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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瀬戸大橋が開通した場合にそのような異質な効果が現れるかどうかを実証的に検証する．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予期せず引き起こす市場アクセスの変化を外生的変分として利用する．分析の結果，ストロー効果とは異なって，大規模な周辺都市が中心都市よりもプロジェクトからより大きな経済的便益を享受することが明らかになった．これは，大規模な公共投資に起因する勝者と敗者の地理的な分布は，交通費用の減少が既存のネットワーク構造に対してどのように影響するかによって決まることを示している．

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Do Winners Win More from Transport Megaprojects?
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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 transportation megaprojects. We empirically investigate whether such an effect manifests in the case of the Great Seto Bridges in Japan, a 70-billion-dollar project implemented in the 1980s-1990s as part of the “Building-a-New-Japan” initiative. We employ the recentered instrumental variable approach in the difference-in-differences design, exploiting the sharp decline in transport costs and its unexpected impacts on market access across cities as the exogenous sources of variation. Contrary to the Straw Effect, we find that large peripheral cities gain more than core cities from the megaproject, demonstrating that the distribution of winners and losers from the megaproject depends on how the transport cost reductions pass through 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 the 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 to 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 into the theory of trade and economic geography various economic mechanisms such as agglomeration economies, endogenous labor migration, and returns to scale, virtually all of which generally predict heterogeneous 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 likely stems more from historical, political, or geographic advantages rather than direct investment in public transportation. This line of argument can be easily adapted to the quantitative spatial model (QSM) to demonstrate that there are generally winners and losers from any given transportation investment in a given network of cities under a variety of initial conditions.

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 **Figure1, Section II**). 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 of such projects was the construction of the Great Seto Bridges: 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, making it one of the most expensive transport megaprojects in Japan and worldwide (see **Table 1, Section II**).

There were concerns, even before the 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 cities, the opponents of the project expressed serious concerns that the economic activities might simply be drawn from the peripheral region (Shikoku) to core cities in the main island such as Osaka and Fukuoka, that the peripheral regions may simply end up with a large financial debt without much economic gain (*Asahi Newspaper*, 1987; 1998), and that it would take at least 42 years for these regions to fully repay the debt (*Mainichi Newspaper*, 2008).

Given this background, our primary objectives are, first, to quantify the heterogeneous causal effects of this transport megaproject on peripheral cities' economic outcomes (manufacturing output, population, 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?). Doing so allows us to empirically evaluate the extent to which the Straw-effect phenomenon has (or has not) manifested in our context and whether the geographic distribution of the economic gains from the project matches that of the financial cost burdens. Addressing these questions is highly policy-relevant, for a large sum of public investments is still being made in transportation infrastructures in low- and middle-income countries.[2]

Accomplishing these goals, however, is empirically quite challenging. There is a large body of economic literature attempting to estimate the causal effect of public transportation investments on a variety of city-level economic variables. This line of literature generally suggests three important empirical challenges. First, the location or timing of public transportation projects is highly endogenous because such projects may target areas expected to experience high or low economic growth. To address this empirical challenge, the earlier literature typically relies on quasi-experimental variation or sharp discontinuities in investment location or timing (e.g., Baum-Snow, 2007; Duranton and Turner, 2012; Faber, 2014; Donaldson and Hornbeck, 2016; Asher and Novosad, 2020; Baum-Snow et al., 2020). Second, the general equilibrium effects might "contaminate" credible quasi-experimental identification strategies.[3] To address this problem, the literature often employs the market access (MA) approach, in which the quasi-experimental variation in transport costs is translated into the changes in the MA variable, capturing all general equilibrium effects (Donaldson and Hornbeck,

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[2] According to the World Bank (2022), $62.1 billion was spent on transportation projects worldwide in 2022 alone, accounting for 68% of the total public investments.

[3] The literature often discusses three types of general equilibrium effects. Cities, connected directly or indirectly through transportation network, may: (i) affect cities far-distant cities not directly impacted ("spillover effect"), (ii) have heterogeneous impacts on cities based on pre-treatment economic and transportation conditions ("stock effect"), and (iii) have "feedback effects" where the economic impact on one city reverberates through others and back to the original city.

2016; Jaworski and Kitchens, 2019; Mori and Takeda, 2019; Baum-Snow et al., 2020; Jedwab and Storeygard, 2022). Third, even if public transportation projects are as good as randomly assigned, either in location or in timing, the MA may still be endogenous because the resulting change in the MA for a city depends on its intrinsic location in the structure of the given economic network (Borusyak and Hull, 2023). To address this fundamental problem, Borusyak and Hull (2023) proposes a recentered instrumental variable approach.

Our empirical strategy takes advantage of all these advances. First, we exploit the sharp decline in transport costs, induced by the construction of the Central Seto Bridge and other highways during the 1980s-1990s, in the difference-in-differences design. Second, we construct the MA variable based on the QSM framework (Allen and Arkolakis, 2014; Redding and Turner, 2015; Redding and Rossi-Hansberg, 2017; Redding, 2020), and use the differential impacts of the Bridge and other highway construction on the MA levels across cities of different economic prosperity as the exogenous source of variation. Third, we apply the "recentered market access" (RMA) as our instrumental variable à la Borusyak and Hull (2023). Intuitively, the RMA extracts the purely exogenous variation from the observed MA, by purging out the expected market access (EMA), i.e., the endogenous component of MA that comes from its geographic network characteristics. That is, 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.

We find that the OLS estimates are positive and statistically highly significant, confirming the positive correlations between the changes in MA and the growth of cities, as measured in manufacturing output, population, and employment. However, our IV estimates suggest that some of these correlations are only spurious. The estimated effects remain positive and statistically significant only on manufacturing output, but turn insignificant on population and employment. In the RMA regressions using the EMA as an additional control, we show that the population and employment sizes of cities respond more to the expectations of the MA growth rather than to the shock components of the MA growth induced by the transport megaproject. Hence, we conclude that the transport megaproject had a positive causal effect on the city-level manufacturing output, but less so on the population and employment levels. These results are indeed consistent with economic theory and the earlier empirical literature.

Furthermore, the estimated impact is not economically small: Using the IV estimate at the mean of the data, the project-induced increase in MA during 1985-1995 leads to a 2.54% increase in manufacturing output on average during the subsequent 10-year period.

Next, we make use of the IV estimates to empirically evaluate the geographic distribution of winners and losers from the transport megaproject. We approach this question in two steps. The first step is to calculate the predicted changes in the cities' economic outcomes due to the transport megaproject over the 1995-2005 period. The second step is to estimate the net benefit of the transport megaproject for each city relative to the counterfactual in its absence. For both steps, we evaluate the impacts of two transportation investment scenarios: (a) both the Central Seto Bridge and the other highways and (b) the Central Seto Bridge only, against the counterfactual without such investments. To simulate the outcomes under the second scenario, we re-calculate the transport costs, removing the other highways, and make use of the QSM to simulate the resulting changes in MA for all cities in our sample. We then use the IV estimates to predict the economic outputs of the cities. To translate these into the net benefits, we make use of the publicly available information on the construction costs and the cost-sharing rules.

Our analysis reveals a number of important results, signifying the importance of accounting for the general-equilibrium effects of transport megaprojects. First, a majority of cities gain net benefits from the transport megaproject, regardless of their initial economic abundance or whether they are directly connected by the project. Second, there is a sign of agglomeration economies in the sense that initially larger cities tend to gain more from the project. This tendency becomes moderate, however, once we account for the construction costs. Third, there is substantial heterogeneity in the distribution of net benefits across cities. In fact, a non-negligible number of cities are estimated to lose substantially from the transport investment within each city-size cohort. Fourth, the Straw-effect phenomenon did not materialize, at least not in the form originally claimed by the critics: Large peripheral cities in Shikoku and Chugoku are estimated to gain substantial net benefits from the project. Lastly, our results indicate that the *pure* effect of the Central Seto Bridge is not necessarily large and that much of the effect of the transport megaproject comes from the *combined* effect of the other highways and the Central Seto Bridge. In sum, our results provide evidence in support of the idea that the distribution of winners and losers from transport projects depends, in a complex way, on how the transport cost reductions pass through in the existing network structures.

Our results also imply an important question for public finance economists: How should we finance a transport megaproject when the general-equilibrium mechanism determines the distribution of winners and losers from the project in somewhat unexpected way? Based on our estimates, the Central Seto Bridge is estimated to generate an annual aggregate net benefit of approximately 34 billion yen for the western Japan region over the period of 1988-2005. This means that in theory, we can re-design the cost-sharing rule in such a way that all cities gain from the project. However, the fact that a non-negligible number of cities are estimated to lose from the project implies that the government's current cost-sharing rule does not match the empirical distribution of economic benefits across cities. How to account for the empirical distribution of benefits in designing the cost-sharing rules may become an important question in the coming era of rapid demographic transition.

Our work closely complements the five strands of literature. To economize space, we only touch on each, with more thorough discussions offered in **Appendix A**. First, it is 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, there is also a 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, 2019; 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, 2019; 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 transportation investments should be shared among stakeholders (Anguera, 2006; Boardman et al., 2018).

II. Background and Data

II-A. Background

Our study area covers the western Japan region, which consists of 23 prefectures with 614 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. The region has two well-known metropolitan areas: the Kinki area and the Kitakyushu area. The Kinki area hosts three major cities: Kyoto, Osaka and Kobe. The Kitakyushu area hosts two major cities: Kitakyushu and Fukuoka. These five cities are labeled "Core" cities (blue triangles) in **Figure 1**. There are also several large cities along the Seto Inland Sea, which serves 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 1**.[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. Our study focuses on the period of public transportation investments in the late 1980s-1990s that are designed to connect peripheral cities to core cities. 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. The Central Seto Bridge [labeled (c)], completed in 1988, connects Kagawa in the Shikoku region to Okayama in the Chugoku region. The East Seto Bridge [labeled (d)], finished in 1998, links Tokushima in the Shikoku region, the Awaji Island, and Hyogo in the Kinki region. Lastly, the West Seto Bridge [labeled (b)], completed in 1999, joins Ehime in the Shikoku region to Hiroshima in the Chugoku region.

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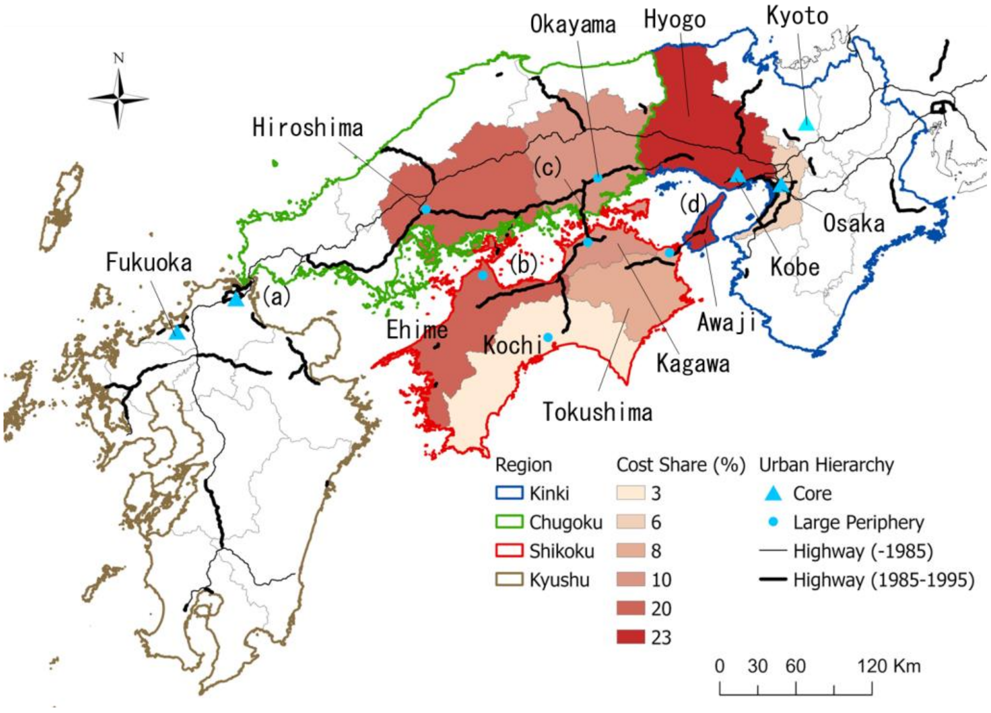
[4] These core cities had a population size of 500,000 or more prior to 1980. The large peripheral cities had a population size of 200,000 or more before 1980. This classification follows the official classification of large cities in Japan.

Figure 1. Major Highway Routes and the Great Seto Bridges in Western Japan



Notes: The area surrounded by blue line is the Kinki region, green is the Chugoku region, red is the Shikoku Island, and light brown is the Kyushu Island. The Kinki and the Chugoku regions lie on the Honshu Island. The prefectures in red are those that directly bear the construction costs of the Great Seto Bridges. The thin black lines represent- highways built before 1985, and the thick black lines represent highways built between 1985 and 1995. Four transport megaprojects are also labeled as (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 2 illustrates the estimated impact of the Central Seto Bridge on transport costs. We calculate the transport cost for each city as the sum of all bilateral transport costs between that city and all other cities in the study area (see a more detailed explanation in **Subsection II-B**).[5] The figure plots the changes in logged values of the transport costs between 1985 and 1995. As shown, the largest reduction in transport cost occurred in the Shikoku region, and the next largest was in the inner part of the main island, implying that the construction of the Central Seto Bridge is critical in explaining the changes in transport costs during this period.

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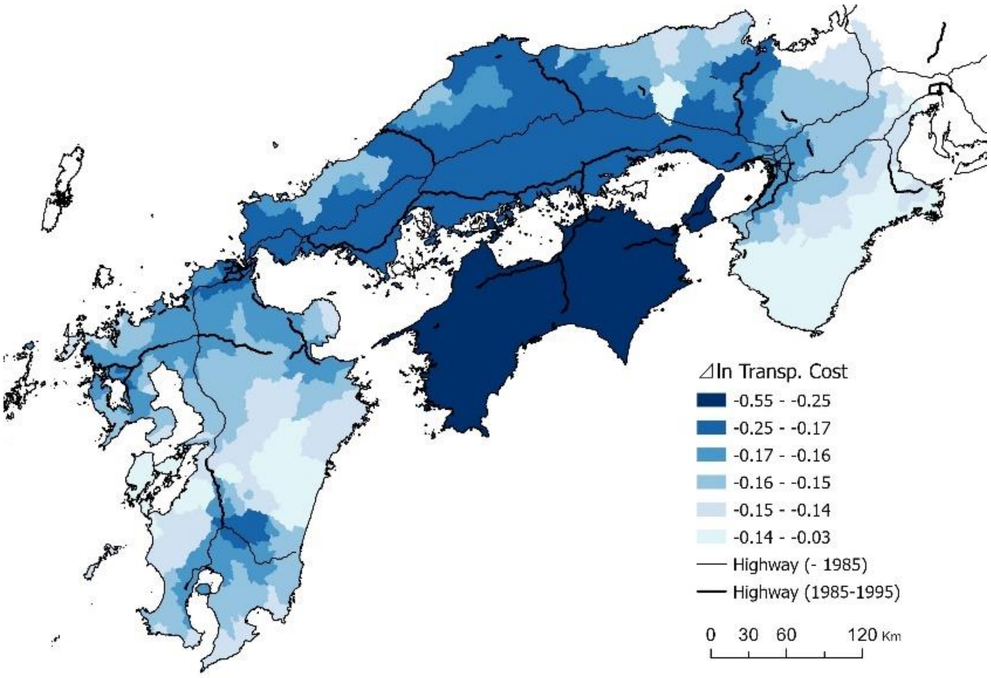
[5] We use the term "transport costs" instead of "trade costs" as in Duranton and Turner (2012) and Redding (2020).

Figure 2. Transport Cost Reductions during the 1985-1995



Notes: This figure shows the changes in logged values of the transport costs from 1985 to 1995. As in Figure 1, the thin black lines represent highways built before 1985, and the thick black lines represent highways built between 1985 and 1995. Transport cost for each city shown in this figure is the sum of all pair-wise transport costs between the city and all other cities in the study area.

From its inception, the construction of the Bridges was highly contentious for several reasons. First, it 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, 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).

Table 1. Construction Costs of Transport Megaprojects

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 1993; Müller and Baumann, 2016; Neuharth, 2006; Faber, 2014; Bundesministerium für Verkehr, Bau und Stadtentwicklung, 2014; Mount, 2014; Hollingham, 2015.

Second, some critics expressed concerns about the Straw effect of the project, arguing that economic activity in peripheral cities in the Shikoku region would be swallowed by the core cities such as Osaka (Ihara et al., 2020). Such a concern is well grounded in economic theory, and hence, not unrealistic. Since Krugman (1991), economists have long investigated how cities grow. It is indeed easy to construct a numerical example in the stylized spatial model where the core cities simply gain more, and the peripheral cities lose from a transportation project. In this paper, we interpret the Straw effect slightly more broadly in a manner consistent with the economic literature: Peripheral cities not just in Shikoku, but also along the inland sea coast of the Chugoku region may lose economic prosperity upon the construction of the Great Seto Bridges.

Lastly, the realization of economic gains from the project and its distribution over space are important from a public finance standpoint. Currently, eight prefectures unevenly bear the burden of the construction costs, and these prefectures have not been able to fully pay the debt after 30 years of its construction. The cost shares of the eight prefectures are shown as shaded areas in **Figure 1**, with darker red colors indicating higher cost shares. Comparing **Figure 1** and **Figure 2**, 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 cost share match the distribution of economic gains?

