Strategic Transportation Investment and Coordinative Policies: Evidence From the U.S. Highway Network

Yuyang Jiang*

Click here for the latest version.
October 23, 2025

Abstract

Transportation networks are often constructed by multiple jurisdictions. When each decision-maker fails to internalize the full surplus generated by their investment, the resulting network can be inefficient. How large are the resulting inefficiencies, and to what extent can coordinative policies improve outcomes? This paper builds a framework to evaluate the welfare implications of non-cooperative transportation investments and the efficacy of subsidies as a coordinative policy. In this framework, regional governments choose investments in their portion of the network to maximize constituents' utility, taking as given investments set by other regions and subsidy rates set by a central government. Applying the model on the U.S. highways, the observed network is underinvested by 15% relative to the national optimum and has incurred a welfare loss equivalent to 30% of the current level of investment. Across space, underinvestment patterns reflect a terms-of-trade externality, a fiscal externality, and spillovers of logistics technology due to through traffic. Finally, counterfactual exercises indicate that raising federal subsidy rates can improve efficiency, but excessively generous subsidies may backfire.

*Princeton University. Contact: `yuyangj@princeton.edu`. I am grateful to my advisors Eduardo Morales and Stephen Redding for their support and guidance. I am indebted to Treb Allen, Gene Grossman, Robert Staiger and John Sturm Becko for many insightful discussions. I thank participants at Princeton Trade Workshop, Dartmouth Globalization Internal Workshop, CEP-LSE-Warwick Junior Trade Workshop, and NBER Transportation Networks meeting for their excellent comments. I owe particular thanks to my discussants, Sara Bagagli and Gabriel Kreindler, for constructive feedback. This research benefited from financial support from the International Economics Section at Princeton University. Part of this research was carried as a Globalization Ph.D. Fellow at Dartmouth College. All errors are my own.

1 Introduction

Transportation infrastructure investment constitutes one of the largest categories of public expenditure across countries. A salient feature of transportation infrastructure is its far-reaching spatial spillovers: highway investments in one jurisdiction benefit not only local users, but also travelers and businesses from elsewhere; moreover, transportation infrastructure redistributes economic activities across locations, creating winners and losers as a consequence of investments.

In contrast to the widespread economic impact, infrastructure planning and construction are often delegated to governments of smaller jurisdictions. The U.S. Federal-aid Highway Program is a case in point. State governments plan the routes, fund highways with state tax revenues, and get a fixed share of the cost reimbursed from the federal government.[1] As state governments represent the interests of their constituents, they do not fully account for the welfare impact of highways on the rest of the nation when making their investment decisions. Absent proper policies to correct incentives, decentralized investment as such will result in inefficiencies in the road network.

Given the tension between substantial spatial spillovers and decentralized policy institutions, this paper investigates the welfare implications of decentralized highway investment and federal highway subsidies in the U.S. Theoretically, it sheds light on the economic mechanisms that give rise to inefficiencies in the lack of cooperation between states. In addition to the classical free-rider problem that would arise from many transportation networks, I show that a terms-of-trade externality and a fiscal externality, arising from differentiated goods trade and population mobility, are also key drivers of inefficiencies in a decentralized network. Taking the theory to the data, the paper quantifies the welfare costs of these inefficiencies in the U.S. highway system by comparing the status quo to two alternative scenarios. First, the optimal network, as would be chosen by a federal government. Second, the network that would be chosen by state planners under alternative rates of the uniform federal subsidy. Through the lens of the model, the optimal network would deliver an increase in welfare equivalent to 30% of current highway spending at the cost of a 19% increase in infrastructure investment. Further increasing the federal subsidy rate could improve the welfare by narrowing the gap to the efficient aggregate investment level, but overly generous subsidies may backfire by imposing excessive fiscal burdens on the rest of the nation while leaving spatial misallocation of investment unresolved.

[1] Tolls play a relatively minor role in U.S. highway financing. Even today, the share of toll revenue in total receipt of U.S. highway budget is only 10%.

The paper starts with suggestive evidence of inefficiencies in the decentralized U.S. highway network. These facts show that crossing state borders increases the cost of highway travels. In particular, conditional on geographic factors and traffic volume, it is slower and takes longer detours to travel across cities belonging to different states, compared to trips between city pairs that belong to the same state. This translates to a higher cost in fuel, wages and time to deliver if the trip passes through state borders. Roads are also more rugged when they are close to state borders, suggestive of relatively lower maintenance efforts for infrastructure near state borders.

The paper continues by developing a general spatial model with policy competition in Nash strategies to describe the distortions in decentralized highway investment. In the model, locations produce differentiated goods that can be traded through the highway network; workers choose their place of residence and workplace based on real wages, local amenities, tax rates and commuting costs. Transportation costs of goods and people are endogenously determined by state governments who invest in highways with state fiscal revenue in a non-cooperative Nash equilibrium. In maximizing her constituents' utility, a state planner faces a trade-off between better infrastructure and lower tax rates, both of which affect migration decisions between states. Federal highway subsidies, administered as a reimbursement of road construction cost by a fixed percentage, influence a state's incentive to invest by providing a discount on the effective cost paid from the state's budget. These subsidies are funded by a uniform federal taxes on all states.

I highlight three types of strategic inefficiencies. The first originates from the terms-of-trade effects. By improving infrastructure, a state lowers the cost of importing from a neighbor. Consequently, local consumers benefit from lower logistics costs, but the higher demand bids up the price for the neighbor's output; for the neighbor, this corresponds to a "terms-of-trade appreciation". From the investor's perspective, the appreciation of the neighbor's product raises the price of imported goods and discourages his investment on the importing facility. Likewise, a reduction in the costs of exporting induces an appreciation of terms-of-trade for the investor, depreciating the neighbor's output. If the reduction of costs in both directions are symmetric, terms-of-trade adjustment ultimately favors the market with a smaller size. A social planner, however, sees only a redistribution of income across locations from terms-of-trade adjustments, with zero aggregate effects absent heterogeneity in marginal utility. This tension leads to insufficient investment on highways facilitating imports for the local investor, as they fail to internalize the positive terms-of-trade externality incurred to exporters.[2]

[2]The direction of distortion on exporting infrastructure depends on the net effect from both the terms-of-trade externality and a logistics technology spillover. Exporting infrastructure generates a negative

A second distortion comes from the network nature of highways. Many highways serve transshipment between locations that do not pay tax dollars into the local budget. While such roads cut costs for outsiders, those gains are not internalized. Due to such spillovers in logistics technology, state investments in the Nash equilibrium are insufficient relative to the total trade cost savings, particularly along corridors with large shares of through traffic.

Third, endogenous local fiscal budgets creates fiscal externalities. This becomes relevant for transportation across regions with active cross-border migration. Locally financed infrastructure affects real wages, prices, and taxes, thereby influencing migration. If a project attracts taxpayers, states that lost those taxpayers must raise taxes on those who remain. From a national perspective, the expansion of tax base to the investor's jurisdiction is partially offset by tax revenues lost elsewhere. This wedge between local and national returns induces overinvestment whenever the local government gains taxpayers from rest of the country from the marginal investment.

Finally, commuting introduces additional sources of inefficiency. Like freight transshipment, highways often serve workers who reside outside the investing state, generating benefits that are not captured in its fiscal base. Beyond this parallel, commuting also interacts with agglomeration and congestion: state planners may seek to discourage residents, so as to improve local amenity, by improving access to other high-amenity areas; they may also attract workers by facilitating commuting from low-productivity areas. Depending on the spatial distribution of productivity and amenities, these incentives may amplify or counteract the externalities from trade.[3]

In observance of these inefficiencies, the network chosen by non-cooperative state planners will be inefficient absent any coordination mechanism, both insufficient in total scale and misallocated due to varying magnitude of externalities across highway segments. How do distortions vary across space? Could alternative federal subsidy policies better align the state governments' incentives with national welfare? The paper proceeds to quantitatively answer these two questions by parameterizing the general model and solving for the network under different policy scenarios. The parameterized model retains the tractability for different channels of externalities, as the first-order effect of any marginal investments on equilibrium prices, wages, population and tax rates can be

terms-of-trade externality for destination markets and motivates overinvestment. It also benefits consumers in the destination market by lowering the logistics costs of their imported goods, a positive spillover that leads to underinvestment.

[3]The incentive to repel residents due to amenity congestion partially off-sets the incentive to attract taxpayers so that each constituent pays less tax. Absent amenity congestion, state planners still find investments towards locations with relatively low productivity palatable, as reducing commuting cost between them attracts more workers to the investor's jurisdiction.

analytically derived from equilibrium conditions.

States may engage in negotiations with one another and the federal government may intervene and demand cooperation between states, which we don't directly observe.[4] To account for these interactions in quantifying the welfare changes, I back out the parameters governing the degree to which states' decisions internalized their impact on other states by their revealed preference. Specifically, I model a state planner's decisions as if he were maximizing an objective function that assigns non-zero weight to the welfare of other states' constituents, and find the altruistic weight such that the observed investment maximizes the implied payoffs. The weight is therefore a reduced-form measure of the effect from negotiations, cooperation and central government interventions. This follows the spirit of Adão et al. (2024): instead of modeling specific institutions, which are difficult to observe in this context, this measure captures how effectively institutional constraints lead governments to internalize the effects of their policies to other jurisdictions. By exploiting the revealed preference, the preference parameter can be estimated without recomputing the game, which is computationally costly. Model estimates indicate that states valued the welfare generated in other states at 0.56 times the value within their own jurisdiction, suggesting a relatively high degree of cooperation.

With the estimated parameters, I first quantify the extent of underinvestment on each highway link by computing the nationally optimal network and compare it with the observed one. Computing the optimal network under endogenous fiscal constraints involves solving the economic equilibrium with goods trade, commuting, endogenous population distribution and tax rates, as well as solving the optimality conditions governing the investments that determine trade and commuting costs; both of them involve hundreds of dimensions. To overcome this challenge, I leverage the computation strategy in Su and Judd (2012) by simultaneously solving for prices and investments, treating equilibrium conditions as constraints to the optimization problem. Depending on the specification, this strategy computes the optimal network with 129 nodes and 502 investment decisions in a time span ranging from several minutes to under an hour.

Given that state planners placed a relatively high Pareto weight on the rest of the economy, imperfect coordination has reduced national welfare by an amount equivalent to 30% of the current highway spending, and the highway network is underinvested by

[4] In practice, during the planning procedure of Interstate Highway System, state highway departments exchanged ideas through a non-public organization named American Association of State Highway Officials, which mainly facilitates route alignment at state borders (Barrow, 1967). Similarly, when designating the U.S. Numbered Highway System, states held regional group meetings to discuss the routes to be included; Bureau of Public Roads sent representatives to these meetings Federal Highway Administration (2017).

roughly 15% relative to the socially optimal level. Zooming into the spatial incidence of underinvestment, I found such patterns correlated with indicators for the aforementioned three types of externalities. In particular, I found that links are more severely underinvested if they serve large shares of external traffic, connect the investor towards a relatively small market, or originate from a fiscally vulnerable state.

Next, I quantify the welfare implications of alternative highway subsidy policies in the Northeast Census Region by recomputing the Nash equilibrium under different subsidy rates. This exercise shows that while moderate raises in highway subsidies can improve efficiency, excessively generous subsidies can backfire. Compared to the status quo with a calibrated 34.5% subsidy, an equilibrium with 70% subsidy can improve the welfare level by an amount equivalent to 25% of current regional highway spending compared to the observed equilibrium, with a 25% increase in infrastructure spending. The gains from elevated subsidies stem from overcoming the overall underinvestment in the current network, but is relatively modest compared to the efficient benchmark, as the optimal network would bring an improvement in welfare equivalent to 105% of current regional highway spending. However, further increasing the subsidy rate could do harm. In an equilibrium with 90% subsidy, welfare level drops relative to the equilibrium with 70% subsidy, despite a further increase in infrastructure spending. At this subsidy level, the passive increase in federal tax rate, as required by incremental subsidy spending, outweighs the positive externalities from infrastructure improvement, resulting in a net loss to the economy.

