as an instrumental variable in our 2SLS framework.

Table C1. The Results of First Stage in Two-Stage Least Squares Regression

	θ =4.0 (1)	θ =1.1 (2)	θ =2.0 (3)	θ =3.0 (4)	θ =5.0 (5)
⊿RMA	1.05 ***	0.72 ***	0.70 ***	0.88 ***	1.08 ***
	(0.09)	(0.08)	(0.11)	(0.13)	(0.10)
R-squared	0.66	0.31	0.46	0.60	0.66
Controls	✓	✓	✓	✓	✓
Observations	615	615	615	615	615

Notes: This table shows the results of the first stage in two-stage least squares regression. We calculate $\Delta \ln MA$, ΔRMA with each trade elasticity. We use the same set of controls as in Table 3. *** 1%, ** 5%, * 10% significance levels and parentheses denote cluster robust standard errors, clustered at the city level.

Appendix D. Sensitivity Analysis of Trade Elasticity

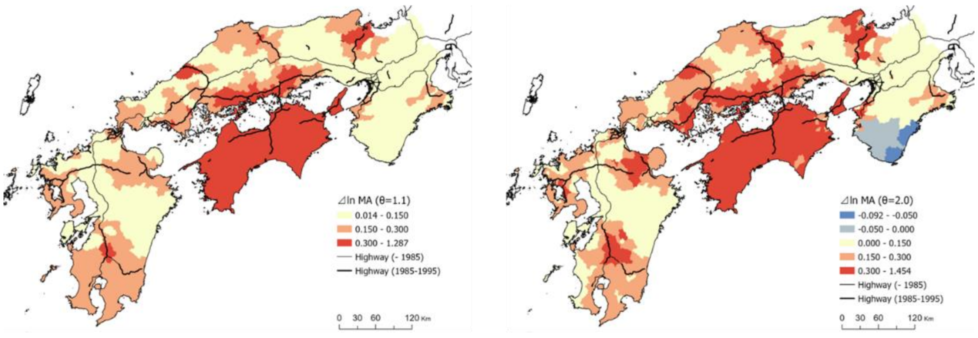
In this section, we report the results of our estimation using alternative trade elasticities. We construct MA variables using trade elasticities for $\theta = 1.1$, $\theta = 2.0$, $\theta = 3.0$, and $\theta = 5.0$.

D.1. Changes in Market Access by Each Trade Elasticity

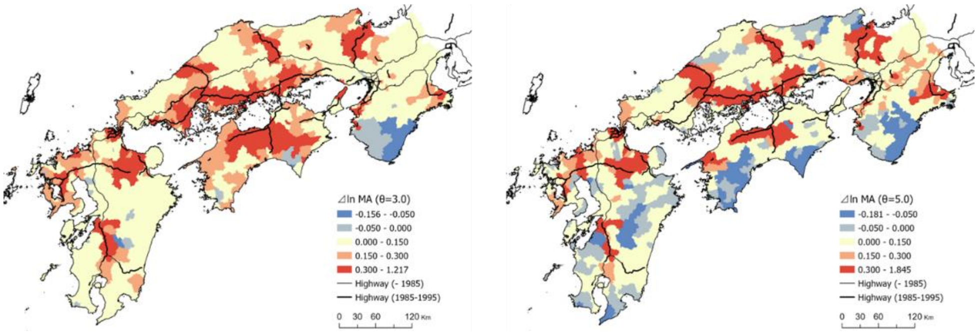
Figure D1 shows the geographic distribution of the MA variables using these trade elasticities θ for the period 1985-1995. The red legend indicates a positively large (logarithmic) change in the MA variable, while the blue legend indicates a negatively large change. As θ decreases, the changes in the MA variable become more closely aligned with the changes in transport costs. This suggests that a smaller θ may not adequately reflect shifts in the size of the economy or capture the full extent of the general equilibrium effect. Furthermore, the figures reveal that when the trade elasticity is set to less than 3, the MA variables within the Shikoku region display a uniform pattern. This indicates a potential limitation in capturing the heterogeneous economic interactions among cities in this region.