II-B. Data

Transport Cost and Market Access Variables: We define a bilateral transport cost between any pair of cities as the sum of the travel time cost and the user fee between the cities. Prior to the construction of the Bridges, transportation in our study area relied heavily 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. To construct the market access variable, we use the population size of each city following Donaldson and Hornbeck (2016) and others. The city-level population data come from the Statistics Bureau of the Ministry of Internal Affairs and Communications (MIC).

Outcome Variables: Our outcome variables are manufacturing output, population, and employment. We use these as our outcomes not only because they 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 from the value of manufactured product shipment from the Industrial Statistics Survey (METI, 1980-2010). For population and employment, we use data from the MIC's Statistics Bureau. We use the labor force population as a proxy for the employment level of each city. Although this may be an inaccurate measure of employment, it is considered a good proxy in the literature because the residential choices of the labor force population highly correlate with the employment demand across 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. These are known as the primary drivers of economic growth (see Krugman (1993) and the quantitative spatial model in **Appendix B**). For the physical characteristics, we follow Faber (2014), and use the average land steepness, 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 taxable income per capita as of 1980 from the Census Statistics (MIC, 1980).

II-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 the full sample, whereas the remaining columns report these by city size as of 1980: small, large peripheral, and core cities.

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 76,900, and the labor force population of 37,900 per city. Overall, cities in the western Japan region were 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 the 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.

Table 2. Descriptive Statistics

			The Size of Economy as of 1980									
			Small Periphery									
	Overall		Lowest Tertile		Second Tertile		Highest Tertile		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)	0.12	(0.20)	0.18	(0.28)	0.19	(0.25)	0.18	(0.12)
⊿EMA	0.10	(0.13)	0.07	(0.13)	0.10	(0.13)	0.12	(0.13)	0.10	(0.07)	0.18	(0.12)
Panel B: Outcome Variables												
i) 1995												
Manufacturing Output (Bn.)	176	(441)	22.3	(45.7)	72.7	(108)	209	(204)	939	(733)	3110	(2139)
Population (K)	76.9	(179)	9.6	(5.0)	29.6	(10.3)	86.9	(41.2)	418	(181)	1556	(607)
Employment (K)	37.9	(125)	4.2	(2.4)	12.8	(4.8)	38.9	(20.6)	198	(101)	1058	(800)
ii) 2005												
Manufacturing Output (Bn.)	173	(397)	29.1	(77.8)	80.8	(150)	211	(242)	910	(855)	2262	(1241)
Population (K)	76.9	(182)	9.2	(5.3)	29.2	(12.4)	85.9	(42.9)	421	(186)	1591	(598)
Employment (K)	35.9	(111)	4.0	(2.6)	12.4	(5.5)	37.4	(20.0)	189	(98.0)	960	(649)
Panel C: Control Variables												
i) Geographical Conditions												
Average Elevation	238	(191)	317	(242)	226	(167)	196	(139)	125	(83.4)	158	(136)
Average Land Steepness	12.8	(7.0)	15.4	(7.9)	12.8	(6.6)	11.3	(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												
Income per capita (K)	1812	(302)	1683	(270)	1770	(222)	1904	(323)	2166	(250)	2192	(136)
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	614		191		191		190		37		5	

Notes: This table shows the means and standard deviations of the variables by city size. This classification is defined based on the 1980 population and the urban hierarchy criteria in Japan. Core cities have populations of 500,000 or more, large periphery cities have populations over 200,000 and below 500,000, and small periphery cities have populations below 200,000. The small periphery cities are further subdivided into three groups: the lowest tertile, the second tertile, and the highest tertile.

III. Empirical Strategy

III-A. The Estimation Equation

Our goal is to quantify the causal effect of the Great Seto Bridges on the economic growth of cities in the western Japan region, with a particular focus on its heterogeneous impacts: which cities gain (or lose) more, and why? The essential problem in identifying the causal effect is that virtually all cities are "treated" via the general equilibrium effects, not just the cities directly connected by the Bridges. Hence, the usual quasi-experimental methods, such as difference-in-differences or regression-discontinuity methods, are unlikely to work well in this context. Instead, we start by the structural market-access equation that can be derived from the quantitative spatial model (Donaldson and Hornbeck, 2016; Redding, 2020; Jedwab and Storeygard, 2022; see the derivation in **Appendix B**):

$$\ln Y_{i,t} = \beta \ln MA_{i,t} + W_{i,t}\gamma + \xi_i + \eta_{i,t} + \epsilon_{i,t}, \tag{1}$$

where $Y_{i,t}$ is a variable that measures the economic size of city i in year t, $W_{i,t}$ 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. We follow Donaldson and Hornbeck (2016) and Jedwab and Storeygard (2022), and define the MA variable, $MA_{i,t}$ for city i at time t, by taking the first-order approximation to the standard market-access equation [see the equation (B.11) in **Appendix B**]:

$$MA_{i,t} \approx \sum_{j \neq i} \tau_{ij,t}^{-\theta} POP_{j,t-1}, \tag{2}$$

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 $MA_{i,t}$ and 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.[7]

To obtain the unbiased estimate of β, we combine three types of identification strategies. Our first strategy is to apply the conventional wisdom from the panel-data methods. We take the first-difference in equation (1) to eliminate the time-invariant unobservable term ξ_i. We also run the regression in lags: i.e., $\Delta(\ln Y_{i,t})$ are regressed on $\Delta(\ln MA_{i,t-1})$. This ensures that

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[6] We also report the results of our estimation using alternative trade elasticities in **Appendix E.2.** Intuitively, θ strikes a balance between transport costs and market size: smaller values assign more weight to transport costs, while higher values assign more weight to the market size. The trade elasticity of $\theta = 4.0$ appears to hit the right balance, as discussed in both Simonovska and Waugh (2014), and **Appendix E.2.**

[7] Following Borusyak and Hull (2023) and Baum-Snow et al. (2020), we also report our estimation results using varying specifications of the MA variable in **Appendix E.4.**

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. 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). Our base specification uses 10-year lags.[8] We also include various controls to absorb the remaining terms, $\Delta W_{i,t}\gamma$ and $\Delta\eta_{i,t}$.

Our second strategy is to exploit the quasi-experimental variation in transport costs induced by the construction of the Central Seto Bridge. The construction of the Central Seto Bridge dramatically reduced the transport costs for not only the connected cities but all cities (**Figure 2**). This creates unexpected changes in the MA variable, particularly for cities far away from the Bridge. Furthermore, **Figure 3-A** reveals that the construction of the Central Seto Bridge (completed in 1988) caused a sharp decline in transport cost in cities in the Shikoku region in the late 1980s, while the construction of the other two bridges in the late 1990s led to relatively small transport cost reductions, with magnitudes similar across regions.

In **Figure 3-B**, we present the changes in MA (in log) 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, and dots represent the values for individual cities. The figure delivers several key messages. First, the correlation between the decline in transport costs and the growth in the MA variable is not uniform. In particular, cities in the Shikoku region experienced both increases and decreases in the MA variable, even though the decrease in transport costs is far more pronounced. 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, and again in 1995 in the Chugoku and the Shikoku regions. The MA growth levels off after 2000, despite the transport cost declines in 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 impacts of transportation cost reductions.

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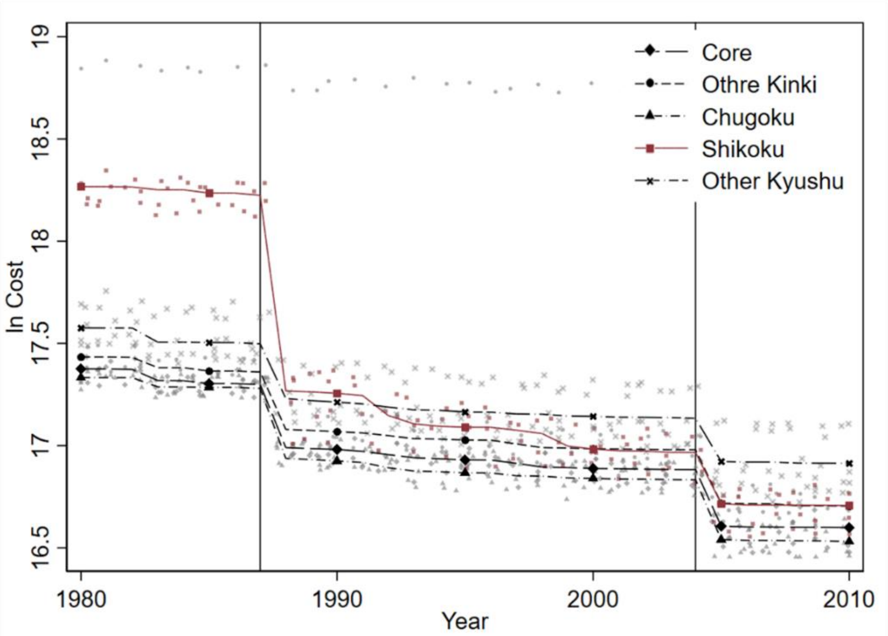
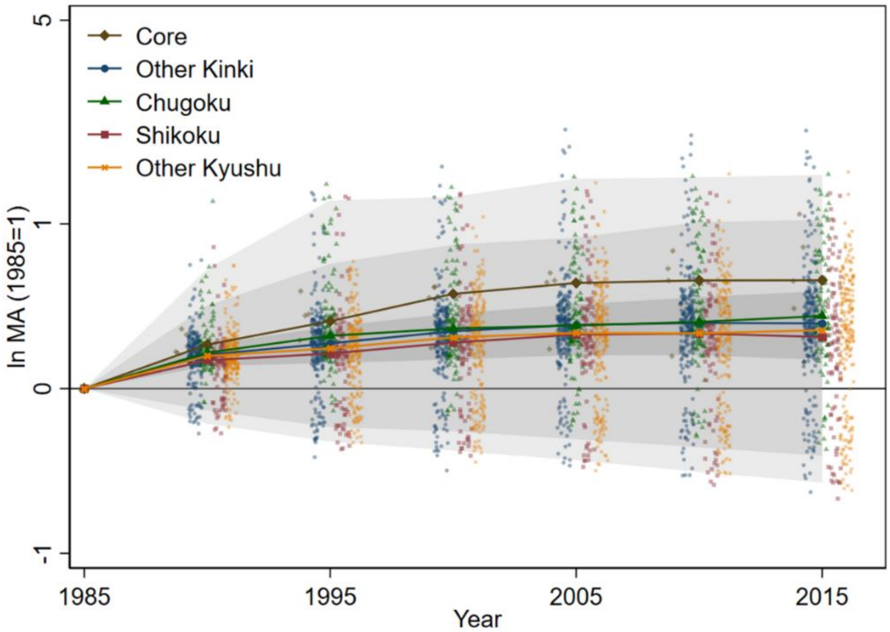
[8] Previous studies estimate this type of regression without a time lag (e.g., Donaldson and Hornbeck, 2016; Jedwab and Storeygard, 2021; Borusyak and Hull, 2023). In **Appendix E.1.**, we also present the estimation results without the time lags as well as varying time lags, and discuss why the 10-year lag is our preferred specification.

Figure 3. Transport Cost Reductions and Change in MA over Time

A. Transport Cost Reduction over Time



B. Changes in Market Access over Time



Notes: Panel A shows the transport cost reduction. Each line represents the median for each region, excluding the core cities. Small dots represent the medians for the prefectures. Panel B shows the changes in MA (in log) relative to the values in 1985. Gray shaded areas represent the 99-percentile range, 95-percentile range, and 75-percentile range of all observations, in order from lightest to darkest color. Each line represents the median for each region. Small dots are the raw values for cities.

Combining these identification strategies, we arrive at the following estimation equation:

$$\Delta(\ln Y_i)_{95-05} = \beta\Delta(\ln MA_i)_{85-95} + g(X_{i,80}) + \Delta\epsilon_{i,95-05}, \tag{3}$$

where $g(X_{i,80})$ is the term that controls for the influence of the observables $\Delta W_{i,t}$ and the unobservables $\Delta\eta_{i,t}$. We use socioeconomic and geographic variables in 1980 as pre-treatment controls. Note that in this specification, we use the difference-in-differences design in terms of the MA variable, exploiting the transport cost shocks as the exogenous source of variation. In a 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.

III-B. The Recentered Market Access Approach

Economists are increasingly concerned with the fundamental endogeneity that remains even after taking all these identification strategies into account. That is, public infrastructure investments are made in cities where higher (or lower) economic growth is expected, thereby inducing the changes in MA according to the *future* expectations. In the earlier literature, economists have used geography-based instruments such as 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, Borusyak and Hull (2023) demonstrate that such geography-based instruments fail to address this fundamental endogeneity because a city's location in the intrinsic structure of economic networks is inherently endogenous. 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 of transport costs $\{\boldsymbol{\tau}^s\}_{s\in S}$. Second, we calculate a sample analogue of the expected value of MA (EMA) that follows 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 "recenters" the MA variable by calculating the difference between the observed and the expected MA for each realized vector of $\boldsymbol{\tau}$: $RMA_i(\boldsymbol{\tau}) \equiv MA_i(\boldsymbol{\tau}) - \mu_i$.

By construction, these 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 arise in a complex manner from the non-random exposure of cities in a given network structure to the "as-good-as-random" assignment. In **Appendix C**, we provide a more detailed account of how the RMA approach resolves the fundamental endogeneity problem in a stylized QSM model.

In the current empirical setup, we operationalize this RMA approach in the following manner. We first randomly select the location and timing of transportation investments in the western Japan, and calculate the corresponding changes in transport costs and the MA variable.[9] We then calculate the expected MA growth for each city as the average of the 10-year growth of the simulated MAs in logs:

$$\Delta EMA_{i,85-95} \equiv E[\Delta(\ln MA_i)_{85-95}] = \frac{1}{S} \sum_{s\in\{1,\dots,S\}} \left[\ln \widetilde{MA}^{s}_{i,95} - \ln MA_{i,85}\right], \tag{4}$$

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 growth as the difference between the observed MA growth and the EMA growth:

$$\Delta RMA_{i,85-95} \equiv \Delta(\ln MA_i)_{85-95} - \Delta EMA_{i,85-95}. \tag{5}$$

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 as a valid instrument because it must be correlated with the realized MA growth (relevance) but uncorrelated with the unobserved error (exogeneity) by construction. On the latter, note that the RMA growth instrument has an intuitive appeal for those who have concerns about bias arising from reverse causality or selection --- the government agencies may decide when and where to make public transportation investments anticipating the expected growth of cities in different areas, but ΔRMA_i purges out that expected growth component from the MA variable. By the same argument, we may

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[9] 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.

alternatively 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.

III-C. The Instrument Validity

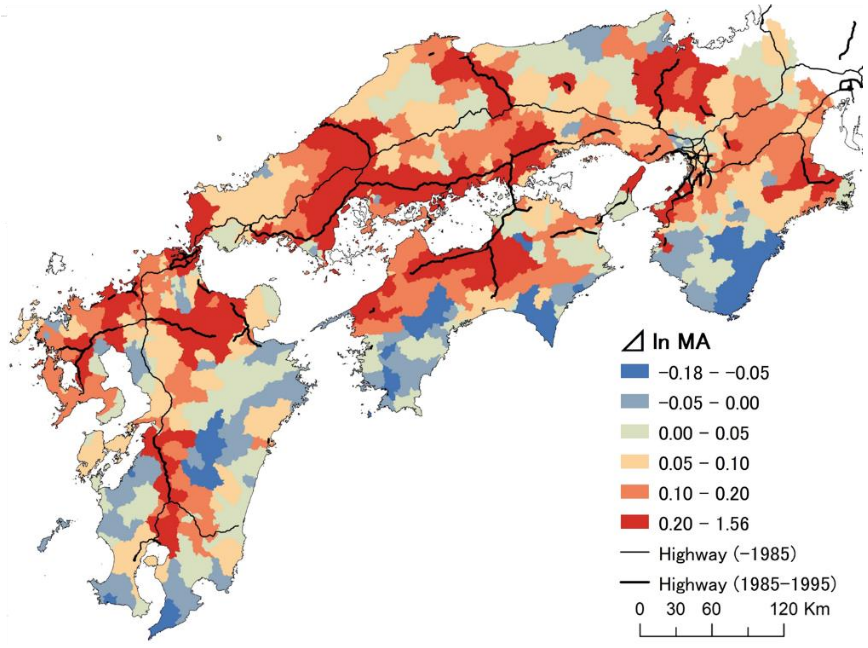
This section discusses the spatial and temporal distribution of both the MA growth and the RMA growth in our study. **Figure 4** shows the changes in logged values of MA (Panel A) and in the logged values of RMA (Panel B) over the period of 1985-1995.

First, the spatial distribution of changes in market access (**Figure 4-A**) does not necessarily coincide with that of transport costs (**Figure 2**). As expected, we see high MA growth in cities where highways were constructed (e.g., near the Central Seto Bridge). However, some cities (e.g., northeastern Kyushu) substantially increase their market access despite the relatively small transport cost reductions there, whereas some other cities (e.g., in the southern Shikoku region) decrease their market access despite their substantial transport cost reductions. Furthermore, cities near Osaka experience negative MA growth despite the new construction of highways there. This reinforces the importance of accounting for the general equilibrium effects of public infrastructure investments.