While the quantification in the paper is tailored to the U.S. highways system, the framework for analyzing efficiency and regional policy in infrastructure networks is applicable to other countries and regions, and to other types of transportation or trade facilitation infrastructure. It is well suited to contexts where governments that cooperate imperfectly make decentralized investment decisions which jointly determine the network used for both trade and commuting, or contexts in which regions develop trade facilities while competing for taxpayers.[5]

Contribution to Literature

This paper contributes to several strands of literature. The first studies the effect of transportation infrastructure on local economic performance and general equilibrium outcomes. From reduced-form evidence to quantitative studies, the literature has found strong effects on growth and spatial distribution of population and economic activities

[5]A prominent example could be the Trans-European Transport Network (TEN-T), where countries construct their portions of the network while co-financing some projects with a common EU fund.

from construction of inter-regional highways and railroads (Baum-Snow (2007), Michaels (2008), Duranton and Turner (2012), Duranton et al. (2014), Faber (2014), Duranton (2015), Baum-Snow et al. (2020), Weiwu (2024); Donaldson and Hornbeck (2016), Nagy (2023), Hornbeck and Rotemberg (2024); see Redding and Turner (2015) for a review. Studies with multiple transportation modes include Baum-Snow et al. (2017), Egger et al. (2023), Ma and Tang (2024), Bonadio (2024) and many others). To identify the causal effect of infrastructure construction, the literature usually leverages exogenous factors that drive the actual location of transportation infrastructure, such as planned, historical or minimum-cost layout of highway network. My study takes an attempt to explain why highways ended up where they are by modeling the political economy of highway construction and strategic interaction between state governments. In particular, it models the formation of highways as a result of Nash game between state governments who represent the welfare of their constituents, mirroring an important institutional feature in transportation policy that prevails in many nations and regions of the world.

To capture the welfare effect of investments in the network, this paper builds on the literature of quantitative spatial models (e.g., Redding and Sturm (2008), Allen and Arkolakis (2014), Redding (2016), Monte et al. (2018), Allen et al. (2020), Tsivanidis (2023), Allen et al. (2024); see Redding and Rossi-Hansberg (2017) for a review). Allen and Arkolakis (2022) developed a model with endogenous transportation cost that tractably captures the welfare effects of marginal infrastructure investment for a given link in an interconnected highway network. This study incorporates endogenous transportation costs into a spatial general equilibrium model with trade and commuting à la Monte et al. (2018), and solves the problem of network optimization for both a single-planner environment and the case with a Nash game between multiple state planners.

The second strand of related literature develops tools to characterize optimal investment in transportation network. A recent economic literature started tackling the optimal transportation network problem in a general equilibrium model with either trade or commuting, where demand for transportation is endogenous to the network (Fajgelbaum and Schaal (2020), Kreindler et al. (2023), Bordeu (2023)). In my study, the optimal transportation network takes account of benefits in both trade and commuting, reflecting a salient feature of highway usage in the United States. It also addresses new computational challenges arising from endogenous construction budget, which creates an interaction between local tax rates and population distribution through workers' migration decisions.

On a related topic, a burgeoning literature studies the inefficiencies under decentralized investment in transportation infrastructure, including commuting roads (Bordeu

(2023), Loumeau (2023)), trade infrastructure (Felbermayr and Tarasov, 2022) and sea ports (Brancaccio et al., 2024). Other studies examined the origins of suboptimal transportation investment in settings with a centralized planner, including political preferences (Fajgelbaum et al., 2023) and path dependence (Santamaria, 2021). Different from previous applications, the U.S. highway system is used heavily for both trade and commuting; my framework offers an understanding of the distortions in non-cooperative investment from both functions and their interactions. In addition, existing discussions on decentralized investment assume completely non-cooperative local decisions. I depart from this assumption by allowing for partial cooperation between authorities and estimating the relevant parameters from the revealed preferences of local planners. Lastly, my framework also allows for the evaluation of central government interventions in local governments' strategic interactions by explicitly modeling local planners' responses to central subsidies.

Several studies have examined the use of transportation policies to address such inefficiencies in a decentralized equilibrium. Policies in these studies are used to address the externalities that atomistic agents create for the aggregate environment – for instance, through congestion externalities or environmental externalities. To the best of the author's knowledge, existing quantitative work has focused on applications in urban commuting networks (Almagro et al. (2024), Hierons (2024)). On the theoretical side, Fajgelbaum and Schaal (2020) characterized the decentralization of the social planner's optimal network with taxes and tolls in the market of competitive shippers and monopolistic construction firms. My study departs from existing works in two aspects. First, the market failure comes from non-atomistic local governments who do not fully account for the welfare effect of their road construction on neighbors' constituents. Second, due to the differentiation in production, the terms-of-trade externality adds to the inefficiencies, a new mechanism to be quantified for alternative policies relative to the existing findings on infrastructure without trade.

Last but not least, this paper contributes to the discussion on implications of non-cooperative government policies. This include discussions on non-cooperative tariffs (Bagwell and Staiger (1999), Ossa (2011), Ossa (2018)), tax competition and subsidy competition in the presence of population mobility (Kanbur and Keen (1993), Oates (1999), Greenstone et al. (2010), Keen and Konrad (2013), Muñoz (2023), Ferrari and Ossa (2023)). From the studies on optimal tariffs and the economics of the WTO, it is well-understood that the terms-of-trade externality gives rise to inefficient outcomes in non-cooperative tariff policies, and that reciprocal negotiations that leave terms of trade unchanged can deliver the efficient outcome. My paper reveals an analogy between better trade infrastructure and lower tariffs, and explains how the terms-of-trade externality accounts for inefficiencies from non-cooperative transportation investment despite in a very different policy realm.[6] I also show that, since local governments face infrastructure budgets endogenous to the size of population, competition for tax revenues incurs a fiscal externality in unilateral optimal taxes and investments: as taxpayers relocate to jurisdictions with high-paying jobs and lower costs of living, locations losing their tax base must raise taxes on remaining residents to maintain infrastructure spending, a welfare effect neglected by local planners who only represent the interest of their constituents.

2 Institutional Background

Highways are the arteries of the U.S. economy. They carry 78% of domestic freight and more than 70% of commuting journeys. Every year in the twenty-first century, the country invests around 1% GDP in highway construction and maintenance.

In this section, I briefly introduce the institutional background in the planning and financing procedure of U.S. highways. This material highlights three important features of the U.S. Federal-aid Highway system: (1) highway planning decisions are decentralized to the states, (2) state and federal taxes are the primary funding source for highway construction, and (3) federal subsidies are implemented in a space-blind procedure.

State Authority in Highway Planning

Most of the highway expenditures are disbursed by state agencies rather than federal agencies. While federal agencies receive about a third of total road-user tax revenue, they disperse less than 1% of total expenditure on construction and maintenance; the majority of federal receipts for highways are transferred to state agencies through the Highway Trust Fund. State agencies collect 64% of total road-user tax revenue, and disburse 70% of total construction and maintenance expenditure. The remainder of state highway receipts are spent by counties, townships and municipalities. [7] [8]

[6] On the government budget side, infrastructure investment differs from cutting tariffs in that it takes real resources away from consumption. In the presence of federal subsidies, the cost of infrastructure is shared among states, hence the amount of resources taken away from the investor state is lower than the social cost of investment.

[7] These numbers came from Table HF-2 and HF-10, Highway Statistics 1990.

[8] Among the total disbursements from State highway receipts applicable to highways, about 64 percent are spent on state-administered highways. Local roads, streets and grants-in-aid to local governments cost roughly 20 percent of the receipts, and miscellaneous expenditures (administration, highway law enforcement and safety, bond interest) pick up the rest. These statistics are summarized in Table SF-2; numbers computed from 1990 Highway Statistics.

States have considerable discretion in how they spend highway funds appropriated by the Federal government. According to United States Code, "The authorization of the appropriation of Federal funds or their availability for expenditure (on Federal-Aid Highways) shall in no way infringe on the sovereign rights of the States to determine which projects shall be federally financed." Even in the highway system with the highest federal share – 90% – for the cost, routes were selected by the state highway engineers. According to the Federal-Aid Highway Act of 1944, which authorized the designation of the Interstate Highway System (then called "a National System of Interstate Highways"), Interstate Highways shall be selected by "joint action of the State highway departments of each State and the adjoining States" (Federal-Aid Highway Act (1944)). This procedure was described in more detail by Barrow (1967), a policy study on the politics of Interstate route selection:[9]

> "...each of the state highway departments submitted to AASHO for review a list of proposed routes to be included in the Interstate System. After considerable interaction and exchange of views among the several states through their AASHO representatives, the proposals were submitted to the Bureau of Public Roads for final review and approval."

This reflects a persistent feature in the federal-aid highway policies: states control the initiative in selecting the system to be approved, and the federal government has the authority to approve or disapprove. The Secretary of Transportation has the authority to require modifications or revisions, but it was limited to cases where a project violates specific restrictions in law or requires use of certain protected land (Davis, 2022). In fact, it was reported that during the designation of urban Interstate Highway System, Bureau of Public Roads accepted practically every urban belt route proposed by the States (Federal Highway Administration (2023)).

Revenue Sources of State-Administered Highways

For each state's Department of Transportation, the primary revenue source deposited for state-administered highways is highway-user tax. These taxes include motor-fuel taxes, motor-vehicle registration fees and motor carrier taxes, and tax rates set by states differ across the US. Together, they contribute about 63 percent of total State highway revenues in 1950, when federal aid accounted for 15%. This share declines since the uptick in

[9]In the quoted text, American Association of State Highway Officials (AASHO) is a non-public organization comprised of highway officials from every state. According to Barrow (1967), the major role of the AASHO in Interstate Highway route selection was to assist in route alignment at state borders.

federal transfer starting from the 1956 Federal-Aid Highway Act. As of 1990, which was close to the completion of the Interstate Highway System, the share contributed by state highway taxes has dropped to 45% of total highway receipts, while the share from federal aid went up to 30%.[10]

The other major revenue source is issuance of bonds, which was comparable to federal aid in 1950 but only accounted for 7% of State-administered highway receipts in 1990. Tolls and appropriations from general funds, comparable in scale to one another, together comprise less than 10 percent of the total revenue even in 1990.

Federal Grants Revenue and Subsidy Allocation

The Federal Highway Administration receives highway excise taxes to fund highway spending and intergovernmental transfers. These include motor-fuel taxes, motor-vehicle use taxes, and taxes on tires, tubes, and accessories. They are all specific taxes, i.e. charged by a fixed amount per unit of quantity. Highway Trust Fund, which channels federal receipts to state highway agencies, receives all the revenues from the federal tax on gasoline, diesel and special fuels, which makes up 70-90 percent of Fund receipts depending on the year. The Fund also receives all revenue from the tax on tires, tubes and tread rubber; on new trucks, buses and trailers (except 1956-1962 when the Trust Fund receives half of these tax); and from the annual heavy vehicle use tax.

Before 1991, funds for Federal-Aid Highways were administered into two systems: The ABC System, consisting of the primary, secondary and urban highways, and the Interstate Highway System, as established by the Federal-Aid Highway Act of 1956. The ABC system received a 50% federal subsidy in earlier years and 80% later, and the Interstate Highway System consistently received 90% federal subsidy. After 1991, ABC system was replaced by National Highway System and the Surface Transportation Program, both of which provides 80% subsidy for projects in the system. Noticeably, the rate does not vary based on geographic characteristics conditional on the system classification.

3 Motivating Facts

In this section, I present a set of facts illustrating that highway infrastructure conditions in the U.S. tend to be worse on road linkages that cross state borders. I show that

[10] These numbers are reported in Highway Statistics, Table SF-3: Receipts for State-Administered Highways.

traveling between cities across state borders is slower, takes more detour, and roads become more rugged when they approach state borders. Later in the paper, the model rationalizes such negative correlation between border crossing and highway investments.

Data

MSA Boundaries And Commuting Flows

I obtain city boundaries from maps of March 2020 Metropolitan Statistical Areas (MSA) defined by the U.S. Office of Management and Budget.

A crosswalk between counties and MSAs for years 2013-2023 are obtained from Quarterly Census of Employment and Wages. For each MSA and MSA-pair, I obtain commuting flows by aggregating up county-pair flows from American Community Survey 2011-2015.

Optimal Routes Between Cities

To measure the infrastructure conditions between locations, I obtain optimal routes for trucks that connect the centroids of a pair of "adjacent" MSAs from HERE API. I define a pair of cities to be adjacent if the connection of their geographic centroids do not cross the territory of any other MSA, and at least one of the two is among the 20 nearest MSAs of the other. This restriction helps avoid spurious correlations between state borders and driving costs. Pairs that cross state borders are often also pairs that route through multiple cities. These multi-city routes tend to involve longer detours and potentially more congestion, due to interaction with local commuting flows. Under this criteria, I obtained 1173 non-repetitive pairs. Figure 1 plots all pairs identified as neighbors in the map. Each pair of red dots connected by blue lines are a pair of neighboring cities.