Figure D1. The Geographic Distribution of the MA Variables by Each Trade Elasticity

A. Trade Elasticity $\theta = 1.1$ B. Trade Elasticity $\theta = 2.0$



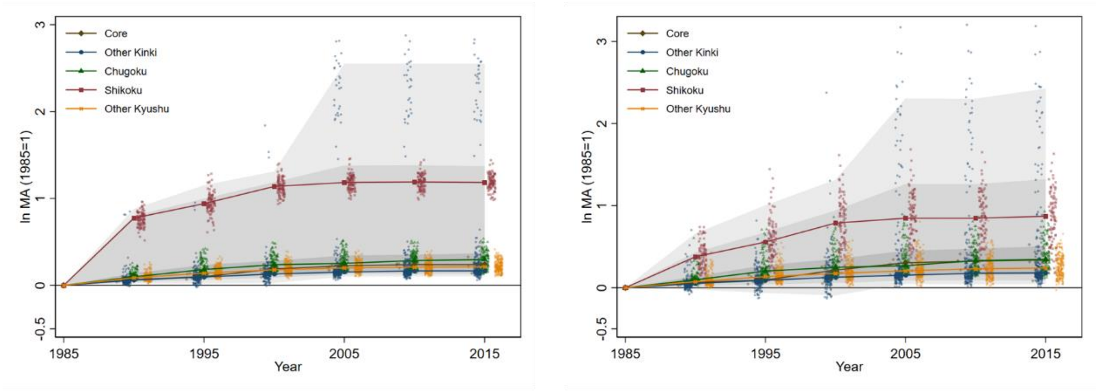
C. Trade Elasticity $\theta = 3.0$ D. Trade Elasticity $\theta = 5.0$



Notes: These figures show the log change in MA variables from 1985-1995. Panel A shows the case $\theta = 1.1$, Panel B shows $\theta = 2.0$, Panel C shows $\theta = 3.0$, and Panel D shows $\theta = 5.0$.

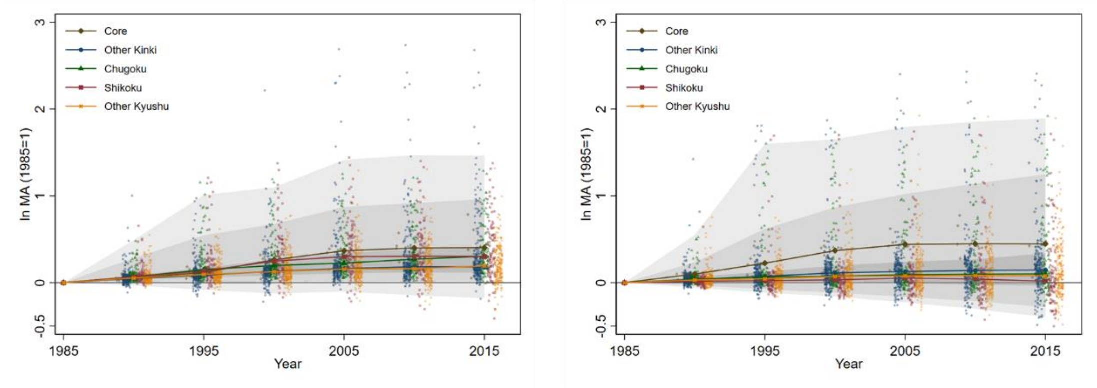
Figure D2 illustrates the changes in the MA variable under varying trade elasticity θ. Gray shaded areas represent the 1st to 99th percentile, 5th to 95th percentile, and 25the to 75th percentile of all observers, in order from lightest to darkest color. Each line represents the median for each region. Dots represent the raw values for cities. Our analysis reveals that a smaller θ results in a quicker capture of the increase in the MA variable, particularly from 1985 to 1990. Additionally, when θ is small, changes in the MA variable closely mirror the changes in transport costs. The MA variable with $\theta = 5.0$ greatly increases between 1990 and 2000. However, it fails to reflect the substantial decline in trade costs in the Shikoku region, as indicated by the negative change at the median value from 1985 to 1995.

Figure D2. Changes in MA Variable over Time by Each Trade Elasticity



A. Trade Elasticity $\theta = 1.1$

B. Trade Elasticity $\theta = 2.0$



C. Trade Elasticity $\theta = 3.0$

D. Trade Elasticity $\theta = 5.0$

Notes: Each figure is drawn in the same format as Panel B in Figure 5. Panel A shows the result of the trade elasticity $\theta = 1.1$, Panel B shows the result of $\theta = 2.0$, Panel C shows the result of $\theta = 3.0$, and Panel D shows the result of $\theta = 5.0$.