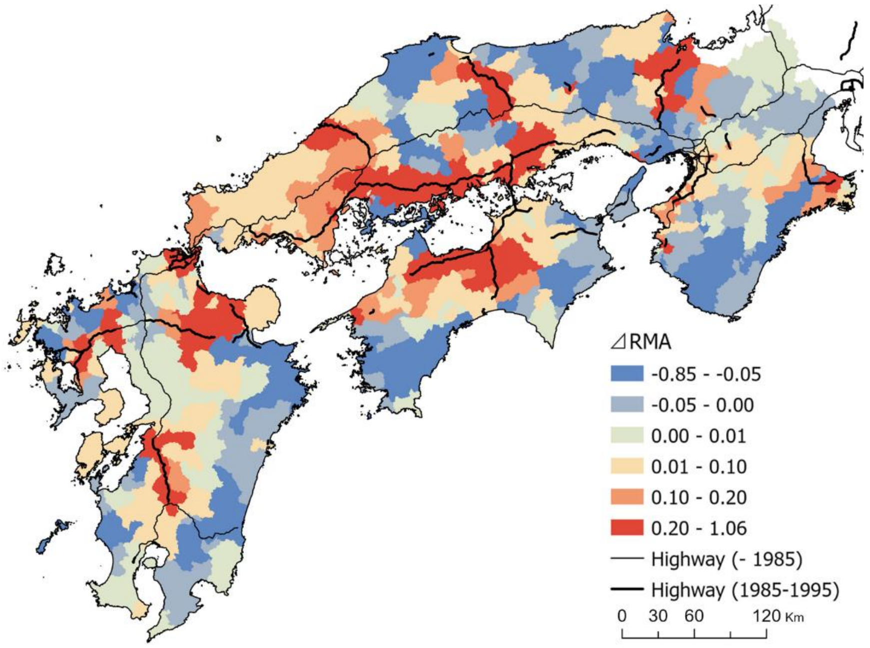
Second, **Figure 4-B** indicates that the RMA growth is spatially highly correlated with the observed MA growth, suggesting that it is indeed a relevant instrument. The figure also illustrates that some of these changes in MA are *unexpected*, in the sense that the changes exceed, or fall short of, the expected MA growth for some cities. For example, the northern Shikoku and the southern Chugoku regions experience large positive changes in RMA, implying that the MA growth due to the construction of the Central Seto Bridge is something we do not expect a priori from the intrinsic structure of economic networks. On the other hand, the core cities, such as Kobe and Kyoto, receive a negative MA shock after accounting for the expected growth. These large cities are expected to grow faster than others due to their geographic advantage, yet the realized MA growth for these cities fell short of that expectation. We exploit this kind of unexpected (exogenous) variation in MA for identification of its economic impact. We report the results of the first stage regression in **Appendix D**.

Figure 4. Spatial Variation in Observed and Recentered Market Access

A. The Changes in Market Access, 1985-1995



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



Notes: Panel A shows the changes in logged values of MA over 1985-1995. Panel B shows the changes in logged values of RMA over 1985-1995. As in **Figure 1**, the thin black lines represent highways built before 1985, and the thick black lines represent highways built between 1985 and 1995.

IV. Estimation Results

IV-A. Main Results

We present the results of the OLS regression of equation (3) as well as the IV regression using the RMA approach in **Table 3**. The first column reports on the OLS estimates while the second and the third columns show the results of the RMA approach, using ΔEMA as an additional control (the second column) and ΔRMA as an instrument for $\Delta \ln MA$ (the third column). For each regression, the estimates on three outcomes are reported: (A) manufacturing output, (B) population, and (C) employment. For all outcomes, we use 1995-2005 as the outcome period. All regressions 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, percentage of elderly, percentage of employees in the manufacturing sector, and the taxable income per capita. These are meant to capture the influence of city-level unobservables on the economic growth trends.

The OLS estimates confirm a positive correlation between the transport-cost-induced changes in MA during 1985-1995 and the observed changes in all three economic outcomes during 1995-2005. The estimated impacts are 0.200, 0.032, and 0.035, respectively, for manufacturing output, population, and employment, and are statistically significant at the conventional levels. Using the mean values reported in **Table 2**, these estimates would have implied 2.60%, 0.42%, and 0.46% increases in these outcomes.

Our RMA results suggest, however, that some of these impacts are spurious. The estimates remain robust to the use of EMA or RMA only on manufacturing output: 0.194 (EMA-OLS) and 0.195 (RMA-IV) and statistically significant. On population, the RMA estimates become smaller than the OLS estimate and marginally significant. On employment, there is a sign that the RMA estimates are imprecise: estimates are insignificant, flip signs, and have relatively large standard errors.

Table 3. Estimation Results

	OLS	EMA-OLS	RMA-IV
	(1)	(2)	(3)
Panel A: Manuf. Output			
⊿ ln MA	0.200 ***	0.194 **	0.195 ***
	(0.069)	(0.090)	(0.074)
⊿ EMA		0.017	
		(0.230)	
R-squared	0.081	0.081	0.081
Panel B: Population			
⊿ ln MA	0.032 ***	0.013	0.019 *
	(0.009)	(0.013)	(0.010)
⊿ EMA		0.055 *	
		(0.028)	
R-squared	0.463	0.466	0.462
Panel C: Employment			
⊿ ln MA	0.035 **	-0.011	0.003
	(0.015)	(0.021)	(0.017)
⊿ EMA		0.130 ***	
		(0.050)	
R-squared	0.393	0.402	0.389
First-Stage F-Stat.			209
Observations	614	614	614

Notes: Asterisks represent 1%, 5%, 10% significance levels. In parentheses are the cluster robust standard errors clustered at the city level. All regressions use the following controls: average land steepness, average elevation, percentage of building areas, percentage of water areas, percentage of wetlands, percentage of elderly, percentage of manufacturing employees, manufacturing output and the taxable income per capita.

As discussed in Borusyak and Hull (2023), the sign and statistical significance of the coefficient on the EMA variable tell us how we might interpret the results. For manufacturing output, the EMA coefficient is positive but insignificant. This implies that the manufacturing outputs of cities respond largely to the unexpected changes in MA and that the confounding effect of the intrinsic expectation of the MA growth is negligible. In contrast, for population and employment outcomes, the EMA coefficient is positive and significant, implying that the population and employment sizes of cities respond to the intrinsic expectation of the MA growth, and hence, its omission would lead to the omitted variable bias. Based on these results, we conclude that the transport megaproject (the Central Seto Bridge and other highways) during 1985-1995 had a positive causal effect on the manufacturing outputs of the affected cities, but had no or limited effect on their population and employment.

These results are economically intuitive and are also consistent with the earlier empirical studies. On one hand, the market access of a city measures how accessible the market demands across cities are to the producers of the city. When there is a positive shock to the city's market access, the firms in the city can increase the value of goods and services they produce through trading *without* relocating their production. Hence, the first-order impacts of the shock are likely to appear in manufacturing outputs. On the other hand, the market access also measures how accessible the goods and services produced across cities are to the consumers of the city. When there is a positive shock to the city's market access, some of the consumers may be drawn to the city. However, the consumers make their residential location decisions based on a longer-term employment prospect for the city. Hence, the population sizes of cities are likely to depend more on the expectation of the future MA growth than on the temporary shocks to the MA growth. The employment sizes of the cities depend on the firms' production locations, which in turn rest on the comparative advantage of the cities and are known to be robust to various shocks and generally take longer time to adjust (Baldwin and Okubo, 2005).

The earlier empirical literature provides evidence in support of these economic mechanisms. For example, Ahlfeldt and Feddersen (2018) find an economically large causal effect of the German high-speed railways on surrounding countries' GDPs and argue that the GDP growth is primarily driven by higher labor productivity rather than employment increase. Gibbons et al. (2019) examine the effects of road openings using the firm-level panel data in Britain and find that road openings causally increase the number of small-scale manufacturing establishments, but do not increase manufacturing employment in the short run. Mayer et al. (2017) study the impact of an enterprise zoning program in France on firms' location and labor market outcomes and find that, although the program has a positive effect on the probability of locating in the enterprise zone, larger establishments are much less likely to relocate than smaller ones.

IV-B. Alternative Specifications

Our main empirical results are based on the specification in equation (3). The specification relies on the following set of assumptions: a 10-year lag between the changes in the MA variable and the outcome, the trade-elasticity parameter of $\theta = 4$, no heterogeneity in the treatment effect β, and the first-order approximation of the MA using the lagged population size. We run several alternative specifications to check the validity of our specification: (a) altering our outcome period to 1980-90, 1985-95, 1990-2000, and 2000-10, (b) using alternative values of trade elasticity, (c) interacting the MA variable with dummies representing various sources of heterogeneity, and (d) fixing the population size of each city at the pre-treatment level instead of the lagged population size when calculating MA in equation (2).

When different outcome periods are used, the OLS estimate on the manufacturing output is statistically insignificant during the placebo period (1980-90), negative but statistically insignificant during the post-treatment periods (1985-95 and 1990-2000), and becomes positive and significant only during 2000-2010 and the IV estimates only magnify these estimates without changing signs. Hence, we conclude that using earlier outcome periods would only pick out the spurious correlation: trade-cost reductions occurred in cities with low economic growth. When smaller trade elasticities ($\theta < 3$) are used, the MA responds too sharply to the changes in transport costs, with magnitudes that are hard to justify. With moderate trade elasticities ($\theta \in [3,5]$), the MA responses as well as the estimates of β are similar to our base specification. To account for heterogeneity, we interact the MA variable with three types of tertile dummies: pre-treatment population size, pre-treatment MA level, and transport cost reductions. We fail to reject the null of joint significance of the interaction terms in these regressions. Hence, we prefer our parsimonious specification assuming the homogeneous effect β. Lastly, we confirm that all of our estimates (both OLS and IV) are robust to using the pre-treatment population size in the MA variable. All these results are reported with more in-depth discussions in the **Appendix E**.

V. The Economic Impact of the Transport Megaproject 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 steps.

The first step is to calculate the predicted changes in the cities' manufacturing outputs due to the transport megaproject over the 1995-2005 period against their pre-treatment population sizes as of 1980. This step 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 the question: Do larger cities tend to grow more than smaller cities due to the transport megaproject? The second step attempts to estimate the net benefit of the transport megaproject for each city relative to the counterfactual in its absence. To do so, we use the publicly available construction cost estimates.

For both steps, we make use of the RMA-IV estimates from **Table 3** and evaluate the impacts of two scenarios, (a) the Central Seto Bridge and other highways and (b) the Central Seto Bridge, against the counterfactual with no such investment. To simulate the outcomes under the second scenario, we re-calculate the transport costs, removing the other highways, and make use of the QSM to simulate the resulting changes in MA for all cities in our sample.

V-A. Geographic Distribution of Economic Impacts of the Transport Megaproject

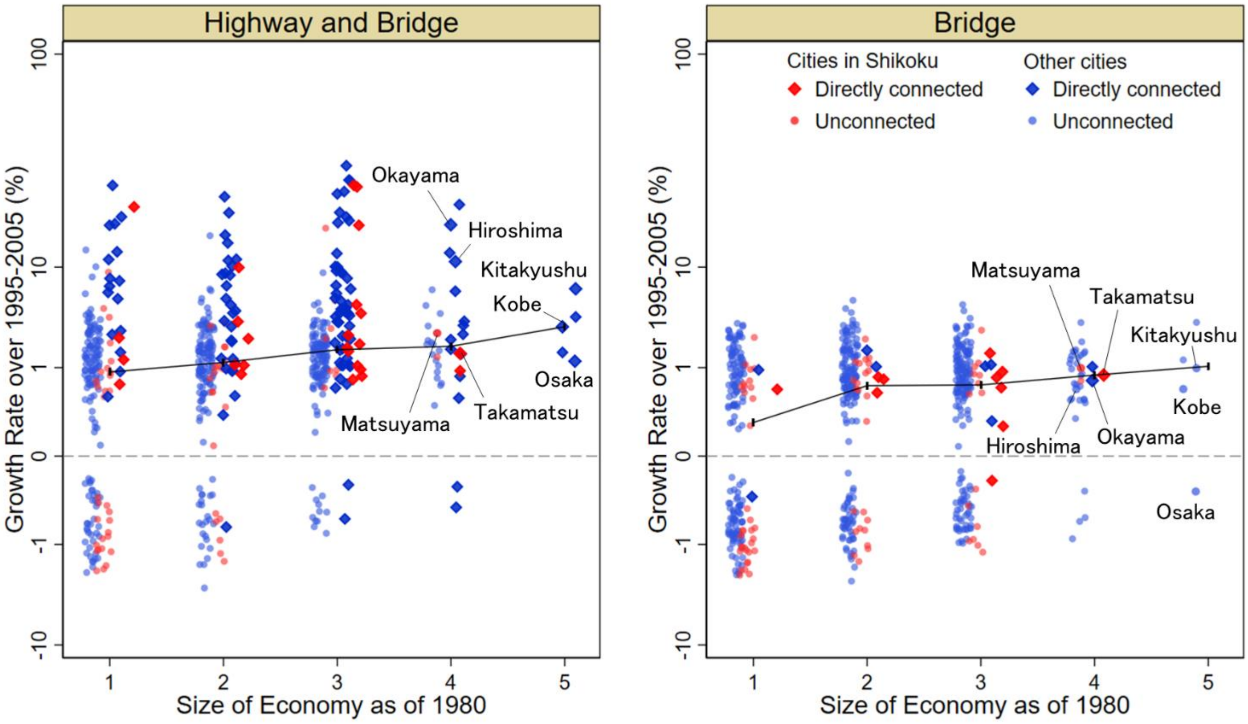
Figure 5 shows the results of the first step. **Panel A** plots the economic impacts of the Central Seto Bridge and other highways on the growth rates of the manufacturing output over the period 1995-2005 against the 1980 population size. In the same manner, **Panel B** plots the impacts of the Central Seto Bridge only. In the figures, the cities directly connected by the transport projects are marked as diamonds while the cities not directly connected are indicated as dots. The cities in Shikoku are marked in red and those in other regions are in blue. **Appendix F** also provides the results showing the impacts on population and employment, which convey essentially the same points we discuss below.

This figure illustrates five important take-away messages. First, **Panel A** shows that the Central Seto Bridge and other highway construction during the 1985-95 period had positive impacts on *virtually all* cities' manufacturing output, and the magnitudes of the impacts are economically large. On average, these cities gain a 2.78% manufacturing output growth rate relative to no transport investment.

Second, there is a sign of agglomeration economy in the sense that larger cities tend to attract more economic activity than smaller cities, though there is substantial heterogeneity within each city-size cohort. At the median, the largest cities (the fifth category) gain manufacturing output by 3.33% (Panel A) and 1.11% (Panel B), whereas the smallest cities (the first category) gain manufacturing output by 0.92% and 0.06%.

Third, there is substantial heterogeneity across cities in these economic impacts, with a non-negligible number of cities experiencing negative output growth. Importantly, there are winners and losers, regardless of the initial city size or whether they are directly connected by the transport projects. We also see that the economic impacts of the Central Seto Bridge differ substantially with and without other highways constructed during the same period. For example, Okayama would have experienced a 20.1% increase in manufacturing output if the other

Figure 5. Economic Impacts of the Transport Megaproject
across Cities of Different Population Sizes



Notes: The size of economy on the horizontal axis is based on the population size as of 1980, following the same classification as in **Table 2**. The cities directly connected by the transport projects are marked as diamonds while the cities not directly connected are indicated as dots. The cities in Shikoku are marked in red and those in other regions are in blue. The black lines indicate the median for each category.

highways were constructed (**Panel A**), but only a 0.66% increase if only the Central Seto Bridge were constructed (**Panel B**).

Fourth, the magnitudes of the estimated impacts are much smaller in **Panel B** than in **Panel A**, implying that the *pure* effect of the Central Seto Bridge is not necessarily large and that much of the effect in **Panel A** comes from the *combined* effect of the other highways and the Central Seto Bridge. In fact, Osaka, the largest city in our sample, is predicted to experience positive output growth if the other highways were constructed (**Panel A**), but negative growth if only the Central Seto Bridge were constructed (**Panel B**). This also signifies the importance of our approach in accounting for the general equilibrium impacts.

Lastly, the Straw effect did not materialize, at least not in the way the critics had anticipated before the construction of the Bridge. The critics were particularly concerned that the economic activity may be drawn from the large peripheral cities (such as Hiroshima, Okayama, Matsuyama, and Takamatsu, that are of critical importance to the regional economy) to the core cities (such as Osaka, Kobe, and Fukuoka). On the contrary, however, these peripheral cities are predicted to gain manufacturing growth of 0.58-1.05% due to the construction of the Central Seto Bridge alone and 1.67-20.1% including other highways. There are cities in the southern Shikoku region that lose from the transport project, but the same is true for cities in other regions.

In sum, we conclude from these observations that the distribution of winners and losers from the megaproject depends, in a complex way, on how the transport cost reductions induced by the project permeate through the existing network structures.

V-B. Geographic Distribution of Net Benefits of the Transport Megaproject

Our next step is to convert these counterfactual impacts into net benefits. To do so, we apply the following simplifying accounting rules.