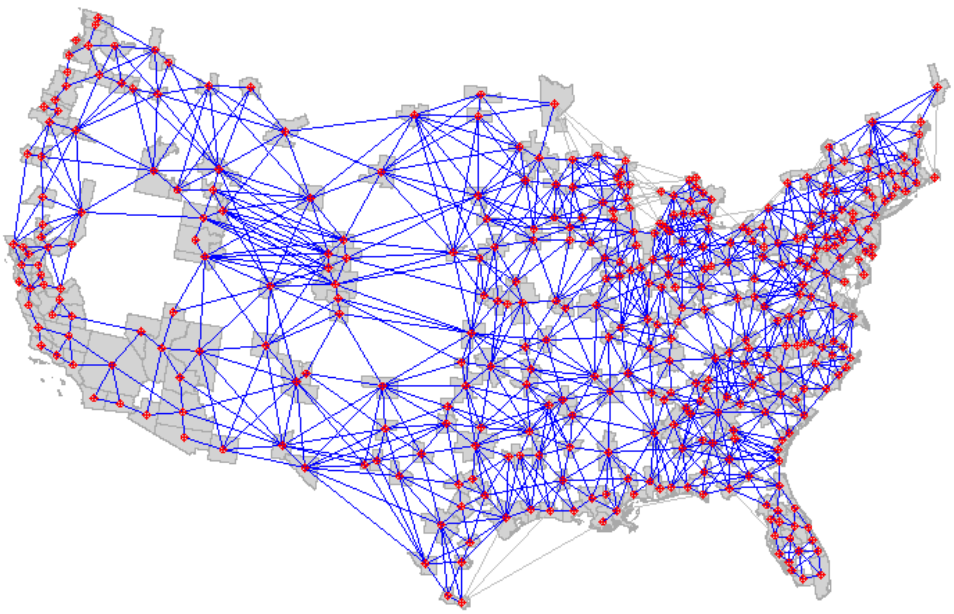


Figure 1: MSA Neighbors

Note: Each blue line connects the centroids of an MSA pair defined as adjacent under the criteria described in section 3. Grey lines connect pairs whose centroids connection do not cross a third MSA but does cross an ocean or a lake. I exclude those from neighboring pairs.

From the optimal truck routing results, I observe the driving distance, estimated time on the road, and elevation at points along the route.

Highway Catalog And Road Condition

Information on highway location, traffic and surface condition is obtained from 2016 Highway Performance Monitoring System (HPMS) published by Federal Highway Administration. It identifies each highway segment by its geo-referenced location, route number (e.g. I-95, US-1), signing system (Interstate, U.S., State, County, etc.), functional system (Interstate, Principal Arterial, Minor Arterial etc.), whether it belongs to the Interstate Highway System, National Highway System, or neither.[11]

[11] All Interstate Highways are part of the National Highway System. National Highway System has broader coverage than Interstate Highway System. The system classification helps determine the eligible subsidy rate from grants dispensed by federal formula funding. The empirical exercise is restricted to roads that at least belong to National Highway Systems, hence controlling for route number automatically

For each segment, the data documents the Annual Average Daily Traffic (AADT), AADT by trucks, and measures for pavement conditions, among other items. In the empirical exercise, I use the International Roughness Index (IRI) from this data to measure the ruggedness of road surface of each segment in space. This statistic has two advantages relative to other measurements of road quality. First, it has relatively complete coverage compared to other pavement condition measures in HPMS. Second, the number comes from an objective measurement procedure, and the index is most commonly used worldwide for evaluating and managing road systems. To be specific, this index is calculated by the inches of suspension movement per mile of travel, and is measured for each 0.1 mile road segment. More suspension movement indicates worse road condition.

Geography

To help control for physical factors that may affect the quality and placement of roads, I use two datasets that details the land surface features of U.S. territory. I sourced an elevation raster from DIVA-GIS, which facilitates the measurement for how much terrain ruggedness there is between a pair of cities. I also sourced a shapefile of U.S. rivers from HydroRIVERS data product. This data contains the geo-referenced location of rivers with a catchment area of at least 10 km^2 or an average river flow of at least 0.1 m^3/sec. It also orders all rivers into the main stem river, the tributaries, and the tributaries that flow into tributaries, etc. I use this order to identify the major rivers in the U.S. by rivers of Order 1 and the city pairs whose direct connections cross one or multiple of them.

3.1 Fact 1: Faster Travel Between MSAs of the Same State

Time on the road is a natural measure for trucking costs between a pair of cities. More time spent on the road incurs extra costs for fuel and driver's wage and less timely delivery. In this practice, I examine how such costs systematically differ depending on whether a route crosses state borders.

Table 1 shows that travel between MSA pairs within the same state takes shorter time, conditional on distance, traffic and geography. *Link Interior* is a dummy that flags MSA pairs belonging to the same state or partially overlapping with the same state. I control for traffic factors including commuting flows out of the origin, entering the destination, and from origin to destination. Geographic factors that might affect engineering difficulty of the road are controlled by variation in elevations and river crossings: $Log(sd(elev))$ measures the logarithm of standard deviation of elevation on the optimal

controls for subsidy rate.

route, and *Cross River* is a dummy that captures whether the straight-line connection between an MSA pair's centroids crosses a major river.

In the preferred specification (column 4), I additionally control for origin fixed effects and destination fixed effects. This specification accounts for unobserved factors at the city level that may shift the demand for better roads, such as availability of public transit, or cost of road construction, such as local institutional constraints for acquiring right-of-way. Conditional on distance, traffic and geography, time spent on the road is shorter by 2.4% if the city pair belong to the same state. From a back-of-the-envelope calculation, this is equivalent to an average saving of 6.1 km traveled on the road.[12]

3.2 Fact 2: Less Detour Between MSAs of the Same State

Another measurement for the cost of traveling is the directness of road connection between locations. Extra mileages relative to a straight connection incurs extra costs on fuel, wages and time to travel. In this empirical exercise, I examine how indirectness of roads systematically differ depending on whether a route crosses state borders. I measure the degree of detour on the optimal path by actual driving distance conditional on the straight-line distance.

After controlling for traffic factors and geographic factors (column 2), I found an average of 2.2% reduction in actual driving distance for a pair of cities within the same state compared to those crossing the state border. To account for unobserved factors at city level that may shift the tortuosity of roads, such as internal geography and local zoning law, column 5 presents the specification absorbing the fixed effects at origin level and destination level. The size of average treatment effect from *Link Interior* increases to 3.2%.

The preferred specification is column 6, where an additional control variable accounts for state borders established by mountains. This variable measures average Terrain Ruggedness Index (TRI) along the straight-line connection between city centroids. In this preferred specification, we observe a significant 3.1% reduction on actual driving distance for city pairs within the same state, which translates to a 5.71 km reduction in straight-line distance and 6.76 km reduction in actual driving distance.[13]

[12] In terms of economic magnitudes, *Link Interior* has an equivalent effect as $0.024/0.859\times100\%$=2.8% decrease in driving distance. Multiplied by the average driving distance 218.3 km between adjacent pairs, this is equivalent to a 6.1 km reduction in driving distance.

[13] In terms of economic magnitudes, *Link Interior* has an equivalent effect as $0.031/0.899\times100\% = 3.45\%$ reduction in straight-line distance. Multiplied by the average straight-line distance 165.6 km, this is equivalent to a 5.71 km reduction in straight-line distance. Average Actual Distance in regression is 218.3 km, which implies a state border effect equivalent to an actual distance of 218.3×0.031=6.76 km.

Table 1: Travel Time On City Links Within Versus Across State Borders

	Dependent variable:			
	Log(Travel Time on Shortest Path)			
	OLS		*Fixed Effects*	
	(1)	(2)	(3)	(4)
Link Interior	-0.020^{**}	-0.022^{**}	-0.036^{***}	-0.024^{**}
	(0.008)	(0.010)	(0.008)	(0.010)
Log(Distance on Path)	0.816^{***}	0.828^{***}	0.863^{***}	0.859^{***}
	(0.007)	(0.012)	(0.010)	(0.018)
Log(Commuter Out)	-0.011^{***}	-0.014^{***}		
	(0.003)	(0.004)		
Log(Commuter In)	-0.007^{**}	-0.012^{***}		
	(0.003)	(0.004)		
Log(Commuter o-d)		0.007^{**}		-0.003
		(0.003)		(0.004)
Log(sd(elev))	0.055^{***}	0.057^{***}	0.029^{***}	0.023^{**}
	(0.004)	(0.004)	(0.008)	(0.009)
Cross River	0.059^{***}	0.063^{***}	0.015^{*}	0.031^{***}
	(0.007)	(0.008)	(0.009)	(0.012)
Constant	-0.939^{***}	-1.035^{***}		
	(0.095)	(0.123)		
Origin FE	*No*	*No*	*Yes*	*Yes*
Destination FE	*No*	*No*	*Yes*	*Yes*
Observations	1,148	921	1,173	921
R^2	0.966	0.957	0.993	0.993
Adjusted R^2	0.966	0.957	0.984	0.980

Note: Sd(elev) is the standard error of elevation on the optimal route. Cross River is a dummy that captures city pairs whose centroid connection crosses a major river. Standard errors clustered by origin and destination MSA. *p<0.1; **p<0.05; ***p<0.01.

Table 2: Driving Distance On City Links Within Versus Across State Borders

	Dependent variable:					
	Log(Driving Distance)					
	OLS			*Fixed Effects*		
	(1)	(2)	(3)	(4)	(5)	(6)
Link Interior	-0.036^{***}	-0.022^{**}	-0.017	-0.047^{***}	-0.032^{***}	-0.031^{***}
	(0.008)	(0.010)	(0.010)	(0.009)	(0.011)	(0.011)
Log(Straight-line Distance)	0.900^{***}	0.900^{***}	0.924^{***}	0.918^{***}	0.899^{***}	0.899^{***}
	(0.007)	(0.012)	(0.013)	(0.011)	(0.021)	(0.020)
Log(Commuter Out)	-0.014^{***}	-0.013^{***}	-0.013^{***}			
	(0.003)	(0.004)	(0.004)			
Log(Commuter In)	-0.013^{***}	-0.011^{**}	-0.012^{***}			
	(0.003)	(0.005)	(0.004)			
Log(Commuter o-d)		0.001	0.002		-0.004	-0.003
		(0.003)	(0.003)		(0.006)	(0.006)
Log(sd(elev))	0.060^{***}	0.062^{***}	0.029^{***}	0.051^{***}	0.057^{***}	0.039^{***}
	(0.004)	(0.004)	(0.007)	(0.008)	(0.009)	(0.009)
Cross River	0.040^{***}	0.040^{***}	0.036^{***}	0.015	0.002	0.001
	(0.007)	(0.009)	(0.008)	(0.011)	(0.011)	(0.011)
Log(Avg TRI)			0.038^{***}			0.056^{***}
			(0.007)			(0.016)
Constant	7.779^{***}	7.721^{***}	7.612^{***}			
	(0.062)	(0.068)	(0.070)			
Origin FE	*No*	*No*	*No*	*Yes*	*Yes*	*Yes*
Dest FE	*No*	*No*	*No*	*Yes*	*Yes*	*Yes*
Observations	1,148	921	921	1,173	921	921
R^2	0.969	0.961	0.963	0.991	0.993	0.993
Adjusted R^2	0.969	0.961	0.962	0.981	0.980	0.981

Note: Sd(elev) is the standard deviation of elevation on the optimal route. Cross River is a dummy that captures city pairs whose centroid connection crosses a major river. Avg TRI is the average Terrain Ruggedness Index along the centroid connection between MSA pairs. Standard errors clustered by origin and destination MSA. *p<0.1; **p<0.05; ***p<0.01.

3.3 Fact 3: More Ruggedness On Roads Approaching State Borders

A more direct examination for road condition is to look at the physical features of road surface. The International Roughness Index (IRI) captures exactly that: More suspension movement during driving reflects more rugged road surface. How costly would that be? According to calculation by the Federal Highway Administration, for a combination truck traveling at 50 miles per hour on a level, straight road, estimated operating cost per vehicle-mile is 16 percent ($0.167) lower at an IRI of 50 rather than 170, and 11 percent ($0.115) lower at an IRI of 95 rather than 170.[14] Given annual Vehicle-Miles Traveled per lane-mile of 2 million in rural Interstate Highways and about fourth them traveled by trucks, these reductions in IRI translate to a reduction in trucker's operation cost of $83,500 and $57,500 each year per lane-mile, respectively.[15]

I use the information in HPMS dataset to characterize how IRI systematically varies as roads approach state borders. To achieve the most comparable groups of highways, I restrict the sample to highways that are in the Interstate Highway System (e.g. I-95), or part of U.S. Numbered Highways (e.g. US-1), or in any lower systems but explicitly cross state borders (e.g. Massachusetts Route 146 and Rhode Island Route 146). I also drop the ones that restricts commercial vehicles from traveling on the road.