D.2. The Estimation Results with Each Trade Elasticity

We demonstrate how the use of different trade elasticities θ in the MA variable change affect the estimation results. **Table D1** presents the results of the EMA-OLS and RMA-IV regressions. In Panel A, results for $\theta = 1.1$ are not statistically significant. Panel B shows results for $\theta = 2.0$, the effect on population is statistically significant and robust across both models, but not for the other two outcomes. The results for $\theta = 3.0$ (Panel C) resemble those of $\theta = 4.0$ for all economic outcomes. However, the results for manufacturing output and employment are not robust across models and have a slightly small the first-stage F-value of 2SLS. In the case of $\theta = 5.0$ (Panel D), we don't observe statistically significant effect on manufacturing output due to the larger variance of the change in the MA variable, which may underestimate the effect for all outcomes. Therefore, the trade elasticity $\theta = 4.0$, supported by Simonovska and Waugh (2014), is the most preferred value in our context.

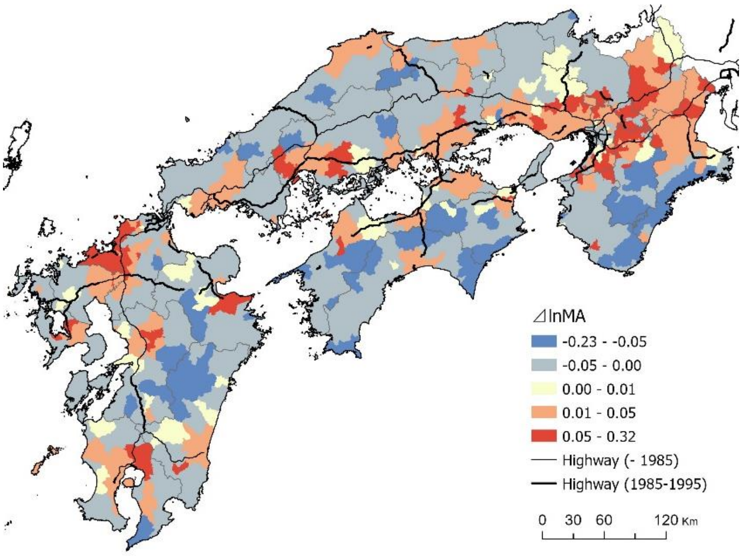
Table D1. The Estimation Results for Each Trade Elasticity

	Manuf. Output		Population		Employment	
	EMA-OLS	RMA-IV	EMA-OLS	RMA-IV	EMA-OLS	RMA-IV
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: θ=1.1						
⊿lnMA	0.059	0.119	0.019	0.016	0.015	0.024
	(0.116)	(0.159)	(0.015)	(0.020)	(0.021)	(0.028)
⊿EMA	-0.158		0.009		-0.024	
	(0.131)		(0.016)		(0.022)	
First-Stage F-stat.		78		78		78
R-squared	0.103	0.090	0.455	0.454	0.373	0.369
Panel B: θ=2.0						
⊿lnMA	0.161	0.260 *	0.031 **	0.032 *	0.008	0.025
	(0.109)	(0.153)	(0.014)	(0.019)	(0.022)	(0.028)
⊿EMA	-0.234 *		-0.003		-0.040	
	(0.132)		(0.015)		(0.025)	
First-Stage F-stat.		44		44		44
R-squared	0.104	0.092	0.453	0.453	0.374	0.369
Panel C: θ=3.0						
⊿lnMA	0.269 ***	0.291 **	0.040 ***	0.042 ***	0.039 *	0.047 *
	(0.098)	(0.119)	(0.014)	(0.015)	(0.023)	(0.025)
⊿EMA	-0.169		-0.019		-0.056	
	(0.186)		(0.018)		(0.040)	
First-Stage F-stat.		48		48		48
R-squared	0.107	0.105	0.454	0.453	0.375	0.371
Panel D: θ=5.0						
⊿lnMA	0.120	0.117	0.035 ***	0.033 ***	0.052 ***	0.049 ***
	(0.092)	(0.080)	(0.010)	(0.010)	(0.019)	(0.017)
⊿EMA	-0.038		-0.018		-0.043	
	(0.216)		(0.016)		(0.040)	
First-Stage F-stat.		129		129		129
R-squared	0.103	0.103	0.457	0.456	0.380	0.377
Controls	✓	✓	✓	✓	✓	✓
Observations	615	615	615	615	615	615

Notes: For each outcome, the first column presents the results of OLS regression with ΔEMA, and the second column reports the results of 2SLS with ΔRMA as the instrument. We use the same set of controls as in Table 3 and 4. *** 1%, ** 5%, * 10% significance levels and parentheses denote cluster robust standard errors, clustered at the city level.