On the cost side, we make use of the publicly available information on the construction costs of the Central Seto Bridge and other highways (*Asahi Newspaper*, 1992; 1994) and their cost shares by prefectures from MLIT (2001; 2011). The estimated cost of the Central Seto Bridge is about 1.13 trillion yen (in 1988 JPY) and that of highways constructed between 1985 and 1995 is about 9.0 trillion yen (in 1988 JPY).[10] 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.

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 (mostly non-pecuniary) benefits. This is arguably a simplifying assumption. However, when discussing the benefits 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. On one hand, the Central Seto Bridge has a useful life of 100 years, while the highways have a useful life of 70 years. Hence, ideally, we would like to do the cost-benefit analysis, estimating the benefit flows over the entire life years of the project. On the other hand, our preferred estimates get at

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[10] We use the estimated cost per kilometer of highways (4.87 billion yen) and multiply it by the total length of highways constructed during the period in western Japan (1,807 km).

the counterfactual impacts of the Bridge and the highways 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 will be paid equally over the useful life and applying the social discount rate of 4% per year following Circular-4 guidelines (which is the same social discount rate used in Japan).

To be precise, we calculate the net benefit of each transportation project for city i during the period 1988 to 2005 as follows:

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

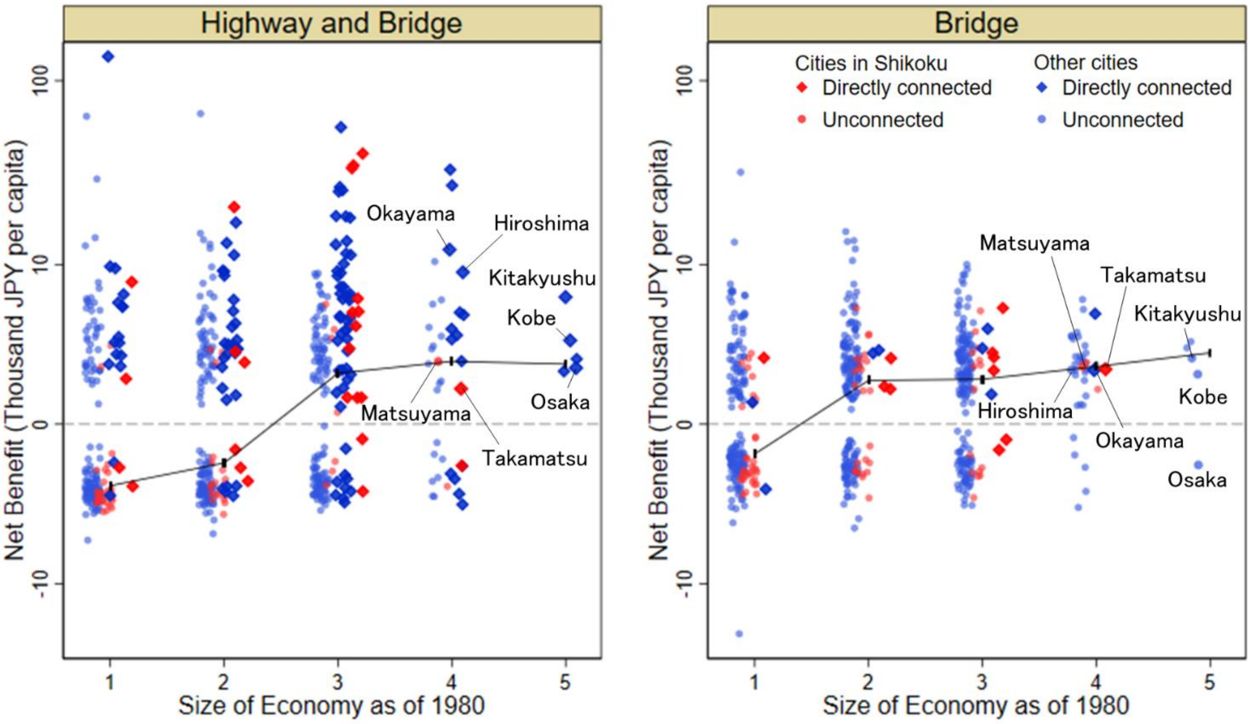
$$B_{i,t} \cong \begin{cases} (\Delta\hat{Y}_{i,95-05})/10 & \text{for } t > 1995 \\ 0 & \text{for } t \leq 1995 \end{cases} \qquad (10b)$$

$$C_{i,t} \cong \hat{C}_i/T \qquad \text{for } \forall\, t \qquad (10c)$$

where ρ is the social discount rate, $\Delta\hat{Y}_{i,95-05}$ is the estimated impact of the transport project on city i's manufacturing output over the period of 1995-2005, $\hat{C}_i$ is the estimated cost burden for city i in 1988 JPY, and T is the project's effective life years. 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 project against the one-time construction cost.

Figure 6 displays the estimates of the net benefits per capita per year for all cities in our sample against their population size as of 1980, in a manner analogous to **Figure 5**. There are several important takeaways from the figure. First, **Figure 6** echoes essentially the same key messages we observe from **Figure 5**: (1) a majority of cities gain net benefits from the transport megaproject, regardless of their initial economic abundance, (2) there is a sign of agglomeration economies, (3) there is substantial heterogeneity in the distribution of net benefits across cities within each category, with some cities losing substantially from the megaproject, and (4) the Straw effect phenomenon did not materialize, at least not in the form originally claimed by the critics, with large peripheral cities in Shikoku and Chugoku gaining substantial net benefits from the project.

Figure 6. Distribution of Net Benefits Across Cities of Different Population Sizes



Notes: The size of economy on the horizontal axis is based on the population size as of 1980, following the same classification as in **Table 2**. As in **Figure 5**, the cities directly connected by the transport projects are marked as diamonds while the cities not directly connected are indicated as dots. The cities in Shikoku are marked in red and those in other regions are in blue. The black lines indicate the median for each category.

Second, the figure demonstrates that the government's current cost-sharing rule does not quite match the distribution of economic benefits across cities. Based on our back-of-envelope calculation, the Central Seto Bridge is estimated to generate an annual aggregate net benefit of approximately 34 billion yen or 460,000 yen per capita for the western Japan region over the 1988-2005. Similarly, if the other highways are included, the transport megaproject is estimated to generate an annual aggregate net benefit of approximately 149 billion yen or 1.33 million yen per capita. This implies that in theory, we can re-design the cost-sharing rule in such a way that *all* cities gain from the project. That is, the net gainers contribute more to the project while compensating the net losers, potentially through taxes and transfers.

Lastly, some of the "winners" in **Figure 5** turn to "net losers" in **Figure 6** once the cost of construction is accounted for. If only the Central Seto Bridge were constructed, 41 cities become net losers despite that they are predicted to gain positive output growth due to the Bridge. If the other highways were constructed in addition, then the number of such cities increases to 217. This is suggestive of an important trade-off from a public finance standpoint: the aggregate net benefit may be larger, the larger the transport investment is, but the need for the redistribution of its economic benefits may also become larger. We also provide additional maps in **Appendix G** to help visualize the geographic distribution of benefits and costs.

There are two caveats to 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 industrial or transport-related air pollution.

VI. Conclusion

We empirically examine the Straw effect phenomenon in the unique historical context of rapid motorization in Japan: Do core cities gain more from large transportation investments than peripheral cities do, or worse, the peripheral cities even lose from such investments? We estimate the heterogeneous causal effect of public transportation projects, using the construction of the Central Seto Bridge and other highways during the 1980s as the source of exogenous variation in transport costs and employing the recentered instrumental variable method in the market-access approach. The estimates are then 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 a majority of cities, not just large cities or cities nearby the Bridge, experience positive growth in manufacturing output. The estimated growth rates are higher for cities that were larger before the construction of the Bridge and other highways. This suggests the existence of agglomeration economies and is indeed consistent with the economic theory, and 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. Importantly, the *pure* effect of the Bridge alone and the *combined* effect of the Bridge and highways yield quite different results, both qualitatively and quantitatively. In particular, the geographic distribution of winners and losers is shown to depend, in a subtle way, on how the cities are connected by the transport projects in the existing transportation network. Thus, our work substantiates the importance of accounting for the complex general-equilibrium effects in evaluating public transportation projects.

Our work also suggests an important question for public finance economists. On one hand, we show that the transport megaproject, either the Central Seto Bridge alone or combined with the other highways, generates a positive aggregate net benefit for the western Japan region. On the other hand, we also show that a large number of cities are estimated to lose from the project, in terms of both the manufacturing output and the net benefits. Importantly, these losers are spatially heterogeneous and *a priori* are hard to predict before the construction of the bridge. How to finance such transport megaprojects in an equitable manner is potentially an important policy question. Due to space and data limitations, we do not explore this question further and it is hence left for future research.

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Appendix

Appendix A.
The Related Literature

This appendix discusses the literature closely related to our study. First, it is related to the theoretical and empirical literature concerning the heterogeneous impacts of transport projects on economic activity, particularly 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, since Krugman (1991), it has been shown that lower trade costs may hurt peripheral cities while having a positive impact on core cities. Empirically, Jedwab and Storeygard (2022) finds a larger positive impact of transport projects on peripheral cities in Africa; Asher and Novosad (2020) find a limited effect of road construction on population growth in India. In contrast, Faber (2014) and Baum-Snow et al. (2020) show a larger positive impact of transportation construction on core cities.

Second, our paper is related to studies that empirically evaluate the causal effects of transportation infrastructure on various economic outcomes (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, 2019; 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 highways on suburbanization in the U.S. Duranton et al. (2014) also show that inter-state highways have a large effect on the weight of city exports in the U.S. Donaldson (2018) investigates the effects of railroad construction on inter-city trade and market integration in India. Duranton and Turner (2012), Ghani et al. (2015), and Banerjee et al. (2020) also empirically examine the impact on the economic growth of cities. These papers use continental countries such as the U.S., China, and India as their study area, unlike in our paper.

Third, it relates to the literature using 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, 2019; Mori and Takeda, 2019; Jedwab and Storeygard, 2022). For example, Redding and Sturm (2008) use an exogenous change in the unification of East and West Germany, and Nakajima (2008) examines the economic separation of Japan and Korea as an exogenous change 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 the transportation construction. Ours differs from these papers in that we address the fundamental endogeneity associated with the MA variable by applying the instrumental variable proposed by Borusyak and Hull (2023).

Fourth, it is also related to the theoretical literature on quantitative spatial models (QSM) (Allen and Arkolakis, 2014; Redding and Turner, 2015; Redding and Rossi-Hansberg, 2017; Redding, 2020). The QSM derives empirically tractable gravity equations not only for goods but also for flows of population, allowing for the empirical analysis of general equilibrium effects. Theoretical studies in new economic geography (e.g., Fujita et al., 1999; Fujita and Thisse, 2002; Baldwin et al., 2003) show that the love of variety, increasing returns to scale, and transport costs lead to a heterogeneous geographic distribution of economic activity. However, these theoretical models are complex and diverge from empirical estimates. The QSM approaches address these empirical challenges. 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). Conversely, Allen and Arkolakis (2014) bases their model on the Armington assumption of perfect competition with differentiated varieties, which differs from Krugman's assumptions of homogeneous tradable goods and a monopolistically competitive market. See the extensive review of these studies offered in Redding and Rossi-Hansberg (2017) and Redding (2020).

Finally, it also relates to the studies that investigate how the burden of large public transportation investments should be shared among stakeholders (Anguera, 2006; Boardman et al., 2018). To the best of our knowledge, few studies investigate the allocation of costs and debt among stakeholders for public investments. Moreover, many of these studies examine the ex-post evaluation of public megaprojects using engineering rather than economic methods. For example, Anguera (2006) provides a cost-benefit evaluation of the construction of the Channel Tunnel between the UK and France. However, the total financial burden in the UK was greater than the estimated benefits, suggesting a net economic disadvantage from its construction. Boardman et al. (2018) provide a case study of a cost-benefit analysis of a mining development project in British Columbia, Canada, showing that it primarily benefits the Canadian National Railway and the federal government.

Appendix B.
The Market Access in the Standard Quantitative Spatial Model

B.1. 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 terrains and climatic conditions while second-nature geography contains human-made elements like political and legal institutions and economic policies. These aspects play an important role in shaping the spatial interaction of economic activities, influenced by both agglomeration forces and dispersion forces, across cities. The QSM allows us to model how such an interaction determines the spatial distribution of economic activities across locations. In this section, we outline the essence of the standard QSM à la Redding and Turner (2015), Redding and Rossi-Hansberg (2017) and Redding (2020).

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

A representative consumer in city n 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 $C_n = \left[\sum_{i\in N} \int_0^{M_i} c_{ni}(\psi)^{\frac{\sigma-1}{\sigma}} d\psi\right]^{\frac{\sigma}{\sigma-1}}$ and H_n are, respectively, the amount of tradable goods and of non-tradable goods consumed in n, with ψ representing each variety, B_n is city n's amenity (e.g., quality, safety), and M_i is the number of variety produced by location i. Maximizing this utility subject to the budget constraint $Y_n = P_n C_n + Q_n H_n$, we can derive the following indirect utility function:

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

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 the price index for city n, which also implicitly defines the market access for consumers (CMA_n), σ is an elasticity of substitution, and Q_n is the price of non-tradable good.

Next, maximizing the consumer's partial utility, we can derive the consumer demand for each tradable good:

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

Consumers increase (decrease) their consumption of variety ψ when the relative price of that variety is low (higher). Using equation (B.2), we can obtain the optimal pricing rule 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 then derive the equilibrium wage from the equilibrium condition for tradable goods[11]:

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

where $FMA_i \equiv \sum_{n \in N} (w_n L_n) \tau_{ni}^{1-\sigma} P_n^{\sigma-1}$ is a measure of market access for firms and ξ is a constant defined as $\xi \equiv \sigma^{-1}(\sigma - 1)\big(F(\sigma - 1)\big)^{-\frac{1}{\sigma}}$.

The equilibrium of QSM can be pinned down by solving for the three set of endogenous variables: bilateral trade flows, population shares, and wages. First, the bilateral trade flows or

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

gravity equations are given by the share of expenditures in location n on goods exported from location i:

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

Second, the population shares are obtained from the population mobility condition[12] as follows:

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

Finally, the market clearing condition in the goods market gives us wages:

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

B.2. The Estimating Equation of Interest in the Market Access Approach

In this section, we outline how the two measures of market access, CMA and FMA, can be shown to yield a single measure of market access (MA) and how it is related to our empirical regression equation of interest.

To show the first, we start by rewriting the FMA by using the relationship between the price index P_n and CMA_n:

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

Since the price index P_n can be rewritten in equilibrium,

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[12] The population mobility condition is derived using equations (B.1) to (B.5) as $L_n = \left[\frac{A_n^{\alpha}B_nH_n^{1-\alpha}(\Gamma_{nn})^{-\frac{\alpha}{\sigma-1}}}{\tilde{V}\alpha\left(\frac{\sigma}{\sigma-1}\right)^{\alpha}\left(\frac{1}{F\sigma}\right)^{\frac{\alpha}{1-\sigma}}\left(\frac{1-\alpha}{\alpha}\right)^{1-\alpha}}\right]^{\frac{\sigma-1}{\sigma(1-\alpha)-1}}$.

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

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

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

In equilibrium, the labor income $w_i L_i$ is equal to the total expenditures on tradable goods, and hence, the following relationship holds:

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

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

$$CMA_n = \sum_{i \in N} \frac{L_i}{F\sigma} \left(\frac{\sigma}{\sigma - 1} \frac{\tau_{ni} w_i}{A_i} \right)^{1-\sigma} = \sum_{i \in N} \tau_{ni}^{1-\sigma} (w_i L_i) FMA_i^{-1}\,. \tag{B.9}$$

Assuming the symmetric trade costs $\tau_{ij} = \tau_{ji}$, the eigenvector solving the equations (B.6) and (B.9) give us that

$$FMA_i = \rho CMA_i, \tag{B.10}$$

where $\rho > 0$ is a scalar.

This indicates that FMA and CMA are essentially identical, with the former simply scaled by ρ. Therefore, we can unambiguously refer to the market access (MA) reflecting both concepts of market access, $MA_i \equiv FMA_i = \rho CMA_i$ (Donaldson and Hornbeck, 2016). Note that by plugging (B.10) into (B.9), we can formally define MA as:

$$MA_i = \rho \sum_{n \in N} Y_n \tau_{ni}^{-\theta} MA_n^{-1}\,, \tag{B.11}$$

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

Second, using these equations, we derive a theoretical relationship that would provide the basis for our regression equation. Using equations (B.8), (B.7), and (B.4) with $MA_i \equiv FMA_i$, the relationship between output Y_i and market access is given by:

$$Y_i = \sum_{n \in N} X_{ni} = \frac{L_i}{F\sigma}\left(\frac{\sigma\xi}{\sigma - 1}\right)^{1-\sigma} A_i^{\frac{\sigma-1}{\sigma}} MA_i^{\frac{1}{\sigma}}.$$

Taking the log, we can obtain the following relationship between output and MA:

$$\ln Y_i = \kappa_1 + \frac{1}{\sigma}\ln MA_i + \frac{\sigma - 1}{\sigma}\ln A_i + \ln L_i\,, \qquad \text{(B.12)}$$

where $\kappa_1 = \ln\left[\frac{1}{F\sigma}\left(\frac{\sigma\xi}{\sigma-1}\right)^{1-\sigma}\right]$ is a constant.