Table 3 illustrates that IRI is on average higher on road segments closer to state borders.[16] In this set of regressions, *State border* is defined as a dummy that captures road segments within 8 km of borders between states. *Coastal Border* flags road segments within 8 km of U.S. coastline, and *Land Border* flags those within 8 km of international land borders. These dummies are mutually exclusive with the *State Border* dummy. Controlling for these borders makes sure we are comparing with the right control group – the highways away from boundaries of states.

In our preferred specification (column 5), controlling for average daily traffic and the most disaggregated set of fixed effects, roads within 8 km of state borders are more rugged by 1.3 IRI points. By absorbing this battery of fixed effects, the comparison is restricted to road segments that belong to the same state, functioning system and route number, which partials out the heterogeneity in budget constraint, functional importance and construction standards. The remaining variation is therefore a relatively clean indication of the government's discretion in maintaining the road.

[14]Source: Highway Economic Requirements System. https://www.fhwa.dot.gov/policy/23cpr/appendixa.cfm
[15]Source: Highway Statistics 2022, Table VM-1; National Transportation statistics 2025, Table 1-36.
[16]This exercise used highway networks in New England area plus New Jersey, New York and Delaware.

Table 3: Road Roughness and State Borders

	Dependent variable:				
	Road Ruggedness (IRI)				
	OLS	*Fixed Effects*			
	(1)	(2)	(3)	(4)	(5)
Log(AADT)	-4.209^{***}	-6.285^{***}	2.670^{***}	2.267^{***}	2.624^{***}
	(0.260)	(0.326)	(0.332)	(0.380)	(0.383)
State Border	0.803	2.972^{***}	1.566^{***}	1.196^{**}	1.331^{**}
	(0.570)	(0.593)	(0.568)	(0.595)	(0.588)
Coastal Border	11.977^{***}	10.231^{***}	8.231^{***}	14.562^{***}	13.127^{***}
	(0.799)	(0.794)	(0.765)	(0.815)	(0.808)
Land Border	2.774^{**}	1.830	-1.448	0.196	0.122
	(1.378)	(1.364)	(1.300)	(1.356)	(1.345)
Constant	121.161^{***}				
	(2.290)				
State FE	*No*	*Yes*	*Yes*	*Yes*	*Yes*
F SYSTEM FE	*No*	*No*	*Yes*	*Yes*	*Yes*
ROUTE FE	*No*	*No*	*No*	*Yes*	*Yes*
Surface Type FE	*No*	*No*	*No*	*No*	*Yes*
Observations	60,136	60,136	60,136	60,136	59,747
R^2	0.008	0.048	0.136	0.184	0.198
Adjusted R^2	0.008	0.047	0.136	0.183	0.197

Note: AADT represents Annual Average Daily Traffic on each lane; State Border, Coastal Border and Land Border are dummy variables indicating whether the segment is within 8 km of a State border, coastal border and international land border respectively. F SYSTEM represents the functional system of the road. *p<0.1; **p<0.05; ***p<0.01.

4 A General Model

This section first presents a closed-economy general competitive equilibrium. It then endogenizes primitives on transportation and taxation by the decisions of non-cooperative local planners, who make investment choices subject to their budget constraint. Through this exercise, I show that a local investment in transportation affects the utility of all location choices in the economy. In particular, locations are exposed to local changes elsewhere through (1) network effects from traffic flows that route over the improved infrastructure, (2) terms of trade adjustments, (3) changes in fiscal burden due to population mobility, and (4) productivity and amenity spillovers due to worker and resident relocation. Each channel points to a direction in which local planners would distort transportation investments compared to social optimal.

4.1 Environment

The economy consists of a set of locations $i = 1, \cdots, N$ linked in goods market through trade and labor market through migration and commuting. The economy as a whole is populated by a measure 1 of workers, each of whom inelastically supplies one unit of labor at their workplace.

Preferences. A location choice ij is a location pair consisting of a place of residence i, where workers consume and enjoy local amenities, and a workplace j where workers supply labor. For location choice ij, the common component of workers' utility depends on individual consumption of the local final good C_{ij}, residential amenity u_i and commuting cost κ_{ij}:

$$U_{ij} = U(C_{ij}, u_i, \kappa_{ij}).$$

On top of this shared component, individuals draw idiosyncratic preference shocks for each location choice. Under choice ij, workers purchase the final good produced in residence i with disposable income e_{ij}:

$$C_{ij} = e_{ij}/P_i$$

where P_i, the price for final goods at location i, is determined by a constant returns-to-scale production technology $D_i(\cdot)$ that aggregates varieties imported from all locations and potentially differs by location:[17]

$$
\begin{aligned}
P_i := \min_{c_k} \sum_k c_k p_{ki} \\
s.t. \quad D_i\left(\{c_k\}_k\right) \geq 1
\end{aligned}
\tag{1}
$$

where p_{ik} is the price of good k in location i, inclusive of trade costs.

Local amenity u_i depends on both location-specific characters, such as availability of other public goods and natural amenities, and the size of residential population: [18]

$$u_i = \bar{u}_i f_i^u(R_i).$$

Individuals take the residential population as given while making their location choices, reflecting a congestion externality. The utility function $U(C_{ij}, u_i, \kappa_{ij})$ implies indirect utility function

$$U_{ij} = V_i(e_{ij}, \{p_{ki}\}_k, u_i, \kappa_{ij}).$$

Individuals then choose the pair of locations that maximize utility, taking as given the choices made by other individuals.

Production. Each location produces a tradable variety with labor. Denote the mass of workers in workplace j by L_j. Output per worker is potentially subject to external economies of scale with respect to total local employment:

$$y_j = \bar{A}_j f_j^y(L_j).$$

With free entry and competitive pricing within each location, firms earn zero profits and sell their goods at marginal cost. Goods are transported subject to iceberg trade costs. The price of good j faced by consumer in location i is

$$p_{ji} = p_j \tau_{ji}$$

where p_j is the factory gate price for the good produced in location j.

[17] While not critical to the results in this section, assuming a shared final good production technology within a place of residence (rather than technologies that differ by workplace, $D_{ij}(\{c_{ij,k}\}_k)$) facilitates a more intuitive interpretation of the technology to convert final goods into highway investment.

[18] The congestion externality can be microfounded by rivalrous public goods or land prices. We assume away any rent from such congestion (e.g. land rents collected by landlords) and only consider congestion costs in the form of disutility.

Workers' budget. Workers pay taxes at their place of residence, and earn the wage at their workplace. Taxes are collected in local final goods. This implies individuals' budget constraint under choice ij

$$e_{ij} = p_j y_j - T_i P_i. \tag{2}$$

In the budget constraint, T_i is the units of final goods paid as taxes by each individual residing in location i; P_i is the price for a unit of the final good at i, as introduced in equation (1).

Local governments' budget. To fund a given combination of local investment decisions $\vec{I}_i$, the local government at location i collects taxes from its residents in the local final good, and convert them one-for-one into capital for infrastructure investment. Denote the mass of residents in i by R_i. Local government at i faces the following budget constraint:

$$K_i(\vec{I}_i) = T_i R_i \tag{3}$$

where $K_i(\cdot)$ captures the units of capital required under a given vector of investment by local government i, $\vec{I}_i$.

Distribution of workers and residents. Consider the population distribution in equilibrium. Denote mass of individuals commuting from i to j by λ_{ij}, which also represents the choice probability of option ij as total population is normalized to 1. In equilibrium, the population distribution that determines productivity and amenity in U_{ij} must also satisfy

$$R_i = \sum_j \lambda_{ij}, L_j = \sum_i \lambda_{ij}. \tag{4}$$

Market clearing. Goods market clearing condition equates the total output of each good j with its total sales:

$$y_j L_j = \sum_{k,l} \tau_{jk} \lambda_{kl} c_{kl,j} (1 + \frac{T_k}{C_{kl}}). \tag{5}$$

For each unit of good j purchased by individuals who choose location option kl, τ_{jk} units must be shipped. Those individuals together consume $\lambda_{kl} c_{kl,j}$ units of good j, while each purchases some extra to pay T_k units of the local final good to the local government. Each unit of final good at location k contains $\frac{c_{kl,j}}{C_{kl}}$ units of variety j, hence the tax requires $\frac{c_{kl,j}}{C_{kl}}T_k$ units of variety j from each individual under option kl. The total sales in the right-hand side then sums up the sales, gross of trade costs τ_{jk}, across all location choices kl.

And lastly, labor market clearing implies

$$\sum_i R_i = 1, \qquad \sum_j L_j = 1. \tag{6}$$

4.2 Equilibrium Responses to Transportation Investment

An investment $\mathrm{d}\vec{I}_i$ made by any given location i incurs direct changes in the matrix of transportation costs: $\mathrm{d}\tau, \mathrm{d}\kappa$, and the local capital expenditure $\mathrm{d}K_i$; these changes induce general equilibrium responses in prices and population distribution, which reshapes the fundamental utility offered by each location option and, ultimately, aggregate welfare. To unpack the channels through which these changes affect fundamental utility, consider the first-order response of indirect utility U_{ij} to a perturbation in location i's investment vector $\mathrm{d}\vec{I}_i$, via the induced changes in $\{\tau_{ij}, \kappa_{ij}, K_i\}_{i,j=1,\cdots,N}$: [19]

$$\begin{aligned} V_{e,ij}^{-1}\mathrm{d}U_{ij} = & -\underbrace{\sum_k m_{ij,k} p_k \mathrm{d}\tau_{ki}}_{\text{import technology}} + V_{e,ij}^{-1} \underbrace{U_{comm,ij}\mathrm{d}\kappa_{ij}}_{\text{commuting technology}} - \underbrace{R_i^{-1} P_i \mathrm{d}K_i}_{\text{direct fiscal costs}} \\ & -\underbrace{\sum_k m_{ij,k}\tau_{ki}\mathrm{d}p_k}_{\text{terms of trade}} + \underbrace{(T_i P_i \mathrm{d}R_i)}_{\text{fiscal externality}} + \underbrace{p_j \bar{A}_j (f_j^y(L_j))'\mathrm{d}L_j}_{\text{productivity spillover}} + \underbrace{V_{e,ij}^{-1} V_{amen,ij}\bar{u}_i (f_i^u(R_i))'\mathrm{d}R_i}_{\text{amenity congestion}} \end{aligned} \tag{7}$$

where $V_{e,ij}$ represents the marginal utility of expenditure for choice ij, $V_{comm,ij}$ represents the marginal (dis)utility of commuting cost, $V_{amen,ij}$ represents the marginal utility of local amenity, $m_{ij,k}$ is the quantity that choice ij imports (exports if negative) from k for each individual, inclusive of consumption and tax contribution but exclusive of trade costs:

$$m_{ij,k} = c_{ij,k} + \frac{T_i}{D_i\left(\{c_{ij,k}\}_k\right)} c_{ij,k} - \mathbb{I}\{j = k\}\, y_j.$$

Note that $\tau_{ij}, \kappa_{ij}, K_i$ are functions of economic fundamentals and investments chosen by governments, which we will consider in the next subsection; $p_k, m_{ij,k}, y_i, L_i, R_i$ and marginal utility of expenditure $U_{e,ij}$ are equilibrium objects determined by $\tau_{ij}, \kappa_{ij,K_i}$ and other economic primitives. Each local change in transportation costs and infrastructure

[19] See Appendix A.2 for derivations.

expenditure will incur changes in every equilibrium object at every location. While the full reaction is non-linear, we use this decomposition to explain the first-order economic trade-offs in local governments' infrastructure investment decisions.

The first two terms in formula (7) capture the technological benefits of improved transportation: lower trade costs reduce spending on iceberg trade costs on imported goods, while lower commuting costs decrease the disutility from commuting. To fund such infrastructure improvements, each current resident must make more fiscal contributions, reflected in the third term. Together, these three terms represent the trade-offs when treating transportation infrastructure simply as a logistic technology: resources are invested to reduce the costs of moving goods and people.