Appendix E. Additional Heterogeneity and Robustness Analysis

Figure E1. Spatial Variation in Recursive Market Access



Notes: This figure shows the log changes in MA variable over 1985-1995: we use lagged values of population to construct the MA variable based on equation (1). This figure shows the difference in logs between the two years. For Panel B, we construct the changes in RMA by using the population as of 1980 for the changes in EMA based on equations (7) and (8).

Table E1. The Estimation Results of Recursive Market Access

	Manuf. Output (1)	Population (2)	Employment (3)
Panel A: $\Delta(\ln Y_i)_{90-00}$			
⊿ ln MA	0.835 *	1.121 ***	1.321 ***
	(0.439)	(0.110)	(0.145)
R-squared	0.068	0.662	0.604
Panel B: $\Delta(\ln Y_i)_{95-05}$			
⊿ ln MA	0.682 *	0.646 ***	1.115 ***
	(0.382)	(0.096)	(0.098)
R-squared	0.103	0.547	0.516
Panel C: $\Delta(\ln Y_i)_{00-10}$			
⊿ ln MA	0.115	0.489 ***	0.698 **
	(0.466)	(0.089)	(0.111)
R-squared	0.062	0.579	0.516
Controls	✓	✓	✓
Observations	615	615	615

Notes: We use the same set of controls as in Table 3. *** 1%, ** 5%, * 10% significance levels and parentheses denote cluster robust standard errors, clustered at the city level.

Table E2. The Estimation Results with Interaction Term

Interaction Terms	Manuf. Output as of 1980			Population as of 1980		
	Manuf. Output (1)	Population (2)	Employment (3)	Manuf. Output (4)	Population (5)	Employment (6)
Tertile						
1st	0.139	0.030	0.027	0.161	0.043 *	0.045
	(0.203)	(0.026)	(0.037)	(0.177)	(0.026)	(0.040)
2nd	0.186	0.054 **	0.081 **	0.327 **	0.049 **	0.101 ***
	(0.120)	(0.025)	(0.039)	(0.156)	(0.020)	(0.032)
3rd	0.266 ***	0.037 ***	0.072 ***	0.202 **	0.038 ***	0.055 **
	(0.102)	(0.013)	(0.020)	(0.094)	(0.014)	(0.022)
⊿EMA	-0.105	-0.024	-0.057	-0.124	-0.023	-0.059
	(0.216)	(0.019)	(0.040)	(0.204)	(0.021)	(0.043)
R-squared	0.092	0.465	0.393	0.116	0.458	0.389
Controls	✓	✓	✓	✓	✓	✓
Joint Test	0.24	0.04	0.01	0.40	0.03	0.14
Observations	615	615	615	615	615	615

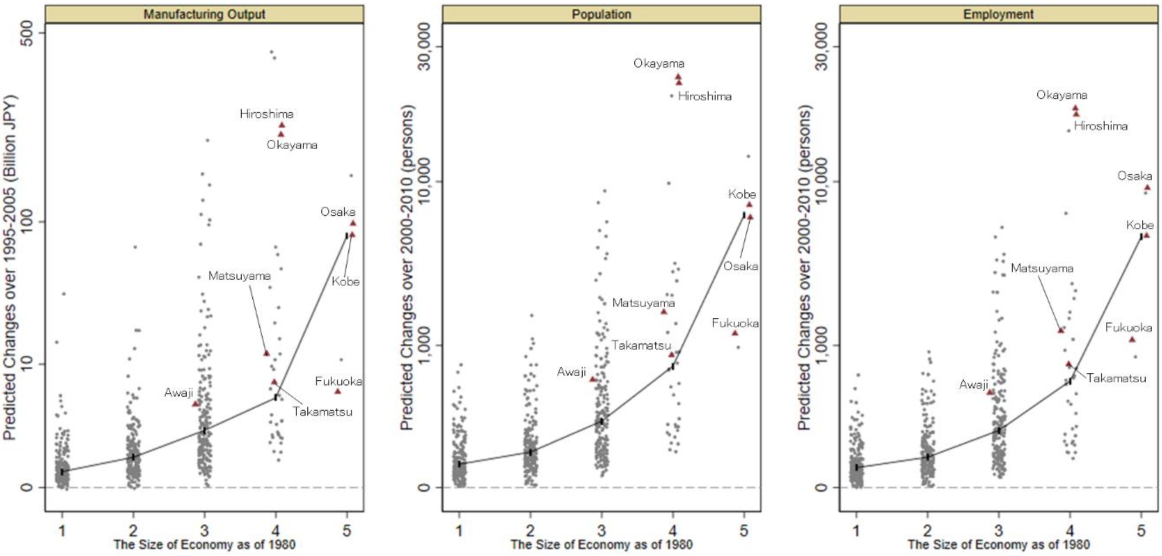
Notes: This table shows the results of the interaction term with manufacturing output as of 1980, and population size as of 1980. Each column presents the results with ΔEMA. For each interaction term, the first column presents manufacturing output, the second column reports population, and the third column shows employment. We use the same set of controls as in Table 3 and 4. *** 1%, ** 5%, * 10% significance levels and parentheses denote cluster robust standard errors, clustered at the city level.