Similarly, we derive the following relationship between population (or employment) and market access:

$$\ln L_i = \kappa_2 + \frac{\alpha(2\sigma - 1)}{\sigma(\sigma - 1)(1 - \alpha)}\ln MA_i + \frac{\alpha}{1 - \alpha}\frac{\sigma - 1}{\sigma}\ln A_i + \frac{1}{1 - \alpha}\ln B_i + \ln H_i\,, \quad \text{(B.13)}$$

where $\kappa_2 = \ln\left[\alpha^{\frac{-\alpha}{1-\alpha}}(1-\alpha)\xi^{\frac{\alpha}{1-\alpha}}\bar{V}^{-\frac{1}{1-\alpha}}\right]$ is a constant. To see this, using the condition that the indirect utility must be equalized across cities as well as the relationships $P_n = CMA_n^{\frac{1}{1-\sigma}}$, $Q_i H_n = (1-\alpha)Y_i L_i$, $\alpha Y_i L_i = w_i L_i$, we obtain:

$$L_i = \alpha^{\frac{-\alpha}{1-\alpha}}(1-\alpha)\xi^{\frac{\alpha}{1-\alpha}}\bar{V}^{-\frac{1}{1-\alpha}} \times A_i^{\frac{\alpha}{1-\alpha}\frac{\sigma-1}{\sigma}} B_i^{\frac{1}{1-\alpha}} H_i MA_i^{\frac{\alpha(2\sigma-1)}{\sigma(\sigma-1)(1-\alpha)}}.$$

Taking the log of this equation, we can obtain (B.13).

Appendix C.
The Essence of the Empirical Problem and Its Solution

This appendix provides the essence of the empirical challenges and how our recentered market access approach might overcome the challenges in the standard quantitative spatial model (QSM) discussed in Appendix B.

C.1. How Does the Empirical Problem Arise?

We now use a simplified version of the 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 a 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 the network arising from the natural or social geographic conditions that are purely exogenous. Cities are homogeneous 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 investments. 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 C1 illustrates the changes in logged values of populations (top panels) and logged values of MAs (bottom panels). These illustrative examples demonstrate the empirical challenges we wish to address in our empirical study. Note that by construction, the public transportation investment is endogenously related to economic variables of the model. However, in this example, we assume that certain empirical challenges are unlikely to be faced by researchers 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. In this setup, the "untreated" cities would be cities C, D, and E in Panel A (B, C, and E in Panel B). Hence, our estimand and sample analogue of interest would be:

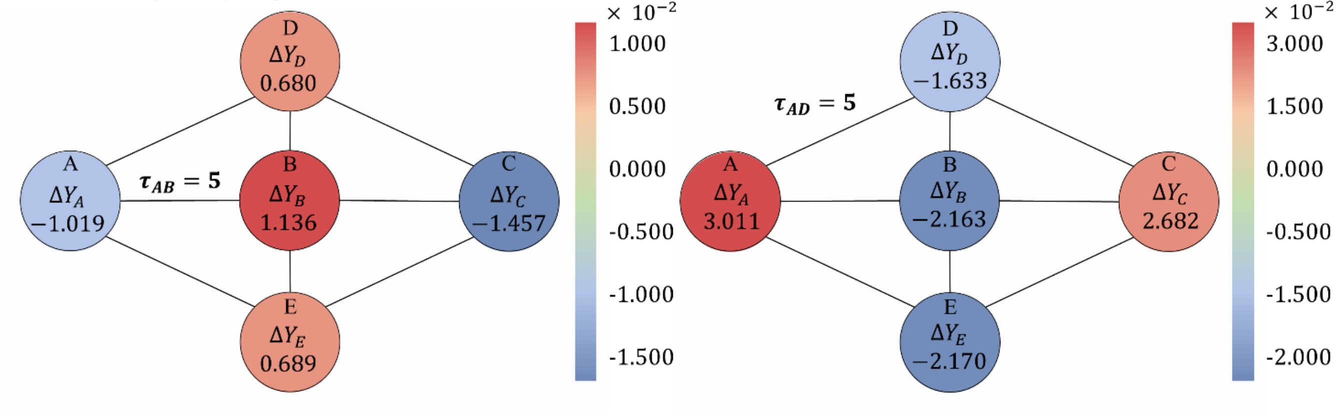
$$E[Y_i(1) - Y_i(0) | i \in N_T] = \frac{\sum_{i \in N_T} \Delta Y_i}{N_T} - \frac{\sum_{i \in N_U} \Delta Y_i}{N_U}. \qquad (C.1)$$

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.

Figure C1. The General-Equilibrium Effects of Public Transportation Investment

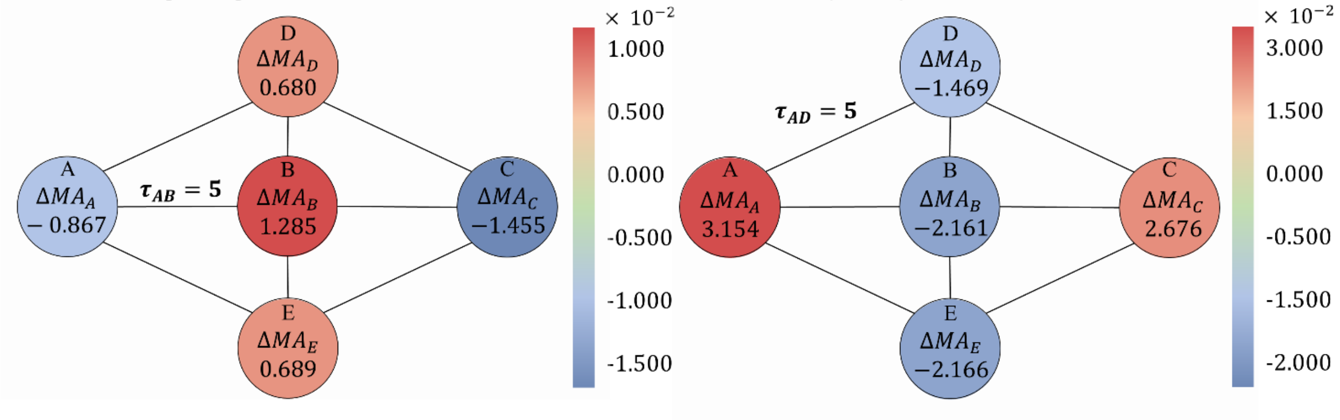
A. Log Change Population: Construction Route A-B

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 changes in logged values of population. Panel A is for the case where trade costs decrease between cities A and B, whereas panel B is for the case where trade costs decrease between cities A and D. Panels C and D show the changes in logged values of MA. Panel C is for the case where trade costs decrease between cities A and B, whereas panel D is for the case where trade costs decrease between cities A and D.

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 equation (C.1) is that there are winners and losers in both the treated and the comparison groups, as seen in Figure C1. In Panel A, city B (“treated”), and cities D and E (“untreated”) experience gains in population, whereas city A (“treated”) and city C (“untreated”) lose. Similar comments apply to Panel B. The problem here is that there seems to be no systematic way 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 transportation infrastructure. In Panel C, the 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:

$$E\left[\frac{\partial Y}{\partial MA}\right] = \frac{\sum_{i\in N} \Delta Y_i}{\sum_{i\in N} \Delta MA_i}. \tag{C.2}$$

We estimate this gradient typically by regressing the change in the outcome of interest against the change 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).

Borusyak and Hull (2023) clarifies that, unfortunately, *even if the assignment of transportation investments is random*, changes in MA may not be random. Figure C1 indeed demonstrates why this is the case. The changes in MA for *each city* depend not only on where the cost shocks occur but also on where each city is located in a given network. In other words, the same (random) cost shock can generate different the 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.

C.2. 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 $\{\tau^s\}_{s\in S}$. Second, we calculate a sample analogue of the expected value of MA (EMA) that follows from this sequence of random draws: $\mu_i \equiv E_s[MA_i|\tau^s] \approx \frac{1}{S}\sum_{s\in S} MA_i(\tau^s)$. Third, we create a recentered instrument by calculating the difference between the observed and the expected MA for each realized vector of τ: $RMA_i(\tau) \equiv MA_i(\tau) - \mu_i$.

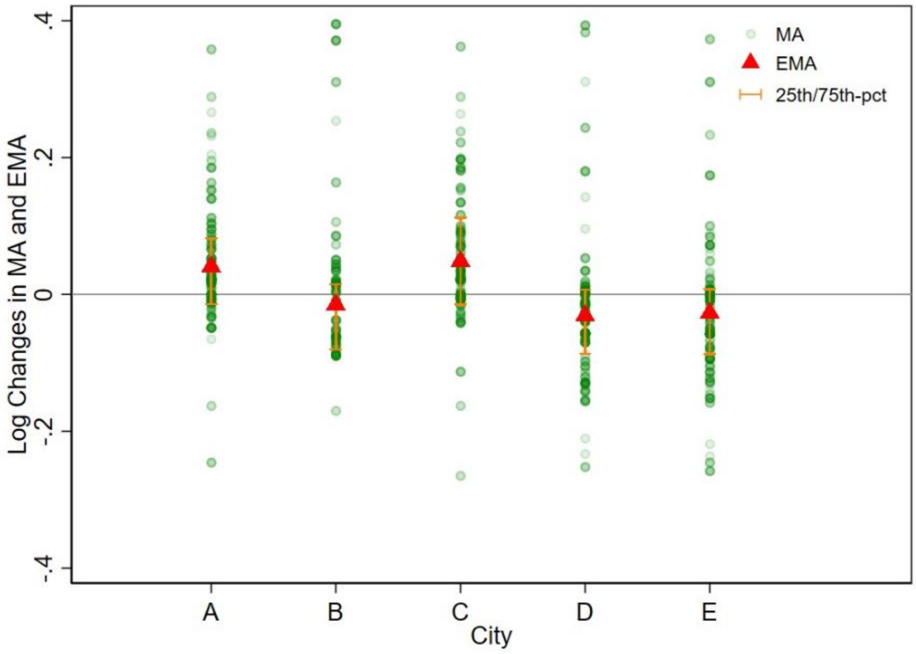
By construction, this recentered MA change must be correlated with the observed change in MA (relevance) and must be orthogonal to any non-random components that are related to the change in MA (exogeneity). Simply put, the approach essentially purges out the "pure shock", which originates from the "as-good-as-random" assignment of public transportation investments, from the observed change in MA 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 C2 illustrates the intuition for why and how this method works. Using the same stylized transportation network in Figure C1, we take 300 random draws of transport costs τ^s. To operationalize the randomization, we assume each draw represents a reduction in the transport cost on a single connected route, or a 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 C2 plots the results of this exercise. For each city, the realized MA change is represented by dots, and the expected change in MA by triangles. All values are logged changes relative to the status quo. The figure demonstrates that each city has a unique distribution of the realized MA change, and the distributions are not centered around zero, despite taking randomized draws of transport costs. Cities A and C tend to receive positive MA growth 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 they are 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 is crucial for ensuring valid identification in our empirical analysis. 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, eliminating this structural dependency.

Figure C2. 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 C1. For each city, the circles represent the realized MA change and the triangles denote the expected MA change in logs.

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

We calculate the MA variable with several values of trade elasticity and use them to estimate the first stage in 2SLS, as we alter the trade-elasticity parameters to check the validity of our main specification, as detailed later in Appendix E.2. This stage is crucial because it tests the validity of our instrumental variable, the recentered market access (RMA) growth.

Table D1 presents the results of the first-stage estimation in the 2SLS regression. The main result in Column (1) shows a statistically significant and positive impact on the change in the MA variable, with a coefficient of 1.12. This result implies a strong relationship between changes in the MA variable and RMA growth. Figure 4 confirms this result: the RMA growth and the change in the MA variable increase more where highways were built during the study period and, conversely, decrease more where no highways existed. The result in Table D1 shows that the variation in the RMA growth, along with socio- and natural-geographic factors can capture about 73% of the variation in the changes in the MA variable, as measured by the R^2. This result suggests that the theoretical relationship between RMA and MA discussed in Appendix B is empirically supported and satisfies the "relevance condition" for our instrumental variable.

We further validate these results by altering the trade elasticity parameter θ in Columns (2) to (5). These different specifications consistently reveal a strong positive relationship between the instrumental variable and the change in the MA variable. This consistency reinforces the robustness of our first-stage estimation and the reliability of the RMA growth as an instrumental variable in our 2SLS framework.

Table D1. 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	1.12 ***	1.44 ***	0.99 ***	1.01 ***	1.17 ***
	(0.08)	(0.16)	(0.11)	(0.10)	(0.07)
R-squared	0.73	0.44	0.61	0.71	0.74
Observations	614	614	614	614	614

Notes: All regressions use the same set of controls as in Table 3: average land steepness, average elevation, percentage of building areas, percentage of water areas, percentage of wetlands, percentage of elderly, percentage of manufacturing employees, manufacturing output and the taxable income per capita. Columns (2) to (5) show the estimates by altering the trade elasticity parameter θ to calculate $\Delta \ln MA$ and ΔRMA. Asterisks represent 1%, 5%, 10% significance levels. In parentheses are the cluster robust standard errors clustered at the city level.

Appendix E.
Alternative Specifications

This appendix presents the results of alternative specifications to check the validity of our main specification as follows: (a) altering our outcome period to 1980-1990, 1985-1995, 1990-2000, and 2000-2010, (b) using alternative values of trade elasticity, (c) interacting the MA variable with dummies representing various sources of heterogeneity, and (d) fixing the population size of each city at the pre-treatment level instead of the lagged population size when calculating MA in equation (2).

E.1. Altering the Outcome Periods

In this section, we estimate the economic impacts of transportation projects using a different outcome period from our main specification, as it is not empirically clear when the economic impacts of transportation infrastructure investments emerge. Our main specification in equation (3) relies on the assumption of a 10-year lag between the changes in the MA variable and the outcome, whereas several previous studies assume no time lag between treatment and outcome (e.g., Donaldson and Hornbeck, 2016; Jedwab and Storeygard, 2021; Borusyak and Hull, 2023).

Table E1 presents the estimation results: the first column for each economic outcome shows the results of OLS estimation, the second column displays those of EMA-OLS estimation, and the third column presents those of RMA-IV estimation. We report the estimation results for altering outcome periods: 1980-1990 in Panel A, 1985-1995 in Panel B, 1990-2000 in Panel C, and 2000-2010 in Panel D.

Panel A, while not strictly applicable, serves as a placebo test that can be conducted within the available data. This test indicates that changes in the MA variable from 1985 to 1995 do not have statistically significant impacts on economic outcomes during 1980 to 1990. This confirms that our treatment not only has no retrospective effect but also has no announcement effect. Interestingly, the EMA variable has a statistically significant positive effect on population and employment, suggesting that inherent geographical advantages positively affect economic growth regardless of the time period.

Panel B represents a similar approach to many previous studies, with no time lag between treatment and outcome (e.g., Donaldson and Hornbeck, 2016; Jedwab and Storeygard, 2021; Borusyak and Hull, 2023), and Panel C shows a specification taking a 5-year time lag between the changes in the MA variable and the outcome. The OLS estimate on manufacturing output is negative but statistically insignificant. In contrast, the EMA-OLS and RMA-IV estimates on manufacturing output are negative and statistically significant. These findings suggest that earlier outcome periods would only pick out the spurious correlation: trade-cost reductions occurred in cities with low economic growth. The OLS estimates on population and employment are positive and statistically significant, while the EMA-OLS and RMA-IV estimates on these outcomes are statistically insignificant. As discussed in Section IV-A, for population and employment outcomes, the EMA coefficient is positive and significant, implying that these are respond to the intrinsic expectation of the MA growth, but the transport megaprojects had no or limited effect.

The results in Panel D are robust to our main specification. The OLS estimates are 0.241, 0.030, and 0.032, respectively, for manufacturing output, population, and employment, and are statistically significant at the conventional levels. The RMA estimates are robust to the use of EMA or RMA only on manufacturing output: 0.308 (EMA-OLS) and 0.288 (RMA-IV), and statistically significant. For population and employment, the RMA estimates become smaller than the OLS estimates. As the Japanese government has pointed out, positive effects of transportation network construction may arise later in Japan. These results suggest that, as mentioned in Section IV-A, focusing on a period with a sufficient time lag from construction timing is appropriate for estimating and assessing the economic impacts of transportation construction. Note, however, that the estimates in Panel D may capture additional effects due to the large time lag from the treatment period.