The second row captures general equilibrium effects on location utility. For production site k, reduced export costs towards external markets improve its terms of trade, as increased demand makes variety k more scarce relative to other varieties. An individual choosing pair ij benefits if the appreciation in goods produced in j outweighs the appreciation of goods consumed and taxed in i.

The final three terms reflect the effect from population mobility. Individuals relocate in response to changes in fiscal burden (term 3), cost of living, and wages (terms 1 and 4); furthermore, a fall in commuting costs attracts more dwellers to the place of residence and workers to the workplace (term 2). As residents relocate, locations losing residents face a shrinking tax base, hence each remaining resident must pay a higher tax to sustain infrastructure spending. Finally, productivity spillover and amenity congestion imply that an influx of workers may raise productivity, while more residents may diminish the attractiveness of local amenity.

4.3 Distortions In Local Planner's Investment From Social Optimal

In what follows, we show how local and national planners evaluate infrastructure projects differently, and associate the direction and magnitude of distortion with margins of externalities. Throughout this section, we assume that the local and national planner faces the same budget constraint; in other words, the national planner cannot reallocate fiscal revenue across locations.[20]

The local planner who governs location i chooses investments and the tax $\left\{\{I_{ij}\}_{j\in\mathcal{N}(i)}, T_i\right\}$ within his jurisdiction, recognizing that these investments affect costs in the full transportation network $\{\tau_{ij}\}_{ij}$, $\{\kappa_{ij}\}_{ij}$. In particular, assume investments and local tax must

[20] We abstract from federal reallocation in this section to focus on the inefficiency induced by the lack of coordination between states; we account for the role of federal reallocation in the quantitative model.

satisfy local budget constraint

$$T_i R_i = K_i(\vec{I}_i), \quad K_i(\vec{I}_i) \equiv \sum_{j \in \mathcal{N}(i)} \delta^I_{ij} I_{ij} \tag{8}$$

where δ^I_{ij} is a construction cost shifter. Since taxpayers contribute to public budgets only in their place of residence, a local planner maximizes a weighted sum of the indirect utilities of residents in his territory:[21]

$$\mathcal{W}_i = \sum_j \omega_{ij} U_{ij}.$$

In contrast, when a national planner chooses the investments and taxes under the same local budget constraints for all locations, she accounts for the welfare of all individuals in the economy, using the same Pareto weights as those which local planners put on their constituents:

$$\mathcal{W}^{SP} = \sum_{ij} \omega_{ij} U_{ij}.$$

As an implication, the only difference between $\mathcal{W}_i$ and $\mathcal{W}^{SP}$ is the set of locations in the summation: local planner i considers only residents in i, whereas the national planner accounts for residents in every location.

In this section, I assume Pareto weights of the following form for analytical tractability:

$$\omega_{ij} = \lambda_{ij} U^{-1}_{e,ij}$$

which weighs indirect utility of each location pair choice proportional to the population, but discounts those with high marginal utility of expenditure. The former can be intuitively motivated by planners' intention to maximize the average utility of its constituents with equal weights on every individual. With the latter, we implicitly assume that redistributive goals have been optimized by other policies in the background, and highway policies do not bear those targets. We can now compare how the objective functions of local planners and social planner respond to a marginal change in infrastructure funded by raising taxes at location i. To fix ideas, consider perturbations to investments made in location i around a socially optimal equilibrium. The deviation of local planner i's private returns from social returns then informs us of the size of the wedge that causes inefficiency in the local planner's unilaterally optimal investments. I will use

[21]This brings the level of as-if altruism, or cooperation between local planners, to the minimum: they do not account for the welfare of others' constituents at all.

three special cases to illustrate three margins of externality in isolation: the technology externality, the terms-of-trade externality, and the fiscal externality.[22]

Special case 1: Technology externality.

Consider a special case of the model in which there are no spillovers in amenity or productivity, population distribution is exogenous, individuals work where they live, and investments in roads induce a symmetric reduction in trade cost for both directions; the trade cost on each link is determined by investments made by planners at both ends of the link jointly. Consider the geography illustrated in Figure 2a. To shut down terms-of-trade effect, assume that location C has a linear aggregation technology and no cost in importing goods:

$$D_c(\{c_k\}_k) = \sum_k \alpha_k c_k, \quad p_{CA} = p_A, \quad p_{CB} = p_B.$$

In addition, the costs of exporting from C to A and B are always higher than the bilateral trade cost between A and B, so that no transshipment flows through C.

Consider the first-order condition for the local planner at location A, holding fixed the investments chosen by B and C. Without loss of generality, consider the condition with respect to investment I_{AB}, which affects both τ_{AB} and τ_{BA}. From utility responses (7) and budget constraint (8), the unilateral optimum must satisfy

$$\underbrace{-M_{AB} p_B \frac{\mathrm{d}\tau_{BA}}{\mathrm{d}I_{AB}}}_{PV_{AB}} = \delta^I_{AB} P_A.$$

In contrast, the social optimal condition requires

$$\underbrace{-M_{BA} p_A \frac{\mathrm{d}\tau_{AB}}{\mathrm{d}I_{AB}} - M_{AB} p_B \frac{\mathrm{d}\tau_{BA}}{\mathrm{d}I_{AB}}}_{SV_{AB}} = \delta^I_{AB} P_A.$$

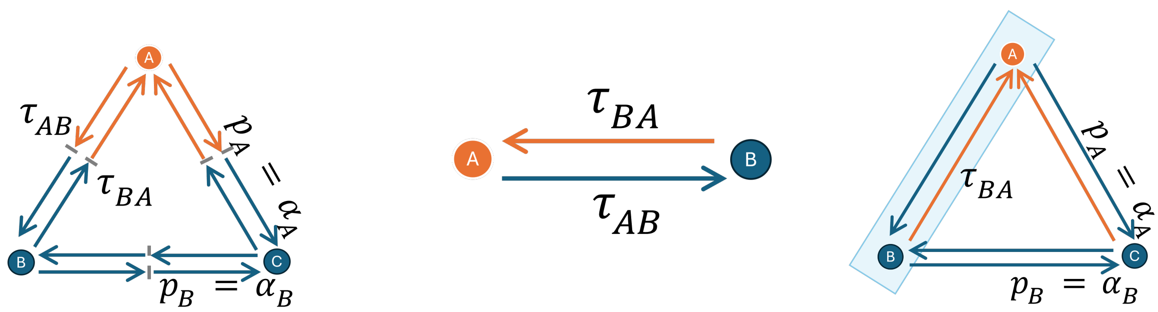
For a marginal investment by A on link AB, while the social cost equals the private cost on the right-hand side, the additional term in social value (SV_{AB}) compared to the private value (PV_{AB}) reflects that social planner additionally internalizes the import cost reduction for B as a result of A's investment. Comparing these two conditions, we can

[22] See Appendix A.1 for more detailed primitives of each example below.

express the wedge in private optimality condition relative to social optimum as follows:

$$SV_{AB}(1-\kappa_{AB}) = \delta^I_{AB}P_A, \quad \kappa_{AB} = \frac{M_{BA}p_A}{M_{BA}p_A + M_{AB}p_B}$$

The formula for wedge κ_{AB} says that, due to the technology externality, the local planner under-invests relative to the social optimum; furthermore, the wedge between private and social optimum is proportional to the share of traffic flows destined for external locations, as measured in the value of goods at the factory-gate price.



(a) Technology Externality (b) Terms-of-trade Externality (c) Fiscal Externality

Figure 2: Geographies With Isolated Externality

Special case 2: Terms-of-trade externality.

Now consider a special case of the model in which two locations trade without migration or commuting. To shut down technology externality, assume each location invests for reducing importing costs but not the exporting cost. Preferences all come with a finite price elasticity, so that the terms of trade endogenously adjust with respect to trade costs. The modified geography is illustrated in Figure 2b.

Consider the first-order condition for the local planner at location A in its investment to reduce the trade cost from B to A. A reduction in τ_{BA} lowers the price for good B faced by location A by saving the iceberg costs, but after general equilibrium responses, the factory-gate price for good B increases, partially off-setting the initial drop in the price. Perceiving both margins of price responses, the unilateral optimum must satisfy

$$\underbrace{-M_{AB}\tau_{BA}\frac{\mathrm{d}p_B}{\mathrm{d}\tau_{BA}}\frac{\mathrm{d}\tau_{BA}}{\mathrm{d}I_{BA}} - M_{AB}p_B\frac{\mathrm{d}\tau_{BA}}{\mathrm{d}I_{BA}}}_{PV_{BA}} = \delta^I_{BA}P_A.$$

However, the social optimum requires

$$\underbrace{-M_{AB}p_B\frac{\mathrm{d}\tau_{BA}}{\mathrm{d}I_{BA}}}_{SV_{BA}} = \delta^I_{BA}P_A.$$

The additional term in private value (PV_{BA}) relative to social value (SV_{BA}) reflects the terms-of-trade externality. The terms-of-trade appreciation for B that is triggered by the reduced trade cost $\mathrm{d}\tau_{BA} < 0$ incurs a transfer from A to B. While a social planner sees no aggregate effect from such a transfer, the local planner at A perceives a weakened purchase power of their constituents' income as the neighbor's good becomes more expensive relative to their own product. As such, they under-invest relative to a socially desirable level. To understand what drives the magnitude of such under-investment, we can solve for the wedge in the private optimality condition as

$$SV_{BA}(1-\kappa_{BA}) = \delta^I_{BA}P_A, \quad \kappa_{BA} = -\frac{\mathrm{d}\ln p_B}{\mathrm{d}\ln\tau_{BA}} > 0$$

The expression for the wedge κ_{BA} says that, due to the terms-of-trade externality, the local planner under-invests relative to social optimal on its importing facility, and the wedge is proportional to the elasticity of the output price at the exporting location with respect to the corresponding iceberg trade cost to import. The rationale is analogous to the one behind unilateral optimal tariffs. Investing less on the infrastructure for importing goods is like charging a tariff.[23] While consumers experience higher cost from the trade cost / tariff, part of the burden is shifted to the exporter, whose product would eventually face a lower price due to a reduction in demand; the extent to which this burden can be shifted depends on how sensitively the exporter's price responds to trade costs/tariffs. A large exporter typically has an elastic supply curve, which implies limited response of its terms of trade respect to trade costs. Towards those markets, the distortion driven by the terms-of-trade externality in local planner's investment is mild.

Special case 3: Fiscal externality.

Consider another special case of the model in which there are no spillovers in amenity or productivity; each location invests for reducing importing costs but not exporting costs, so that technology externality is shut down. To exclude the terms-of-trade exter-

[23]While both policies transfer fiscal revenue to households, tariff raises revenue from foreign country whereas reducing infrastructure investment increases consumable goods from local production.

nality, assume that location C has linear preferences, faces no cost in importing goods, but high exporting costs so that transshipment doesn't happen, as in special case 1. Different from the previous cases, we allow workers to endogenously choose their location between A and B but without the option to commute, and hold fixed the population at location C. The modified geography is illustrated in Figure 2c.

Consider the first-order conditions for the local planner at location A, in particular for the investment decision to reduce the trade cost from B to A. As τ_{BA} decreases, the import price for good B faced by location A falls due to the savings from trade costs, but this comes at the cost of raising the per-capita tax contribution at location A. While lower costs for consumption attracts taxpayers, higher taxes repels residents and triggers emigration. Observing this trade-off, the unilateral optimum must satisfy

$$-M_{AB}p_B\frac{\mathrm{d}\tau_{BA}}{\mathrm{d}I_{BA}} + T_A P_A \frac{\mathrm{d}R_A}{\mathrm{d}I_{BA}} = \delta^I_{BA}P_A, \qquad \frac{\mathrm{d}R_A}{\mathrm{d}I_{BA}} = \frac{\partial R_A}{\partial \tau_{BA}}\frac{\mathrm{d}\tau_{BA}}{\mathrm{d}I_{BA}} + \frac{\partial R_A}{\partial T_A}\frac{\mathrm{d}T_A}{\mathrm{d}I_{BA}}.$$

The term $T_A P_A \frac{\mathrm{d}R_A}{\mathrm{d}I_{BA}}$ reflects the fact that, whenever an investment plan attracts new residents, they generate additional income to the local government budget, which alleviates the tax burden for every local taxpayer. On the other hand, the social optimum requires

$$-M_{AB}p_B\frac{\mathrm{d}\tau_{BA}}{\mathrm{d}I_{BA}} + (T_A P_A - T_B P_B)\frac{\mathrm{d}R_A}{\mathrm{d}I_{BA}} = \delta^I_{BA}P_A.$$

Unlike local planner A, the social planner notices that taxpayers gained at location A comes at the cost of a reduced tax base at location B: each resident at location B now must pay more taxes as a result of the emigration. Therefore, if the investment and associated tax adjustment triggers a relocation of workers from B to A, this project is less desirable in the eyes of the social planner compared to incentives faced by local planner A. But if the relocation happens in the opposite direction, this project generates higher social value than the unilaterally perceived value. The sign of the distortion in unilateral investment induced by the fiscal externality therefore depends on the direction of the population relocation in response to marginal investments and the associated taxes.