Appendix F. Additional Counterfactual Analysis

In this section, we investigate additional counterfactual analysis. Our main estimation calculates the change in the MA variable by using market size data from one period earlier to avoid endogeneity problem. We test other approach in this section. First, we use the 1985 population for the 1985 MA variable calculation and the 1995 population for the 1995 calculation. This approach yielded results very similar to those in **Figures 7** and **8**, so we do not report them. Second, we use the 1980 population for both the 1985 and 1995 MA variable calculation.

We show the results of this second approach in **Figure F1**. This figure, like **Figure 7**, plots the predicted changes in the cities' economic outcomes during 1995-2005. It shows that the core cities and large peripheral cities, that are winners in **Figure 7**, are also clearly winners. However, two notable differences arise: first, Fukuoka, a core city in the Kyushu region and physically distant from the bridge, experience smaller economic growth. Second, no cities experience negative growth, indicating that all cities have the potential to benefit from the project. These differences stem from the fact that the MA variable of this approach does not reflect changes in market size. **Figure F2**, similar to Figure 8, plots the impact of the Central Seto Bridges on the economic outcomes during 1995-2005. The results in **Figure F2** are almost identical to those seen in **Figure 8**. Both analyses indicate Awaji Island and the larger peripheral cities in the Seto Inland Sea area are the main winners of the transportation megaproject.

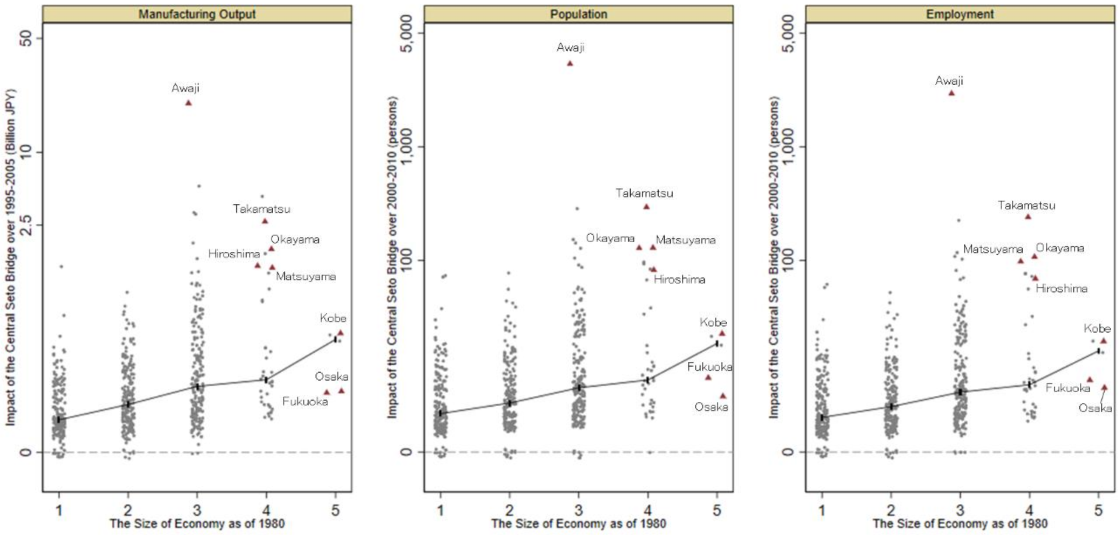
Figure F1. The Economic Impacts across Cities of Different Population Sizes in the Case of Population as of 1980



Notes: The figure uses the same classification of population size as in Figure 7. Each point represents the estimated impacts over the 1995-2005 period. The black line shows the median of each the size of the economy.