Table E1. The Estimation Results for Altering the Outcome Period

	Manufacturing Output			Population			Employment		
	OLS	EMA-OLS	RMA-IV	OLS	EMA-OLS	RMA-IV	OLS	EMA-OLS	RMA-IV
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel A: 1980-1990									
⊿ ln MA	0.073	-0.046	-0.009	0.017	-0.013	-0.004	0.013	-0.029	-0.016
	(0.065)	(0.091)	(0.074)	(0.011)	(0.016)	(0.012)	(0.016)	(0.023)	(0.018)
⊿ EMA		0.332			0.084 **			0.119 **	
		(0.203)			(0.038)			(0.049)	
R-squared	0.072	0.077	0.070	0.476	0.480	0.474	0.571	0.576	0.569
Panel B: 1985-1995									
⊿ ln MA	-0.071	-0.218 **	-0.173 **	0.025 *	-0.011	0.001	0.028 *	-0.039 *	-0.019
	(0.057)	(0.087)	(0.074)	(0.013)	(0.020)	(0.015)	(0.016)	(0.024)	(0.018)
⊿ EMA		0.411 **			0.102 **			0.188 ***	
		(0.198)			(0.040)			(0.054)	
R-squared	0.077	0.084	0.074	0.421	0.428	0.418	0.509	0.521	0.504
Panel C: 1990-2000									
⊿ ln MA	-0.035	-0.219 ***	-0.162 **	0.035 ***	0.004	0.013	0.039 ***	-0.026	-0.006
	(0.052)	(0.077)	(0.068)	(0.012)	(0.017)	(0.014)	(0.014)	(0.021)	(0.016)
⊿ EMA		0.514 ***			0.088 **			0.183 ***	
		(0.195)			(0.036)			(0.052)	
R-squared	0.069	0.081	0.065	0.434	0.440	0.431	0.467	0.482	0.462
Panel D: 2000-2010									
⊿ ln MA	0.241 ***	0.308 ***	0.288 ***	0.030 ***	0.013	0.018 *	0.032 **	0.007	0.015
	(0.078)	(0.098)	(0.090)	(0.009)	(0.012)	(0.009)	(0.013)	(0.019)	(0.015)
⊿ EMA		-0.189			0.046 *			0.071 *	
		(0.183)			(0.026)			(0.041)	
R-squared	0.062	0.063	0.061	0.530	0.532	0.529	0.456	0.460	0.455
First-Stage F-Stat.			209			209			209
Observations	614	614	614	614	614	614	614	614	614

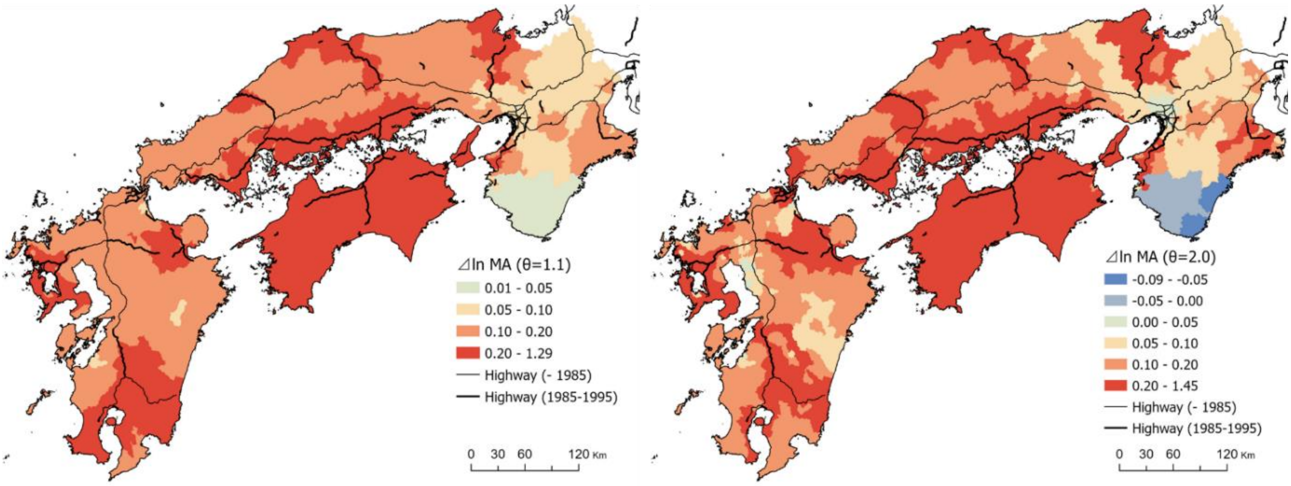
Notes: Asterisks represent 1%, 5%, 10% significance levels. In parentheses are the cluster robust standard errors clustered at the city level. All regressions use the same set of controls as in Table 3: average land steepness, average elevation, percentage of building areas, percentage of water areas, percentage of wetlands, percentage of elderly, percentage of manufacturing employees, manufacturing output and the taxable income per capita. The first column for each economic outcome shows the results of OLS regression, the second column shows those of OLS regression with ΔEMA, and the third column shows those of 2SLS with ΔRMA as the instrumental variable. Each panel represents a different period for outcomes: Panel A for 1980-1990, Panel B for 1985-1995, Panel C for 1990-2000, and Panel D for 2000-2010.

E.2. Alternative Trade Elasticities

Trade elasticity is an important parameter that balances the size of the market and transport costs in equations (1) and (B.11). If the balance is incorrect, it may not properly reflect the general equilibrium effect, which depends on the size of the market, resulting from lower transport costs. Unfortunately, however, we assume the trade-elasticity parameter $\theta = 4$, following Simonovska and Waugh (2014) since we do not estimate trade elasticity. Therefore, we calculate and estimate the MA variable with several values of trade elasticity in this section.

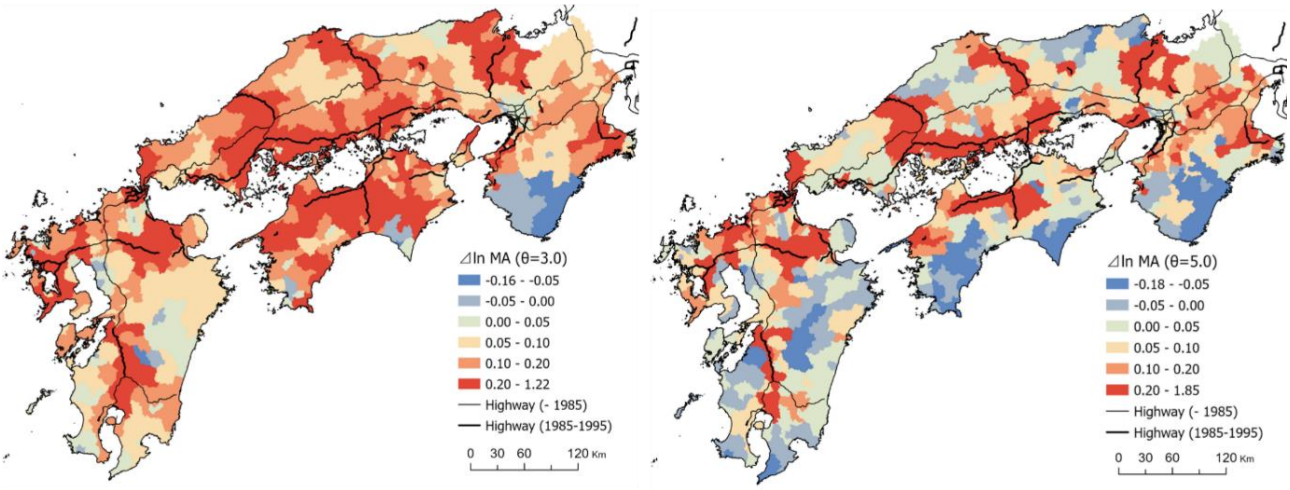
Before analyzing, we present the geographic distribution and its change over time when we vary the trade elasticity. Figure E1 shows the geographic distribution of the changes in logged values of MA using trade elasticities $\theta \in [1.1, 2.0, 3.0, 5.0]$. The red legend represents a large positive logarithmic change in the MA variable, whereas the blue legend indicates a large negative change. As θ decreases, the MA responds too sharply to the changes in transport costs. Panels A and B in Figure E1 are similar to the geographic distribution of transport cost reductions shown in Figure 2. This suggests that a smaller trade elasticity ($\theta < 3.0$) may not adequately reflect shifts in the size of the economy or capture the full extent of the general equilibrium effect. On the other hand, when $\theta \in [3,5]$, the geographic distribution closely resembles that shown in Figure 4-A.

Figure E1. The Geographic Distribution of the MA Variables by Each Trade Elasticity



A. Trade Elasticity $\theta = 1.1$

B. Trade Elasticity $\theta = 2.0$



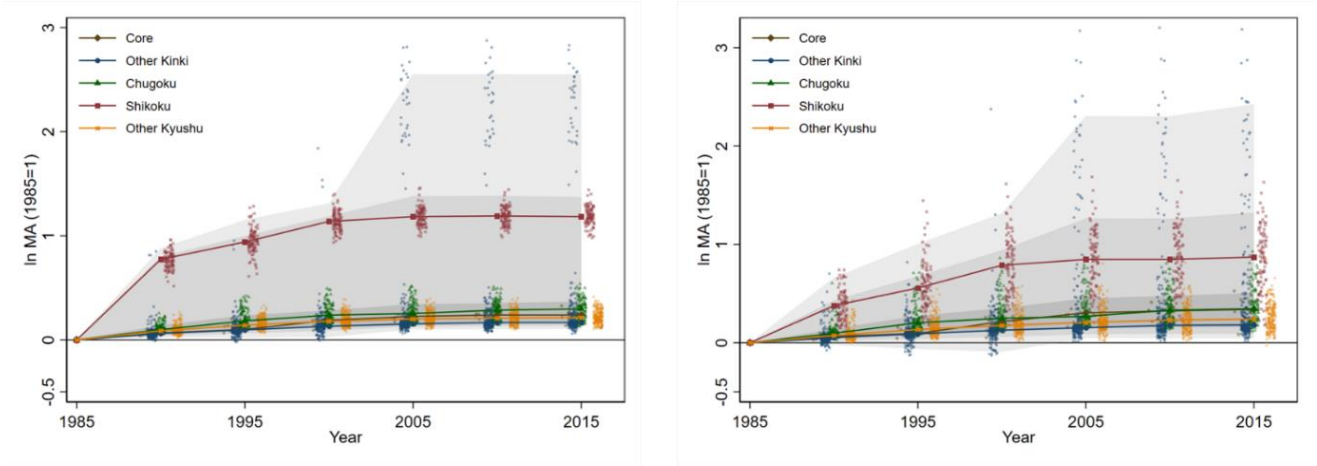
C. Trade Elasticity $\theta = 3.0$

D. Trade Elasticity $\theta = 5.0$

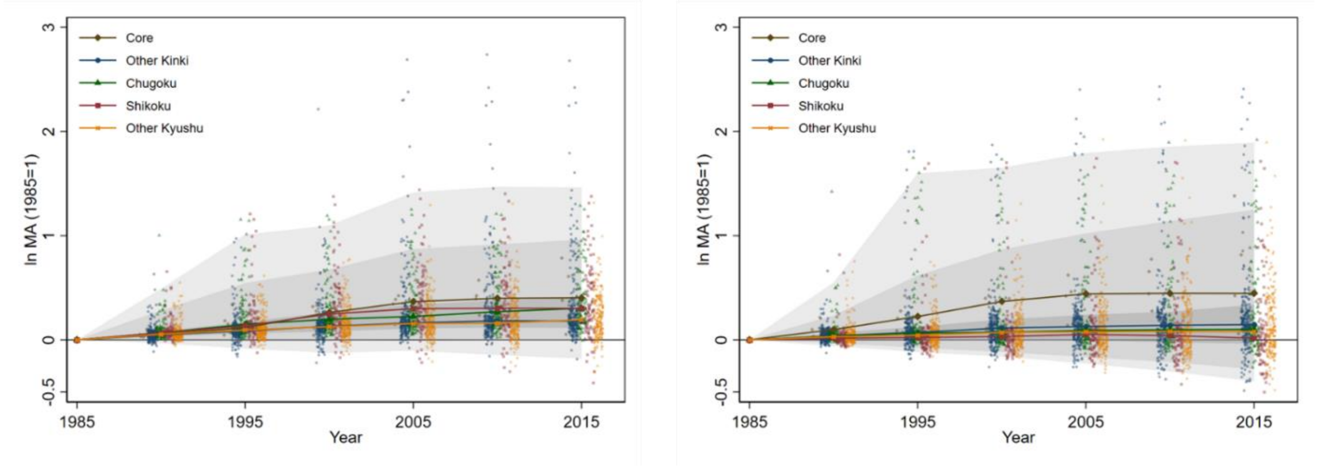
Notes: These figures show the changes in logged values of MA from 1985-1995. Panel A shows the case $\theta = 1.1$, Panel B shows $\theta = 2.0$, Panel C shows $\theta = 3.0$, and Panel D shows $\theta = 5.0$. As in Figure 1, the thin black lines represent highways built before 1985, and the thick black lines represent highways built between 1985 and 1995.

Figure E2 illustrates the changes in MA (in log) relative to the values in 1985 as a result of the reduction in transport costs. The gray shaded areas, from lightest to darkest, represent the 1st to 99th, 5th to 95th, and 25th to 75th percentiles of all observations, respectively. Each line represents the median for each region. Dots represent the raw values for cities. These figures indicate that the MA variable increases faster in the Shikoku region with lower trade elasticity ($\theta < 3.0$), reflecting the change in transport cost reductions within Shikoku. The figures also show that when the elasticity is small, a rapid change in MA occurs in two stages: 1985-1990 and 2000-2005. The sharp increase in the MA variable over 2000-2005 clearly reflects the decline in transport costs in 2005 shown in Figure 3-A, rather than the decline in transport costs due to the opening of the Central Seto Bridge. This graphical result, as well as Figure E1, supports the finding that when we use smaller trade elasticities ($\theta < 3$), the MA responds too sharply to the changes in transport costs, with magnitudes that are hard to justify.

Figure E2. 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 shows the changes in MA (in log) relative to the values in 1985, in a manner analogous to Figure 3-B. 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 $\theta = 5.0$.

Table E2 presents the impacts of changes in the MA variable with each trade elasticity on economic outcomes. As in Table E1, the first column of each economic outcome shows the results of OLS estimation, the second column shows those of EMA-OLS estimation, and the third column shows those of RMA-IV estimation. Each panel corresponds to a different trade elasticity: $\theta = 1.1$ in Panel A, $\theta = 2.0$ in Panel B, $\theta = 3.0$ in Panel C, and $\theta = 5.0$ in Panel D.

Panel A shows that the results for $\theta = 1.1$ are not statistically significant, except for population. This effect on population may only pick out spurious correlations. This is because the variation of the MA variable is similar to the transport cost variations, making small-size and low-growth cities in the Shikoku region, which would normally be the untreated group, become the treated group. The fact that the EMA growth, which should be positive, is estimated to be statistically significant and negative supports this argument. Panel B shows that both EMA-OLS and RMA-IV estimates are marginally significant rather than statistically significant. Given the geographic variation in Panel B, it indicates that we may not correctly estimate the causal effects between the MA variable and economic growth.

The results in Panels C and D are robust to our main specification. In Panel C, the OLS estimates are 0.262 and 0.035, respectively, for manufacturing output and population, and are statistically significant at the 1% significance level. The RMA estimates are robust to the use of EMA or RMA only on manufacturing output: 0.278 (EMA-OLS) and 0.278 (RMA-IV) and statistically significant. In Panel D, the OLS estimates are 0.142, 0.028, and 0.033, respectively, for manufacturing output, population, and employment, and are statistically significant at the conventional levels. The RMA estimates are 0.133 and 0.016, respectively, for manufacturing output and population, and are statistically significant at the 5% significance level.

Table E2. The Estimation Results for Altering Trade Elasticity

	Manuf. Output			Population			Employment		
	OLS	EMA-OLS	RMA-IV	OLS	EMA-OLS	RMA-IV	OLS	EMA-OLS	RMA-IV
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel A: θ=1.1									
⊿lnMA	-0.040	-0.118	-0.087	0.028 ***	0.066 ***	0.051 ***	0.002	-0.019	-0.011
	(0.074)	(0.190)	(0.121)	(0.008)	(0.020)	(0.014)	(0.013)	(0.035)	(0.024)
⊿EMA		0.102			-0.050 **			0.028	
		(0.254)			(0.022)			(0.040)	
First-Stage F-stat.			85			85			85
R-squared	0.073	0.073	0.072	0.463	0.466	0.458	0.389	0.389	0.388
Panel B: θ=2.0									
⊿lnMA	0.088	0.206 *	0.209 *	0.033 ***	0.027 *	0.027 *	-0.005	-0.011	-0.011
	(0.089)	(0.110)	(0.113)	(0.012)	(0.016)	(0.015)	(0.019)	(0.024)	(0.024)
⊿EMA		-0.256			0.013			0.013	
		(0.164)			(0.022)			(0.029)	
First-Stage F-stat.			79			79			79
R-squared	0.073	0.076	0.071	0.461	0.461	0.461	0.389	0.389	0.389
Panel C: θ=3.0									
⊿lnMA	0.262 ***	0.278 ***	0.278 ***	0.035 ***	0.021	0.021	0.021	-0.011	-0.010
	(0.084)	(0.097)	(0.096)	(0.012)	(0.015)	(0.013)	(0.019)	(0.024)	(0.022)
⊿EMA		-0.050			0.045			0.101 *	
		(0.217)			(0.034)			(0.052)	
First-Stage F-stat.			96			96			96
R-squared	0.082	0.082	0.082	0.461	0.463	0.460	0.390	0.394	0.388
Panel D: θ=5.0									
⊿lnMA	0.142 **	0.127	0.133 **	0.028 ***	0.009	0.016 **	0.033 ***	-0.008	0.008
	(0.057)	(0.082)	(0.062)	(0.008)	(0.011)	(0.008)	(0.012)	(0.018)	(0.013)
⊿EMA		0.041			0.051 **			0.111 ***	
		(0.209)			(0.023)			(0.042)	
First-Stage F-stat.			259			259			259
R-squared	0.079	0.079	0.079	0.464	0.467	0.462	0.394	0.403	0.391
Observations	614	614	614	614	614	614	614	614	614

Notes: Asterisks represent 1%, 5%, 10% significance levels. In parentheses are the cluster robust standard errors clustered at the city level. All regressions use the same set of controls as in Table 3: average land steepness, average elevation, percentage of building areas, percentage of water areas, percentage of wetlands, percentage of elderly, percentage of manufacturing employees, manufacturing output and the taxable income per capita. Each column is the same as in Table E1. Each panel represents different trade elasticities: Panel A with $\theta = 1.1$, Panel B with $\theta = 2.0$, Panel C with $\theta = 3.0$, and Panel D with $\theta = 5.0$.