General case. Finally, consider the full model with endogenous commuting costs, agglomeration and amenity congestion, and a general geography. Investments on highways simultaneously reduce trade costs and commuting costs. Unilaterally optimal investment requires

$$-\sum_{j,k} M_{ij,k}\tau_{ki}\mathrm{d}p_k - \sum_{j,k} M_{ij,k}p_k\mathrm{d}\tau_{ki'} + T_iP_i\mathrm{d}R_i + \sum_j V_{e,ij}^{-1}V_{comm,ij}\lambda_{ij}\mathrm{d}\kappa_{ij} + \sum_j p_jL_j\lambda_{ij|j}\mathrm{d}y_j(L_j) + \sum_j V_{e,ij}^{-1}V_{amen,ij}\lambda_{ij}\mathrm{d}u_i(R_i) = P_i\mathrm{d}K_i \qquad (9)$$

and social planner's optimality condition is

$$-\sum_{i',j,k} M_{i'j,k}p_k\mathrm{d}\tau_{ki'} + \sum_i T_iP_i\mathrm{d}R_i + \sum_{ij} V_{e,ij}^{-1}V_{comm,ij}\lambda_{ij}\mathrm{d}\kappa_{ij} + \sum_j p_jL_j\mathrm{d}y_j(L_j) + \sum_{i,j} V_{e,ij}^{-1}V_{amen,ij}\lambda_{ij}\mathrm{d}u_i(R_i) = P_i\mathrm{d}K_i. \qquad (10)$$

The difference in local and social returns (from the left-hand sides of equations (9) and (10)) now involves three additional distortions.

First, the network externality of commuting infrastructure: when commuters cross the jurisdiction of i, local planner i internalizes commuting cost reductions only for workers who reside within her own boundary. This leads to distortions in investment analogous to the ones induced by the technology externality in trade: links hosting more traffic share from commuters who reside outside of planner i's jurisdiction are more severely under-invested.

Second, productivity spillovers due to worker relocation are only partially internalized. Local planners capture productivity spillovers everywhere to the extent that their residents commute to those areas. All else equal, local planners favor links that attract workers to the top commuting destinations of its residents. For instance, the planner of New Jersey would invest in a way that attracts more workers there (as most residents commute locally and gain from local productivity), but would be also interested in increasing workers in New York, as it gains a share of the productivity increase in New York through New Jersey residents who commute there.

Finally, amenity spillovers push local planners to reduce local residents so that each resident enjoys better local amenities; this effect off-sets the fiscal incentive that we discussed in special case 3, and the net effect depends on the net value of a resident: his tax contribution made to the local government less the marginal reduction in local amenity that he causes to all existing residents.

The last two effects trigger competition among local planners to steal workers and, conditional on the distortions from the fiscal externality, to repel residents. One of the consequences is amplified distortions on trade infrastructure induced by terms of trade externalities, so that as a workplace, the local planner's jurisdiction offers a higher wage thereby attracting workers. The other strategy local planners would adopt is to manipulate commuting infrastructure: invest more towards locations with relatively high amenities, and invest less towards locations with relatively high productivity. This echoes the insight from Bordeu (2023): holding fixed commodity prices, reductions in commuting costs reinforce geographic specialization, namely workers further concentrate to productive locations and residents migrate to high-amenity locations. In the current setting, the last two spillovers call for more workers, which improves productivity through agglomeration, and fewer residents, which improves local amenity by reducing congestion. Therefore, spillovers themselves incentivize local planners to prioritize neighbors with lower productivity and better amenity, although these incentives may be offset by fiscal incentive, which favors more residents, and terms-of-trade manipulations, which favor investments towards larger markets. As such efforts neglect the spillover effects in the rest of the economy due to workers' endogenous location choices, incentives from spillovers are distortionary for commuting infrastructure.

5 Quantitative Model

In this section, I introduce further functional form assumptions and details of the interaction between federal and state governments to prepare the model for data calibration. I first introduce the canonical assumptions on production, consumption and migration decisions in quantitative spatial models for an environment with exogenous taxes and transportation costs. Next, I introduce the construction technology that relates taxes, trade costs and commuting costs through investments. I then state the problems faced by state and federal planners who invest in highways using the construction technology, with fiscal rules that reflect the institutional feature of the current federal highway subsidies.

5.1 Environment with Exogenous Transportation Costs And Taxes

Worker's Consumption Preference

Workers value the differentiated varieties with constant elasticity of substitution, and have idiosyncratic preferences across location pairs of place of residence and workplace.

The welfare of individual ϕ working in location i and living in location j is

$$U_{ji,\phi} = \frac{b_{ji,\phi}}{\kappa_{ji}} \left(\sum_k c_{ji,k}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} u_j$$

where c_{kj} is the per-capita quantity of the variety produced in j and consumed in i, $\sigma \in (1, \infty)$ is the elasticity of substitution across varieties, and u_j is the local amenity. Local amenities are subject to congestion by local residents R_i. Workers take the local amenities as given when making their location choices, and rationally conjecture the distribution of residents in equilibrium. In particular,

$$u_j = \bar{u}_j R_j^b.$$

The preference shocks $b_{ji,\phi}$ are independently drawn from a Fréchet distribution,

$$G(b) = exp(-b^{-\varepsilon}), \varepsilon > 1.$$

Production

Each location i produces one unique variety. A continuum of firms hire workers to produce and price their output in perfect competition, taking their productivities as given. Such productivities are rationally conjectured by firms from the equilibrium distribution of workers. Each worker provides a unit of labor inelastically conditional on working in location i, produces A_i units of the local variety where A_i is the local productivity, and earns wage w_i. Productivity of local firms potentially depends on the measure of local workers due to external economies of scale:

$$A_i = \bar{A}_i L_i^a.$$

This implies factory gate price at location i

$$p_i = \frac{w_i}{\bar{A}_i L_i^a}. \tag{11}$$

Varieties produced at each location can be traded subject to an iceberg trade cost. The cost to ship goods from location i to location j is τ_{ij}, which we endogenize through highway construction in the next subsection.

Worker's Location Choice

Workers are geographically mobile and choose the pair of locations for residence and work that maximize their utility. Their indirect utility when working in i and living in j is

$$\begin{aligned} V_{ji,\phi} &= b_{ji,\phi} w_i (1 - t_j) u_j / \left(\kappa_{ji} P_j\right) \\ &= \frac{b_{ji,\phi} p_i (1 - t_j)}{\kappa_{ji} P_j} \bar{u}_j \bar{A}_i L_i^a R_j^b \end{aligned}$$

where t_j denotes the income tax rate at location j, and the local price index P_j is given by optimal consumption choice

$$P_j = \left(\sum_i \left(p_i \tau_{ij} \right)^{1-\sigma} \right)^{\frac{1}{1-\sigma}}. \tag{12}$$

Define fundamental utility for location choice ji as

$$U_{ji} = p_i (1 - t_j) \bar{u}_j \bar{A}_i L_i^a R_j^b / \left(\kappa_{ji} P_j \right).$$

This is the level of utility provided by location ji net of idiosyncratic preferences. As a result of workers' optimal location choices, the share of workers working in location i and living in location j is

$$\lambda_{ji} = \frac{U_{ji}^{\varepsilon}}{\sum_{i',j'} U_{j'i'}^{\varepsilon}} \tag{13}$$

which is also the number of workers commuting from j to i by normalizing total labor to 1. The expected utility conditional on optimal location choices is equalized due to population mobility and the Frechet preference shock, and it relates to fundamental utilities by

$$W = \Gamma(\frac{\varepsilon - 1}{\varepsilon}) \left(\sum_{i',j'} U_{i'j'}^{\varepsilon} \right)^{1/\varepsilon}. \tag{14}$$

As an implication of equation 13, distribution of workers and residents satisfy

$$L_j = \sum_i \frac{\left(p_j \bar{A}_j L_j^a / \kappa_{ij}\right)^\varepsilon}{\sum_j \left(p_j \bar{A}_j L_j^a / \kappa_{ij}\right)^\varepsilon} R_i \tag{15}$$

$$R_i = \sum_j \frac{\left(\left(1 - t_i\right) \bar{u}_i R_i^b P_i^{-1} / \kappa_{ij}\right)^\varepsilon}{\sum_i \left(\left(1 - t_i\right) \bar{u}_i R_i^b P_i^{-1} / \kappa_{ij}\right)^\varepsilon} L_j, \tag{16}$$

and average residential income satisfy the following relationship with workplace wages

$$v_j = \sum_i \lambda_{ji} w_i / R_j = \sum_i w_i \frac{\left(w_i / \kappa_{ji}\right)^\varepsilon}{\sum_k \left(w_k / \kappa_{jk}\right)^\varepsilon}, \tag{17}$$

Spatial Equilibrium

The spatial equilibrium is defined by a set of prices and population distribution $\{p_i, L_i, R_i, w_i, v_i\}_i$ that satisfy labor market clearing,

$$\sum R_i = \sum L_j = 1, \tag{18}$$

commodity market clearing,

$$w_i L_i = \sum_j \left(p_i \tau_{ij} / P_j\right)^{1-\sigma} \left(v_j R_j (1 - t_j) + K_j P_j\right), \tag{19}$$

local price indices P_i given by equation 12, wages w_i given by equation 11, residential income v_i given by equation 17, distribution of workers L_j and residents R_i given by equations 15 and 16, together with the choice of numeraire

$$\sum_i w_i L_i = 1. \tag{20}$$

5.2 Road Investment Technology

Trade Costs

Trade cost for traveling through link ij takes the following form:

$$d_{ij} = \begin{cases} t_{ij|i} t_{ij|j} & i \neq j, \\ 1 & i = j. \end{cases} \tag{21}$$

In the formulation above, $\bar{t}_{ij|i}$ captures the traveling cost by trucks from origin i to destination j paid within the boundary of i, and the total cost on link ij is the product of the costs paid in both sides of the border. d_{ij} equals infinity if pair ij are not connected by a direct highway link (but can be connected by routing through multiple links). Costs are log-linear in travel time, which in turn depends on highway investment and miles of travel:

$$t_{ij|i} = exp(\zeta_1 \times \text{time}_{ij|i}), \qquad \log(\text{time}_{ij|i}) = \log t_0 + \phi \log \text{miles}_{ij|i} - \gamma \log I_{ij|i} + \epsilon_{ij|i} \quad (22)$$

To compute the bilateral trucking costs from the link-specific costs above, I adopt the assumptions in Allen and Arkolakis (2022). Define a route between i and j as a sequence of nodes in the network: $r = (r_0, r_1, r_2, \cdots, r_L)$ where $r_0 = i, r_L = j$. Assume cost of travel accumulates multiplicatively: $\tau_{ij,r} = \prod_{n=0}^{L-1} d_{n,n+1}$. Suppose travelers from i to j make cost-minimizing *route* choices subject to Frechet shocks with shape parameter ρ. The bilateral trade cost between l, k can be found by

$$\tau_{lk}^{truck} = \left(\left(I - \widehat{d}^{-\rho} \right)^{-1} \right)_{lk}^{-1/\rho} \quad (23)$$

where $\widehat{d}$ is the matrix of d_{ij}, the cost of traveling link ij; the matrix has value of infinity in the diagonals to prohibit consecutively revisiting the same node.