Figures F1 and **F2** differ from **Figures 7** and **8**, because they cannot consider changes in the market size (i.e., we set the 1980 market size of the MA variable in **Figures F1** and **F2**). This difference reveals an important insight. **Figures 8** and **F2** evaluate the impact of the construction of the Central Seto Bridge. Since these two results are almost the same, the impact of local construction, such as the bridges, appears to be relatively independent of changes in market size. On the other hand, we examine the broader impacts of highway construction in **Figures 7** and **F1**. These two figures show slightly different results, suggesting that the impact of broader highway construction is largely dependent on changes in the market size. This emphasizes the importance of our approach, which considers changes in market size, in capturing the general equilibrium impacts of highway construction.

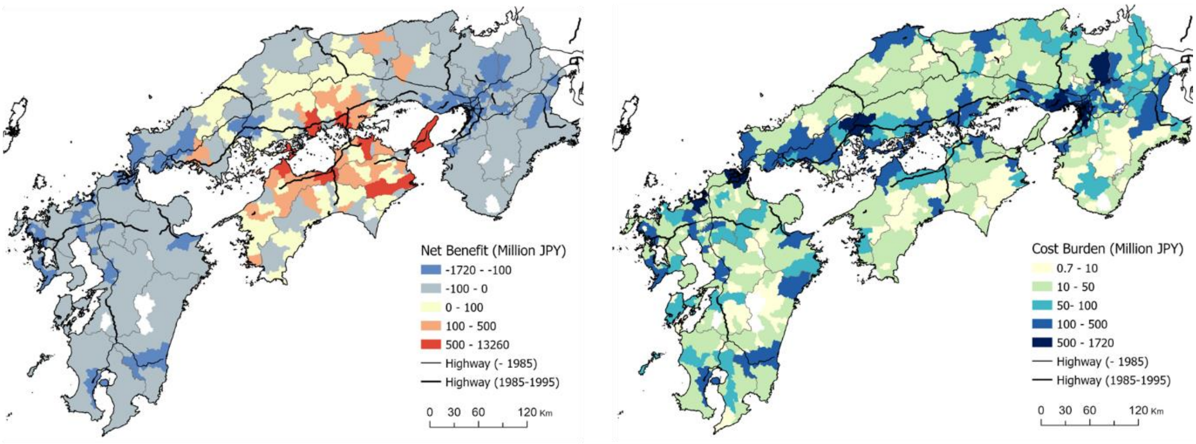
Figure F2. Economic Impacts Across Cities relative to the Counterfactual without the Central Seto Bridge in the Case of Population as of 1980



Notes: The figure uses the same classification of population size as in Figure 7. Each point represents the counterfactual impact of the construction of the Central Seto Bridge over 1995-2005. The black line shows the median of each the size of the economy.

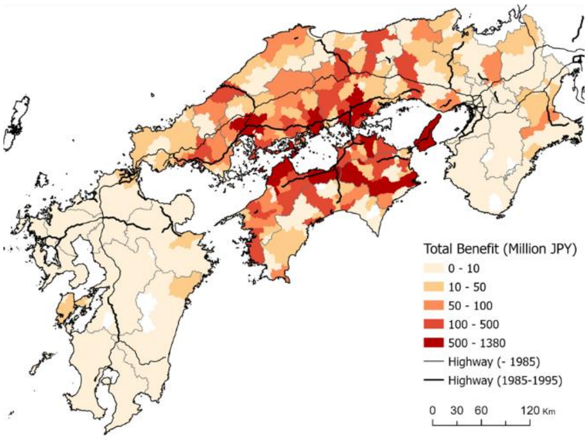
Appendix G.
Geographical Distribution of Counterfactual Predictions

Figure G1. Geographical Distribution of Net Benefit, Cost Burden, and Total Benefit


A. Net Benefit

B. Cost Burden

C. Total Benefit



Notes: These figures show spatial distributions of net benefit (Panel A), cost burden (Panel B), total benefit manufacturing output (Panel C) over 10-years during 1995-2005. Each panel shows values in units of JPY as of 1988.