E.3. Heterogeneity

Our main specification is valid when the elasticity is homogeneous or if heterogeneity is uncorrelated with MA changes because it estimates the average elasticity of a city's economic size with respect to the market access. Yet, omitting the true MA variable defined in equation (B.11), as in equation (1), may create unobserved heterogeneity in economic impacts that may be correlated with the changes in MA. To address this concern, we estimate a version of equation (3) allowing for the heterogeneous effects of MA:

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

where $\mathbb{I}[\cdot]$ is an indicator, which equals one if city i belongs to a group G_r and zero otherwise. We classify cities into three groups (heterogeneity dummies) using the following three alternatives: the tertiles of change in transport cost from 1985 to 1995, population size as of 1980 and MA level as of 1985. Unfortunately, we have only a single instrumental variable; hence, we instead use the EMA as a control, which has already been shown to be helpful in addressing endogeneity.

Table E3 presents the estimation results based on the above equation. Columns 1 to 3 show the results of interaction terms with changes in transport costs from 1985 to 1995, Columns 4 to 6 show those of interaction terms with population size as of 1980, and Columns 7 to 9 show those of interaction terms with the level of the MA variable as of 1985. The first column of these three interaction terms represents the effect on manufacturing output, the second column indicates the effect on population, and the third column shows the effect on employment. All regressions use the same set of controls as in Table 3: average land steepness, average elevation, percentage of building areas, percentage of water areas, percentage of wetlands, percentage of elderly, percentage of manufacturing employees, manufacturing output and the taxable income per capita, and the EMA variable.

For all results, the p-value of the joint hypotheses test exceeds 0.05, which means that we fail to reject the null hypothesis of no interaction effects on economic outcomes. This does not necessarily imply that heterogeneous effects are omitted, even if we use the MA variable based on equation (1). The results for population and employment show, as in our main estimation, that they are relatively more affected by the intrinsic expectation of the MA growth rather than by the transport-cost-induced changes in the MA variable.

For the interaction terms with changes in transport costs, the estimate on manufacturing output is a statistically significant 0.204% increase in the lowest tertile, where transport costs decrease the most, while a marginally significant 0.351% increase in the highest tertile. For the interaction terms with the population size as of 1980, the estimate on manufacturing output is a statistically significant 0.195% increase in the highest tertile, while a marginally significant 0.293% increase in the second tertile. For the interaction terms with the level of the MA variable as of 1985, the estimates on manufacturing output are statistically insignificant. The results for the first two interaction terms suggest that statistically significant larger manufacturing output growth occurs where economic growth is expected. However, the magnitude of the coefficients does not follow the order of the tertiles, suggesting that this outcome may grow under complex general equilibrium effects.

For the interaction terms with changes in transport costs, the effects on population and employment are statistically insignificant, but the economic impacts are unexpectedly smaller as the reduction in transport costs is larger. This supports our main estimations that these economic outcomes do not respond to lower transport costs through the megaprojects. For the interaction terms with the population size as of 1980, the effects on these outcomes are statistically insignificant. However, for the interaction terms with the level of the MA variable as of 1985, the estimate on population is a statistically significant 0.157% increase in the highest tertile, while the estimate on employment is a marginally significant 0.146% increase in the second tertile. In contrast to manufacturing output, these two economic outcomes mostly follow the order of the tertiles. These results suggest that cities that enjoy economic abundance prior to the transportation investment tend to gain more from an increase in the MA variable.

Table E3: The Estimation Results with Interaction Term

Interaction Terms	Log Change in Transport Cost			Population as of 1980			Market Access as of 1985		
	Manuf. Output (1)	Population (2)	Employment (3)	Manuf. Output (4)	Population (5)	Employment (6)	Manuf. Output (7)	Population (8)	Employment (9)
Tertile									
1st	0.204 **	-0.001	-0.017	0.020	0.008	-0.044	0.124	0.005	-0.037
	(0.093)	(0.013)	(0.022)	(0.198)	(0.026)	(0.040)	(0.133)	(0.014)	(0.026)
2nd	-0.013	0.040	-0.006	0.293 *	0.015	0.016	0.167	0.024	0.012
	(0.299)	(0.039)	(0.050)	(0.158)	(0.022)	(0.035)	(0.101)	(0.015)	(0.024)
3rd	0.351 *	0.007	0.010	0.195 **	0.018	0.004	-0.102	0.157 **	0.146 *
	(0.193)	(0.031)	(0.047)	(0.094)	(0.015)	(0.023)	(0.351)	(0.070)	(0.080)
⊿EMA	0.001	0.057 *	0.124 **	0.034	0.055 *	0.136 ***	0.108	0.048 *	0.138 ***
	(0.221)	(0.030)	(0.050)	(0.233)	(0.029)	(0.050)	(0.241)	(0.026)	(0.048)
Joint Test	0.055	0.774	0.862	0.114	0.638	0.630	0.325	0.089	0.061
R-squared	0.084	0.474	0.402	0.084	0.468	0.411	0.094	0.490	0.450
Observations	614	614	614	614	614	614	614	614	614

Notes: Asterisks represent 1%, 5%, 10% significance levels. In parentheses are the cluster robust standard errors clustered at the city level. This table shows the results of the interaction term with changes in transport costs from 1985 to 1995, population size as of 1980, and level of market access as of 1985. All regressions use EMA growth and the same set of controls as in Table 3: average land steepness, average elevation, percentage of building areas, percentage of water areas, percentage of wetlands, percentage of elderly, percentage of manufacturing employees, manufacturing output and the taxable income per capita. For each interaction term, the first column presents manufacturing output, the second column reports population, and the third column shows employment.

E.4. Fixed Market Size in MA

There are several ways to address endogeneity arising from the market size that constitutes the MA variable. Our main strategy is to use a lagged market size against transport costs (e.g., Donaldson and Hornbeck, 2016). Other prior studies take the strategy of fixing the market size at the pre-transportation project level with respect to changes in transport costs (e.g., Borusyak and Hull, 2023; Jedwab and Storeygard, 2022). In this section, we construct the MA variable by using the population as of 1980, before the project, as the market size.

Table E4 shows results in a manner analogous to Table 3. Most estimates in Table E4 closely resemble those in Table 3, ensuring that the results are robust to our main specification. Transport megaprojects during the period 1985-1995 have statistically significant and positive impacts on manufacturing output in all specifications, and on population in OLS estimates and RMA-IV estimates. The RMA-IV estimates show that transport megaprojects lead to an increase in manufacturing output by 2.01% and population by 0.21% over the period 1995-2005, using the fact that the MA variable with a fixed market size increased by 10.4% during 1985-1995. However, we note an important difference between Table E4 and Table 3: the magnitudes of the EMA-OLS and RMA-IV estimates are almost the same as those of the OLS estimates. In contrast to previous studies, the EMA estimates in Column 2 for each economic outcome are not statistically significant, and their magnitude is small.

Table E4. The Estimation Results for Utilizing Market Access with Fixed the Market Size

	OLS (1)	EMA-OLS (2)	RMA-IV (3)
Panel A: Manuf. Output			
⊿ ln MA	0.173 **	0.203 **	0.193 ***
	(0.068)	(0.091)	(0.074)
⊿ EMA		-0.088	
		(0.244)	
R-squared	0.079	0.079	0.079
Panel B: Population			
⊿ ln MA	0.021 **	0.019	0.020 **
	(0.009)	(0.012)	(0.010)
⊿ EMA		0.006	
		(0.024)	
R-squared	0.459	0.459	0.459
Panel C: Employment			
⊿ ln MA	0.006	0.004	0.005
	(0.015)	(0.019)	(0.016)
⊿ EMA		0.008	
		(0.043)	
R-squared	0.389	0.389	0.389
First-Stage F-Stat.			202
Observations	614	614	614

Notes: Asterisks represent 1%, 5%, 10% significance levels. In parentheses are the cluster robust standard errors clustered at the city level. All regressions use the same set of controls as in Table 3.: average land steepness, average elevation, percentage of building areas, percentage of water areas, percentage of wetlands, percentage of elderly, percentage of manufacturing employees, manufacturing output and the taxable income per capita.

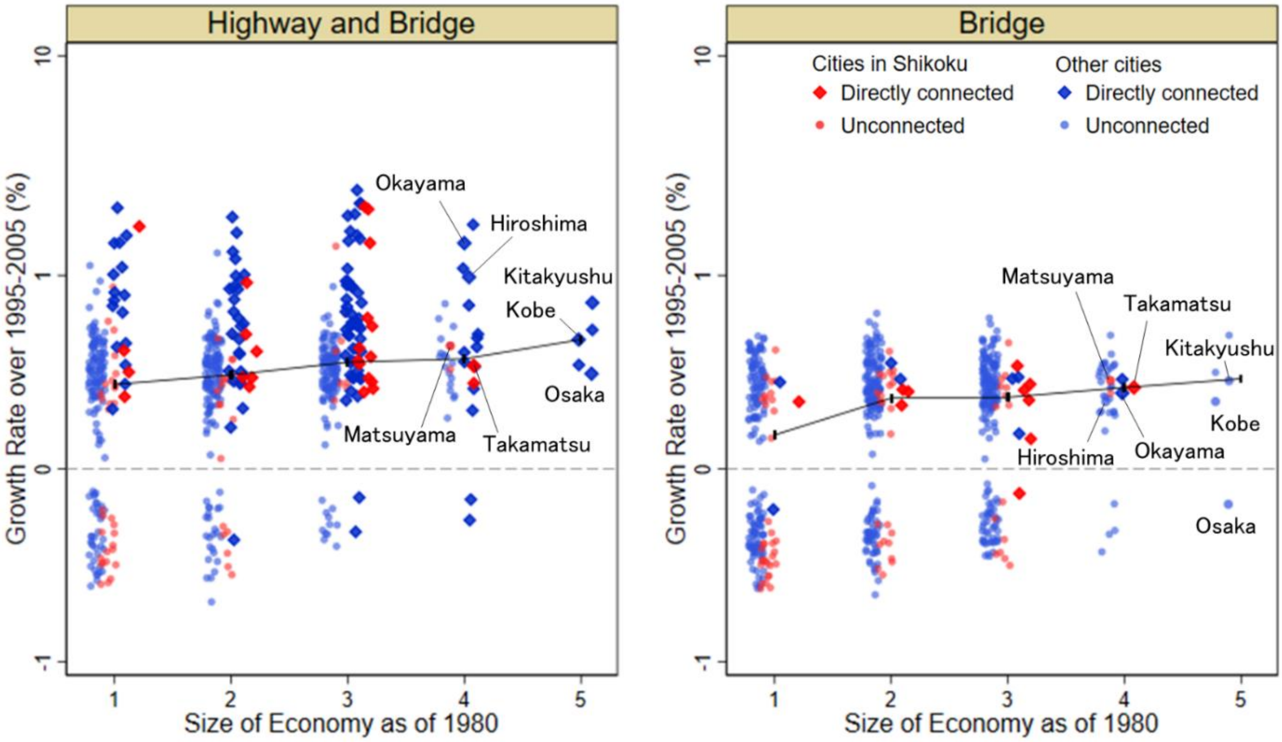
Appendix F.
Economic Impacts of the Transport Megaproject on Population and Employment

This appendix provides the evaluation of the economic impacts on population and employment of two scenarios: (a) the Central Seto Bridge and other highways and (b) the Central Seto Bridge, against the counterfactual with no such investment, as described in Section V-A. Figure F1 shows the economic impacts of transport megaprojects on population, and Figure F2 shows those on employment. The left side of each figure plots economic impacts of the Central Seto Bridge and other highways on the growth rates over the period 1995-2005 against the 1980 population size. In the same manner, the right side of each figure plots the impacts of the Central Seto Bridge only. In the figures, the cities directly connected by the transport projects are marked as diamonds while the cities not directly connected are indicated as dots. The cities in Shikoku are marked in red and those in other regions are in blue.

Figure F1 shows that cities gain population by 0.26% (Panel A) and 0.06% (Panel B) relative to no transport investment, on average. At the median, the largest cities (the fifth category) gain population by 0.32% (Panel A) and 0.11% (Panel B), whereas the smallest cities (the first category) gain population by 0.09% and 0.006%, respectively. Figure F2 shows that cities gain employment by 0.04% (Panel A) and 0.01% (Panel B) relative to no transport investment, on average. At the median, the largest cities (the fifth category) gain employment by 0.06% (Panel A) and 0.02% (Panel B) whereas the smallest cities (the first category) gain employment by 0.02% and 0.001%, respectively.

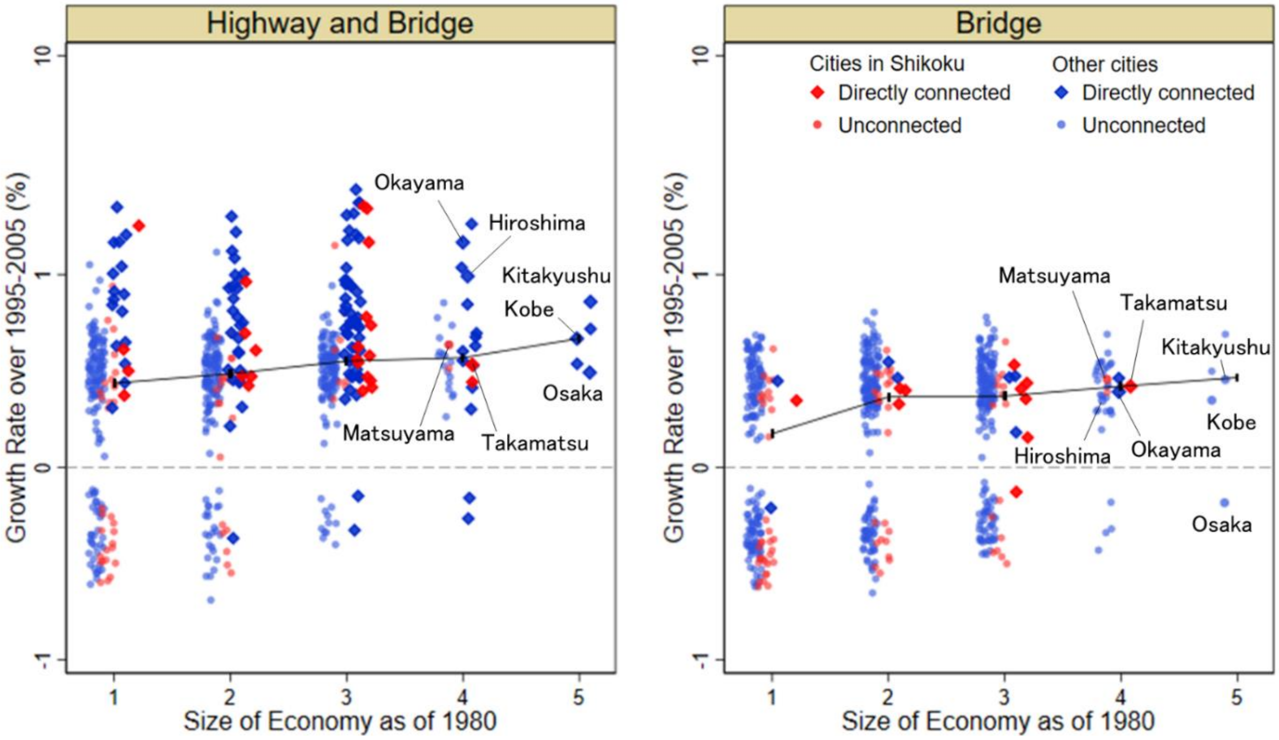
These results show essentially the same pattern as the results presented in Section V-A: (1) a majority of cities gain economic benefits from the transport megaproject, regardless of their initial economic abundance, (2) there is a sign of agglomeration economies, (3) there is substantial heterogeneity in these economic impacts across cities within each category, with some cities losing substantially from the megaproject, (4) the Straw effect phenomenon did not materialize, at least not in the form originally claimed by the critics, and (5) the magnitudes of the estimated impacts are smaller in Panel B than in Panel A, implying that the pure effect of the Central Seto Bridge is relatively small and much of the effect of the projects comes from the combined effect of the other highways and the Bridge.

Figure F1. Economic Impacts of the Transport Megaproject on Population across Cities of Different Population Sizes



Notes: The size of economy on the horizontal axis is based on the population size as of 1980, following the same classification as in Table 2. As in Figure 5, In the figures, the cities directly connected by the transport projects are marked as diamonds while the cities not directly connected are indicated as dots. The cities in Shikoku are marked in red and those in other regions are in blue. The black lines indicate the median for each category.

Figure F2. Economic Impacts of the Transport Megaproject on Employment across Cities of Different Population Sizes



Notes: The size of economy on the horizontal axis is based on the population size as of 1980, following the same classification as in Table 2. As in Figure 5, In the figures, the cities directly connected by the transport projects are marked as diamonds while the cities not directly connected are indicated as dots. The cities in Shikoku are marked in red and those in other regions are in blue. The black lines indicate the median for each category.