To match the level of trade costs implied by trade flows, I assume an alternative transportation mode exists for each bilateral pair ij, regardless of whether the pair share territorial borders. The cost is described by τ_{ij}^{alt} and is a function of straight-line distance between i and j:

$$\tau_{ij}^{alt} = \exp(\zeta_2 \text{dist}_{ij}^{\psi}). \quad (24)$$

Finally, let ρ_m capture the elasticity of substitution between modes, which can be microfounded by travelers' discrete choices under *link-specific* Frechet shocks with shape parameter ρ_m. The bilateral trade cost is then

$$\tau_{ij} = [(\tau_{ij}^{truck})^{-\rho_m} + (\tau_{ij}^{other})^{-\rho_m}]^{-1/\rho_m}. \quad (25)$$

Commuting Costs

Commuting costs between different destinations follow a similar form as trade costs. In particular,

$$k_{ij} = \begin{cases} \delta^k d_{ij} & i \neq j, \\ 1 & i = j. \end{cases} \tag{26}$$

In the formulation above, $\delta^k d_{ij}$ describes the cost of commuting between different locations i and j, where δ^k allows commuters to respond more sensitively to travel costs than truckers do. The bilateral commuting cost between l, k can be found by

$$\kappa_{lk} = \left(\left(I - \widehat{k}^{-\rho}\right)^{-1}\right)_{lk}^{-1/\rho} \tag{27}$$

where $\widehat{k}$ is the matrix of k_{ij}, the cost of commuting on link ij; $\widehat{k}$ has value of infinite where it denotes pairs that do not share borders and in the diagonal.

5.3 State Planner's Problem

Let $J(g)$ be the set of locations within jurisdiction of state government g, and $\mathcal{N}(i)$ be the set of locations connected by a direct highway link with location i, so that $d_{ji} < \infty \, \forall j \in \mathcal{N}(i)$. A direct highway link consists of the trunk highway and the access roads, which I assume must be constructed proportionally: a 10% widening in the trunk highway must be matched with a 10% widening in its access roads.

State governments and the federal government collect income taxes to purchase non-tradable final goods at each location $i \in J(g)$, which can be used to build highways within the location of purchase. States can reallocate tax revenue within its jurisdiction, and the federal government can reallocate tax revenue across states. When procuring final goods in $i \in J(g)$ for highways on link ij, state government g gets s_{ij}^F dollar reimbursed by federal government for each dollar spent. All locations in state g share the same keep-tax rates: $1 - t_i = (1 - t^F)(1 - t_{g(i)}^S) \, \forall i \in J(g)$, which reflect the multiplicative of federal keep-tax rate $1 - t^F$ and state keep-tax rate $1 - t_g^S$.

A state government values the total welfare of her constituents, which accounts for both the size of population in her jurisdiction and the average welfare of these constituents. In addition, they choose investments as if they partially internalize other state governments' value. This can be driven by actual political alliance and/or negotiations in the highway planning procedure that we do not observe. Finally, they derive political payoffs from highway investments. Such payoffs reflect the net effect of both positive and negative incentives for highway construction that come from factors outside of constituents' utility, such as lobbying by highway construction firms and environmentalist protests. These incentives shape government decisions regardless of their administrative levels: federal planners would face the same non-utilitarian incentive if they were to take charge of highway planning, as lobbyists and protesters would redirect the same pressure to the federal policy maker. Despite their influence on governments' investment decisions, these incentives do not constitute any welfare to the spatial economy on their own.

In the Nash equilibrium, the federal government first announces the subsidy rates s_{ij}^F for each highway link ij. At the same time, it commits to satisfy the budget constraint by adjusting the scale of uniform federal tax so that fiscal revenue equals the expenditure on highway subsidies.[24] The level of federal tax therefore depends on the investments chosen by states. Observing the federal policies, states choose their optimal investment on each highway link connected to their territory. They recognize the impact of their investment choices on federal taxes and all states' taxes. State taxes and federal tax are then set to satisfy their respective budget constraints.

Formally, we define the unilateral optimal strategy of state planner g and Nash equilibrium as the following.

Definition 1 (Unilateral Optimal Strategy) *Taking the investments chosen by other state planners $\{\{I_{i'j'}\}_{i'\in J(h),j'\in\mathcal{N}(i')}\}_{h\neq g}$ and federal subsidies s_{ij}^F as given, the unilateral optimal investments by state government g is the set of $\{I_{ij}\}_{i\in J(g),j\in\mathcal{N}(i)}$ that solve the following problem:*

$$
\begin{aligned}
&\max_{\{I_{ij}\}_{i\in J(g),j\in\mathcal{N}(i)}} \mathcal{W}_g = \sum_h \Omega_{gh} \sum_{l\in J(h),k} \lambda_{lk} W + \sum_{i\in J(g),j\in\mathcal{N}(i)} r_{ij} I_{ij} \\
&s.t. \qquad t_h^S \sum_{i\in J(h)} v_i R_i = \sum_{i\in J(h),j\in\mathcal{N}(i)} P_i (1-s_{ij}) \delta_{ij}^I I_{ij} \qquad \forall h, \\
&t^F \sum_{g,j\in J(g)} (1-t_g^S) v_j R_j = \sum_{g,i\in J(g),j\in\mathcal{N}(i)} P_i s_{ij} \delta_{ij}^I I_{ij}, \\
&I_{ij} \geq 0,
\end{aligned}
$$

road construction technology (21)-(27), and the equilibrium conditions (11), (12), (15)-(20). In equilibrium conditions (11), (12), (15)-(20), taxes and infrastructure expenditure are determined

[24]The assumption of uniform federal tax brings the benefit that relative keep-tax rates only depends on state taxes, so that the presence of federal subsidy in a Nash equilibrium do not affect the spatial allocation of population by reallocating fiscal burden across locations.

by

$$1 - t_i = (1 - t^S_{g(i)})(1 - t^F), \qquad K_i = \sum_{j \in \mathcal{N}(i)} \delta^I_{ij} I_{ij}.$$

In this formulation, $\sum_{l \in J(h),k} \lambda_{lk} W$ describes the total utility of constituents in jurisdiction h, which we will refer to as "utilitarian payoff" of government h. Ω_{gh} are the welfare weights by which planner g values the utilitarian payoff of planner h relative to his own, so that $\Omega_{ii} = 1 \, \forall i$. r_{ij} captures the political payoff associated with any marginal investment on link ij.

This objective function formulation indicates that the planner values both the mass of constituents she attracts and the average utility of them. The incentive to attract more constituents can be microfounded by two types of incentives. The first comes from fiscal revenue outside of highway policies: as more residents bid up the land price, state governments can extract more revenue from property taxes and land rents. The second comes from political bargaining power in other federal decisions: as the size of constituents grows, the state gets a larger weight when voting for federal decisions. In the appendix, I show that the exact weighting between size of population and average utility affects strategic inefficiency only through the relative weighting between the appeal of own jurisdiction and the appeal of other locations in the economy. Admittedly, an equal weighting on size of population and average utility imposes a stronger assumption on state planners objectives, but it brings the benefit that the only difference between state and federal planners' objectives came from the Pareto weights. This helps us focus on the inefficiency from state planners imperfectly internalizing policy impacts on social welfare.

Finally, in the budget constraint, δ^I_{ij} is a construction cost shifter that arises from heterogeneity in engineering difficulties, length of the link, and the density of access roads in a state. The shifter captures the units of local final goods required to construct one extra lane on the trunk highway and for the matching construction on access roads. While the density of access roads can in principle be an endogenous choice by states, we assume it's exogenous by holding fixed δ^I_{ij} throughout the paper. The assumption implies that trunk highways and access roads have unit elasticity of substitution, hence the model abstracts away from potential increasing or decreasing marginal cost of trunk highways due to complementarity or substitutability with access roads.

Definition 2 (Nash Equilibrium) *Let $\sigma_g = \{I_{ij}\}_{i \in J(g), j \in \mathcal{N}(i)}$ denote a set of investment chosen by state g, and $\theta^F = \{\{s^F_{ij}\}_{i,j \in \mathcal{N}(i)}\}_g\}$ denote a set of federal subsidies. The Nash equilibrium under federal policy θ^F is a profile of investments $\{\sigma_g\}_g = \{\{I_{ij}\}_{i \in J(g), j \in \mathcal{N}(i)}\}_g$ such that, for each state g, σ_g solves the problem in Definition 1 given $\{\sigma_h\}_{h \neq g}$ and federal policy θ^F.*

5.4 Federal Planner's Problem

For a benchmark of optimal highway network, consider the allocation of highway investment that a federal planner would choose. We maintain the constraint on uniform tax rates within each state. In addition, we restrict the federal choices on the state keep-tax vector to those proportional to the one in the observed equilibrium. Different from Nash equilibrium, the federal planner faces one national budget constraint rather than many state budget constraints. Formally, we define the optimal tax and investment as the following:

Definition 3 (Optimal Investment) *The national optimal investment is the set of* $\{\{I_{ij}\}_{i\in J(g),j\in\mathcal{N}(i)}, t_g\}_g$ *that solve the following problem:*

$$\begin{aligned}\max_{t_g,\{I_{ij}\}_{j\in\mathcal{N}(i),i\in J(g)}\ \forall g} \mathcal{W}^{national} &= W + r_{ij}I_{ij}\\ s.t. \sum_{g,i\in J(g)} t_g v_i R_i &= \sum_{g,i\in J(g),j\in\mathcal{N}(i)} P_i\delta^I_{ij}I_{ij},\\ 1-t_g &= \xi\times(1-t^{data}_g) \qquad \forall g,\\ I_{ij} &\geq 0,\end{aligned}$$

road construction technology (21)-(27), and the equilibrium conditions (11), (12), (15)-(20).

The national government's objective is the sum of the average utility of all population and the political payoffs of highway construction.[25] When a state government is fully altruistic, her objective coincides with that of the national government.

6 Estimations

In this section, I describe the procedure to back out the location-specific productivity and amenities. With these parameters, I proceed to estimate the construction technology and state planners' preferences. Throughout the estimation procedure, I assume the observed highway network reflects a steady state of the game between state planners without uncertainties. Correspondingly, the annual expenditure observed in data are interpreted as the reinvestment to make up for the capital depreciation each year.[26]

[25] Average utility coincide with the total utility in the country as total population is normalized to 1.

[26] The annual growth of constant-price net capital stock of roads has significantly slowed, from 4.94% in 1960s to 0.70% in 2007-2018. Given a 20-year service life of pavements according to BEA, it does take continuous reinvestment to sustain the current system performance. (Kornfeld and Fraumeni, 2022)

There are three primary datasets used in the estimation. The first is Freight Analysis Framework (FAF) 5.6.1. This data provides the value of bilateral trade flows between 129 domestic destinations in the contiguous U.S. territory, disaggregated by mode of transportation. In particular, we can compute the share of value carried by trucks among all goods shipped for each pair of destinations. The FAF zones together cover the entire contiguous United States. FAF also provides the highway network on which the federal administration estimates the national distribution of truck flows. I use the same highway network to measure highway investments and driving distance between locations.

The second data describes commuting flows across jurisdictions in the US. I use the county-pair level commuting flows in 2016-2020 American Community Survey (ACS) and aggregate them up to the FAF zone level. I supplement this data with the effective state highway tax rates in 2017 computed from the Federal Highway Administration publication *Highway Statistics* and personal income from BEA 2017 release. I detail this procedure in section 6.3.1.

Lastly, to measure the cost of investment for each highway link, I use the cost metrics provided by Highway Economic Requirements System published by Federal Highway Administration. This data provides the dollar cost of adding a lane-mile by seven categories of environment and 4 categories of highway functional class. I detail the conversion of these dollar costs to units of the model in section 5.3.

To focus on the parameters essential to the inefficiency mechanisms, I calibrate the following parameters to the literature. Following Monte et al. (2018), I set elasticity of substitution between varieties to $\sigma = 4$, location preference dispersion $\varepsilon = 3.3$. Following Allen and Arkolakis (2014), I set the agglomeration elasticity $a = 0.1$ and amenity congestion elasticity $b = -0.3$.

6.1 Location-specific Economic Fundamentals

Assuming that trade costs and commuting costs are symmetric in each bilateral pair: $\tau_{ij} = \tau_{ji}, \quad \kappa_{ij} = \kappa_{ji}$, I use the Head and Ries (2001) method to back out bilateral trade costs from bilateral trade flows X_{ij} and bilateral commuting costs from bilateral commuting flows λ_{ij} between U.S. domestic destinations:

$$\tau_{ij} = \left(\frac{X_{ij} X_{ji}}{X_{ii} X_{jj}} \right)^{-1/2\sigma}, \tag{28}$$

$$\kappa_{ij} = \left(\frac{\lambda_{ij}\lambda_{ji}}{\lambda_{ii}\lambda_{jj}} \right)^{-1/2\varepsilon}. \tag{29}$$

I then use the market clearing condition 19 to invert fundamental productivity $\bar{A}_i$. I use the workers' income $w_i L_i$ implied by equation 17, with $v_i R_i$ given by residential income from BEA data and λ_{ij} given by commuting probabilities from ACS data. I use the share of expenditure given by total value of inbound goods (including from itself) in FAF data. With the productivities, I compute local price indices P_i. I then use resident distribution 16 to invert fundamental amenity $\bar{u}_j$ given the inferred P_i, observations on L_i, R_i from ACS data, and state tax rates $t_{g(i)}$. We discuss the construction of state tax measures in subsection 6.3.1.