Appendix G.

Geographical Distribution of Net Benefit, Cost Burden, and Total Benefit

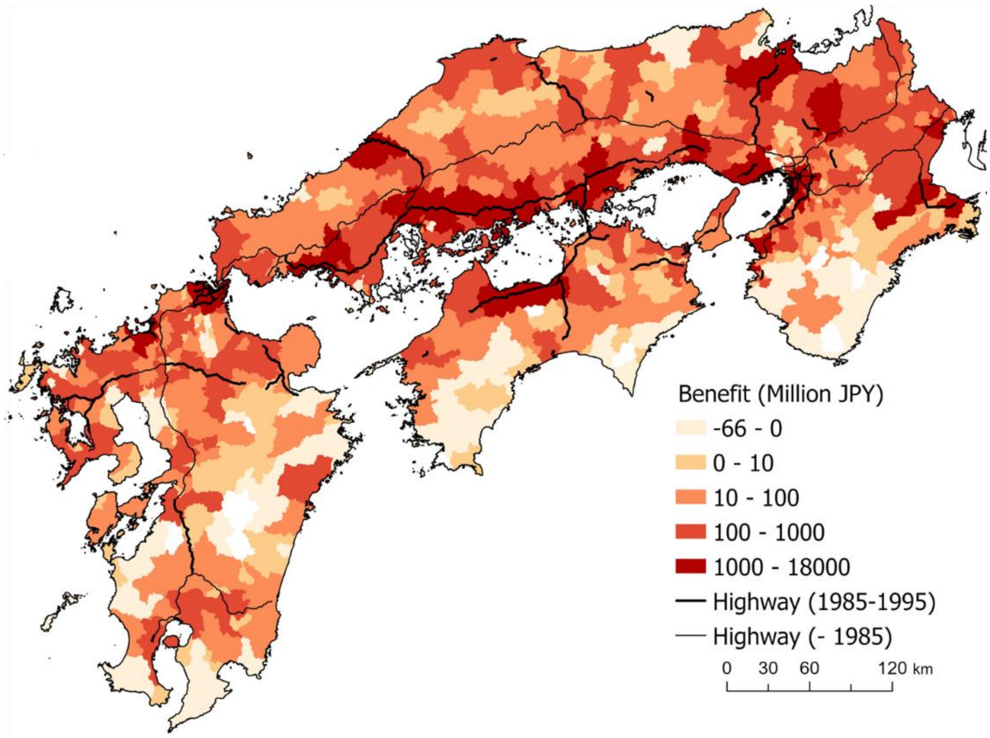
This appendix presents the geographic distributions of economic benefits estimated in Section V-A, construction cost burden, and the net benefits per capita estimated in Section V-B. Figure G1 shows the geographical distribution of the Central Seto Bridge and other highways, while Figure G2 shows that of the Central Seto Bridge only. In both figures, Panel A shows city-level economic benefits per year estimated from the IV estimates of manufacturing output in Table 3, Panel B shows city-level cost burden per year estimated from the publicly available information on construction costs, and Panel C shows the net benefits per capita per year estimated by equation (10a).

Figure G1 shows that cities newly connected by highways during 1985-1995 tend to have higher economic benefits and net benefits. Both economic and net benefits are particularly high in the inland sea coastal areas of the Chugoku and Shikoku regions. In large peripheral cities such as Okayama and Hiroshima, the economic benefits are even higher, and the benefits are commensurate with the heavy cost burden. In cities without highways (e.g., southern Shikoku and southern Kinki regions), the economic benefits tend to be negative, and consequently, the net benefits are also negative.

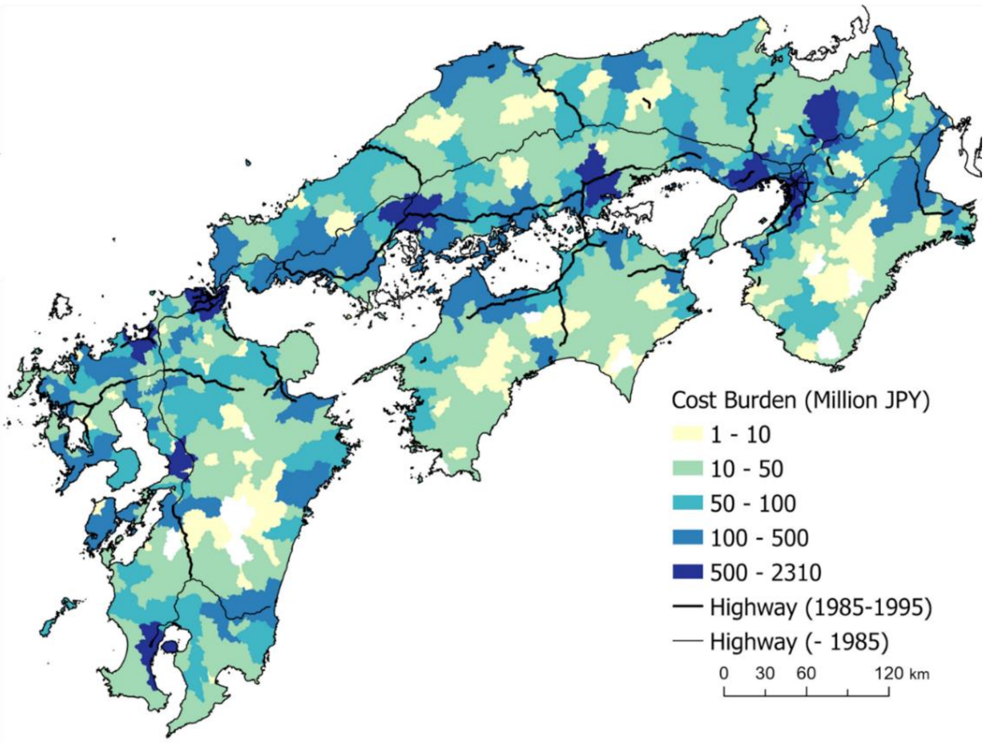
Panel A of Figure G2 shows that larger economic benefits are enjoyed in cities located in Okayama and Kagawa prefectures, which are directly connected by the Central Seto Bridge, and cities that were connected by highways as of 1985. This indicates that a local investment, such as connecting two points in Okayama and Kagawa prefectures, generates economic benefits across western Japan. This figure also shows negative economic gains in cities located in the northern Kinki, the southwestern Shikoku, the eastern Kyushu, and parts of the inland sea coast regions, while Figure G1 shows positive economic benefits for these cities. This implies that the effect of the Bridge is smaller than that of the other highways and the Bridge. Panel C of Figure G2 shows that the cities in the inland sea coast areas of Okayama and Kagawa prefectures and in the eastern Kinki region enjoy larger net benefits. In addition, many cities where highways existed before 1985 gain positive net benefits. Although the *pure* economic effect in Figure G2 is smaller than the *combined* effects shown in Figure G1, the city-level net benefit loss is reduced because the cost burden is much lower. Thus, these geographical distributions support the importance of accounting for the complex general-equilibrium effects in evaluating public transportation projects.

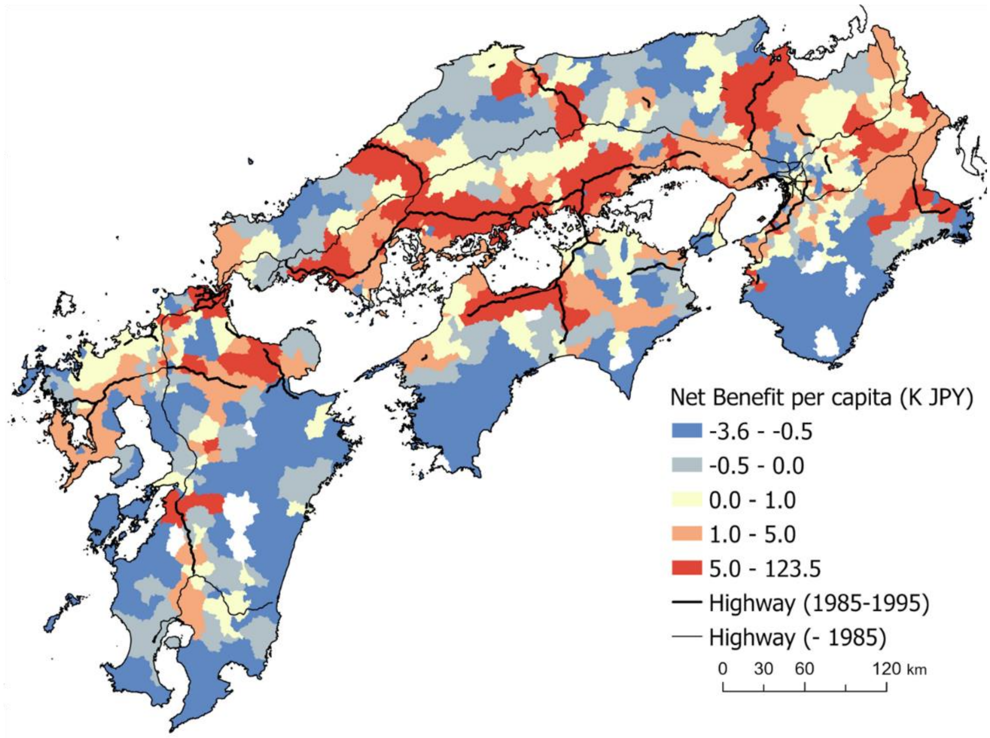
Figure G1. Geographical Distribution of Net Benefit, Cost Burden, and Total Benefit from the Central Seto Bridge and Highway

A. Economic Benefit



B. Cost Burden



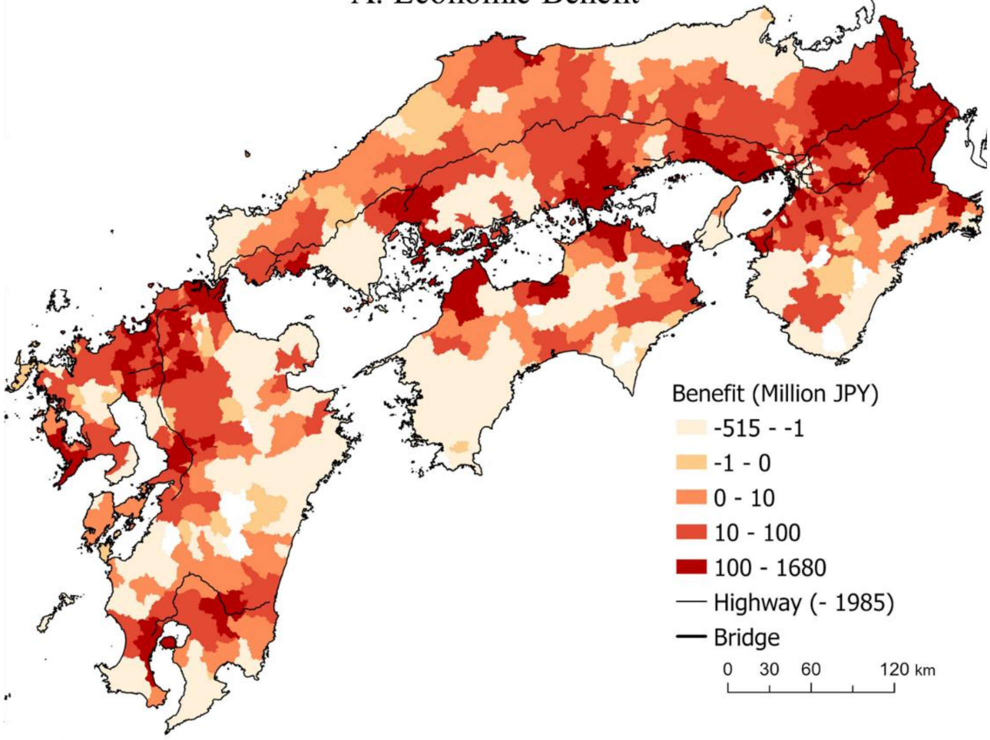


C. Net Benefit

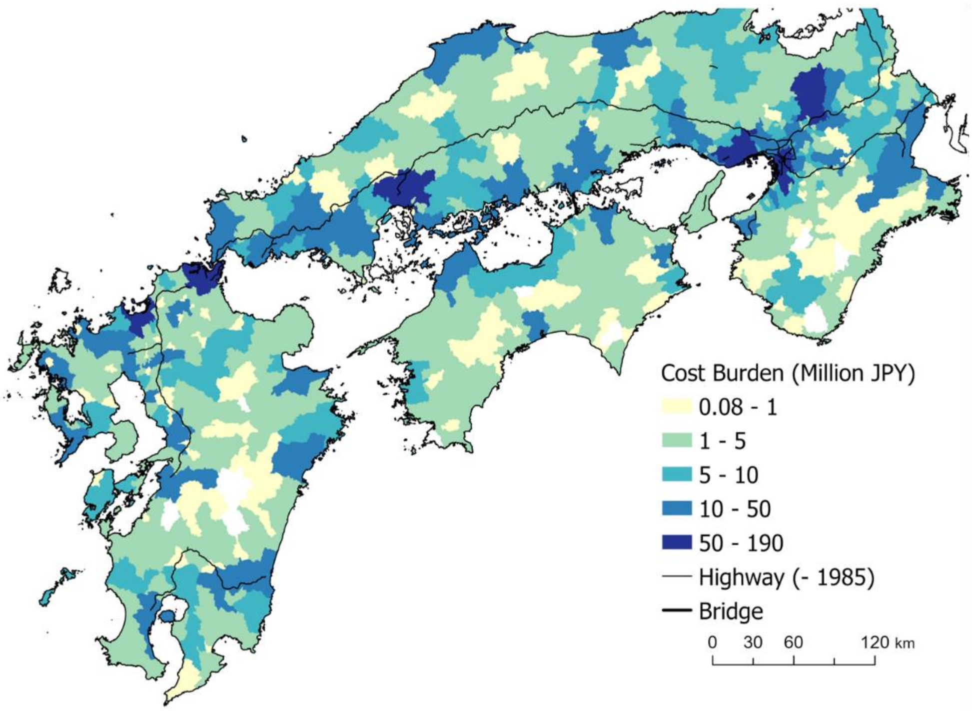
Notes: Panel A shows that the city-level economic benefit from manufacturing output per year, Panel B shows the city-level cost burden per year, and Panel C shows the net benefit per capita per year. Each panel shows values in units of JPY as of 1988. As in Figure 1, the thin black lines represent highways built before 1985, and the thick black lines represent highways built between 1985 and 1995.

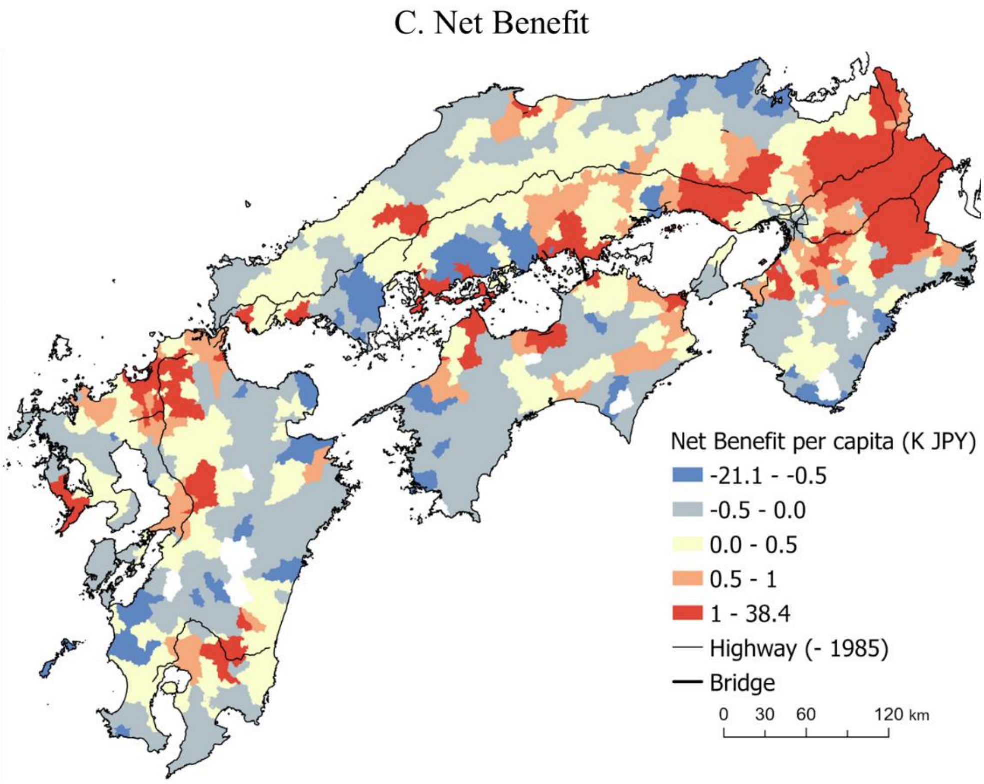
Figure G2. Geographical Distribution of Net Benefit, Cost Burden, and Total Benefit from the Central Seto Bridge

A. Economic Benefit



B. Cost Burden





C. Net Benefit

Notes: Panel A shows that the city-level economic benefit from manufacturing output per year, Panel B shows the city-level cost burden per year, and Panel C shows the net benefit per capita per year. Each panel shows values in units of JPY as of 1988. As in Figure 1, the thin black lines represent highways built before 1985, but the thick black line represents the Central Seto Bridge.