6.2 Highway Construction Technology

6.2.1 Measurement of Highway Investment

I measure the investment intensity $I_{ij|i}$ by the mileage-weighted number of lanes on the segments of optimal path connecting centroids of i and j that locate within the territory of i. If a pair of locations share the border but the optimal path between their centroids crosses a third state, I define them as non-adjacent pairs in the network. The same measuring process also yields the mileage spent in each side of the state border on optimal route (if it ever crosses one) between a pair of locations. I use this mileage as the *miles* variable in estimations. I separately compute the great circle distance between the centroids as the *dist* variable associated with the cost of traveling in alternative mode.

6.2.2 Estimate Trade Costs

From equation (22), we can estimate the parameters determining the relationship between miles, investments and truck travel time by linear regression. We obtained estimates of distance elasticity of 0.892 and investment elasticity of -0.171, close to what the existing literature found. One potential endogeneity concern with equation (22) is the possibility of an omitted variable bias: if investment $I_{ij|i}$ responds to unobserved factors that also affect time to travel, the residual would not be orthogonal to observed investment. In Appendix C, I show that including such factors has a quantitatively trivial effect on the investment elasticity, which is an order of magnitude smaller than the standard deviation.

From equation (21), we can re-write the link-specific costs as

$$\tau_{ij} = exp(\zeta_1 \text{time}_{ij}) \times (s_{ij,truck})^{1/\rho_m}, \tag{30}$$

$$\frac{s_{ij,truck}}{1 - s_{ij,truck}} = \frac{\tau_{truck,ij}^{-\rho_m}}{\tau_{other,ij}^{-\rho_m}} \tag{31}$$

where $s_{ij,truck}$ is the probability of choosing truck transportation between pair ij, which we proxy by the value share of goods from i to j transported by trucks in FAF data. We can then leverage the log-transform of the relationships above to obtain estimation equations for $\psi, \rho_m, \zeta_1, \zeta_2$:

$$\log d_{ij}^{obs} = \zeta_1 \text{time}_{ij} + \rho_m^{-1} \log(s_{ij,truck}^{obs}) + e_{ij}, \tag{32}$$

$$\log\left(\frac{s_{ij,truck}^{obs}}{1 - s_{ij,truck}^{obs}}\right) = -\rho_m(\zeta_1 \text{time}_{ij} - \zeta_2 \text{dist}^{\psi}) + \log \nu_{ij} \tag{33}$$

where e_{ij} is an i.i.d. measurement error on the actual $\log d_{ij}$, and ν_{ij} is an i.i.d. measurement error on the actual relative share of trucks and alternative modes. To impute the travel time between non-adjacent pairs in a model-consistent way, I assume the route substitution elasticity ρ is sufficiently high, so that the choice probability on the optimal path is close to 1. Given this assumption, I use the expectation formula in equation (23) to compute the expected truck travel time between non-adjacent pairs, and use that as a proxy for the time to travel on the optimal route. I then jointly estimate equations (32) and (33) by generalized method of moment. This procedure yields estimates of the distance elasticity of alternative mode $\psi = 0.143$, substantially lower than the one corresponding to trucking ($\phi = 0.892$); the cost of trucking time is estimated at $\zeta_1 = 0.121$, and that of alternative mode is estimated at $\zeta_2 = 0.558$; the elasticity of substitution between modes is estimated at $\rho_m = 35$.

With e_{ij} and ν_{ij} both being measurement errors, the estimation above does not suffer from endogeneity issues. Endogeneity concerns may arise if the error terms came from unobserved components of trade costs by each mode. If trucking costs have an unobserved component conditional on time, this will enter both e_{ij} and $s_{ij,truck}$ through the trucking cost between pair ij. If the costs by the alternative mode have an unobserved component conditional on distance, and if that component is observed by the strategic investors, this component will enter both ν_{ij} and time_{ij} through the endogenous investments $I_{ij|i}, I_{ij|j}$. Under these alternative assumptions, one needs to instrument the endogenous outcomes in GMM. To address the first endogeneity concern, I instrument the shares by the Euclidean distance between locations, an exogenous shifter to the costs by alternative mode. For the second issue, I instrument time_{ij} with investment shifters exogenous to the costs by the alternative mode. In particular, I use the alignment of the centroid connections with longitude and latitude following Michaels (2008), the idea being that Interstate Highways tend to run either west-east or north-south, a pattern inherited from the initial conception of transcontinental highway system by President Franklin Delano Roosevelt in 1937.[27] Table 11 shows the impact on parameters if we take these alternative assumptions on error terms. Overall, the cost of trucking time ζ_1 and mode elasticities ρ_m are robust with respect to these endogeneity concerns, whereas the price curve for the alternative mode along the distance is steeper and shifts downward. This shift in price curve implies that the cost towards 1 mile away with the original estimates would now be achieved at 0.88 miles with these estimates under different assumptions. This in turn implies a wider range under which trucking is the dominant mode, and therefore broader spatial scope for the thoroughfare effect in the trucking network.

6.3 Estimate State Government Preference and Investment Costs

6.3.1 Mapping Highway Policy to the Model

I use *Highway Statistic* to compute the relevant taxes and subsidies in U.S. highway policies. I first compute the total revenues by each state used for state-administered highways net of any bond issuance, as in table SF-3 of the publication. Subtracting the payments from other governments, I obtain the revenue from each state governments, R_g^S. I also obtain the revenue payed from federal funds, R_g^F. I then compute the federal subsidy rate as

$$s_{ij}^F = s^F = \frac{\sum_g R_g^F}{\sum_g (R_g^F + R_g^S)}.$$

Next, I obtain the state aggregate personal income from U.S. Census, Y_g. I then compute the highway tax rates imposed by states as

$$t_g^S = R_g^S / Y_g$$

[27] The road network hand-drawn by Roosevelt consisted of five north-south and three east-west lines. However, it did not specify the precise geographic routing or construction standards. The 1947 plan of Interstate Highway System, which went through state planning and extensive exchange of ideas, exhibited for greater complexity and substantial departures from this simple grid.

and the total highway tax faced by each state as

$$t_g = t_g^S + \frac{\sum_g R_g^F}{\sum_g Y_g}.$$

6.3.2 Dollar Cost of Highways

The Highway Economic Requirements System published by Federal Highway Administration provides cost of adding a lane-mile by seven categories of environment for four functional classes: Interstates, Other Principal Arterial, Minor Arterial and Major Collector.[28] I use the total cost across all segments on the optimal route at each side of the border to get the dollar cost of adding a lane along the optimal route, $\tilde{\delta}^I_{ij|k=i,j}$. When a link is intra-state, I assume that $\tilde{\delta}^I_{ij|i} = \tilde{\delta}^I_{ij|j}$.

The dollar cost differs from the cost measure of the model in three aspects: first, it only captures the cost on the optimal route, but misses the costs on access roads. Second, the input metrics are national averages, which covers the cost heterogeneity across states. And finally, they are denoted in units of dollar, whereas highway construction in the model takes local final goods. To convert the dollar cost into the correct units, I solve for a state-specific cost shifter δ_g so that, when the construction costs (in units of final goods) on ij in the territory of i is $\delta_{g(i)}\tilde{\delta}_{ij|i}$, the model-predicted state highway taxes (including the federal impost) matches their empirical counterparts: [29]

$$\vec{t}_g^{model}(\{\delta_{g(i)} \times \tilde{\delta}_{ij|i}\}_{g,i\in J(g),j\in\mathcal{N}(i)}) = \vec{t}_g. \tag{34}$$

6.3.3 State Planners' Preference

I estimate state planners' preferences exploiting the analytical first-order conditions of state planners' problems. Because preference parameters and equilibrium outcomes enter separately in first-order conditions, one can estimate the parameter without resolving the game, which would be computationally costly. By satisfying the optimality

[28] These categories include three terrain ruggedness type in rural area (Flat, Rolling, Mountainous) and four size types for urban area (Small Urban, Small Urbanized, Large Urbanized, Major Urbanized).

[29] An alternative strategy in the literature is to calibrate *link-specific costs* so that, given an assumption on state planners' Pareto weights on other states, their first-order conditions on investment decisions are exactly satisfied. I show in the appendix that, when calibrating the costs to match all FOCs implied by zero Pareto weights on rest of the economy (so that states are purely self-interested), the model will imply highway taxes several times higher than those reported in the data, even when considering the years of relatively high taxation during Interstate Highway System construction. This suggests forces outside of the fiscal costs have prohibited more highway investments; otherwise it takes negative Pareto weights on the rest of the economy to rationalize the observed highway taxes.

condition on edge ij controlled by state planner g, we rule out local perturbations to the observed investment I_{ij} that may increase the payoff to state planner g.

In particular, we assume that states have the same Pareto weights Ω on every other state in the rest of the economy, and postulate that political payoffs r_{ij} has a mean common to all locations, β, and an idiosyncratic component e_{ij} specific to each link. Furthermore, since these political incentives came from localized interest groups, e.g. highway construction firms within the state planner's jurisdiction or local neighborhoods suffering an environmental impact from highway projects nearby, we argue that their idiosyncrasy e_{ij} should be orthogonal to the welfare effect induced outside of the jurisdiction. More precisely, political payoffs should be orthogonal to the variation in externality that is not induced by the variation in the level of the investment. This constraint is relevant because the observed investment I_{ij} depends on its own political payoff e_{ij} through first-order conditions, and depends on political payoffs elsewhere $\{e_{kl}\}_{(k,l)\neq(i,j)}$ through the equilibrium investments in those locations $\{I_{kl}\}_{(k,l)\neq(i,j)}$, which affects the level of externality $\frac{\mathrm{d}(W-W_{g(i)})}{\mathrm{d}I_{ij}}$. As a result, e_{ij} are also correlated with the externality term through the level of investments chosen in equilibrium.

To obtain the clean variation in externalities that do not contain information on political payoffs, I simulate vectors of marginal externalities evaluated at randomized investment vectors and take the average across simulations:

$$\frac{\mathrm{d}\widehat{(W-W_{g(i)})}}{\mathrm{d}I_{ij}} = \frac{1}{100}\sum_n \frac{\mathrm{d}(W-W_{g(i)})}{\mathrm{d}I_{ij}}\Big|_{\{I_{kl}\}_{k,l\in\mathcal{N}(k)}^{rand(n)}}$$

where $\frac{\mathrm{d}(W-W_{g(i)})}{\mathrm{d}I_{ij}}\Big|_{\{I_{kl}\}_{k,l\in\mathcal{N}(k)}^{rand(n)}}$ is the marginal externality incurred by investment on link ij evaluated at the n-th randomized investment vector $\{I_{kl}\}_{k,l\in\mathcal{N}(k)}^{rand(n)}$.[30] Since these investments are off-equilibrium, marginal externalities implied by them do not correlate with the realized political payoffs. The correct set of preference parameters should then satisfy the orthogonality between the average externalities and the realized political payoffs.

Formally, letting

$$-e_{ij} = \frac{\mathrm{d}W_{g(i)}}{\mathrm{d}I_{ij}} + \Omega\frac{\mathrm{d}(W-W_{g(i)})}{\mathrm{d}I_{ij}} + \beta,$$

[30] The same IV strategy has been adopted in Fajgelbaum et al. (2023).

we estimate (Ω, β) from the moment conditions

$$\mathbb{E}_{ij}[e_{ij}] = 0,$$

$$\mathbb{E}_{ij}\left[\frac{\mathrm{d}(\widehat{W - W_{g(i)}})}{\mathrm{d}I_{ij}} \times e_{ij}\right] = 0.$$

The altruistic weight Ω is estimated to be 0.56, suggesting a relatively high extent to which state planners internalized their impact on the rest of the economy. The estimated mean for political payoffs is -8.23×10^{-4}, suggesting that the net effect from highway lobbying and environmental protests on average discourages highway investments. These values substantially varies across links, with a standard deviation of 9.03×10^{-4}. For instance, a link with net zero political payoffs would fall within one standard deviation of the mean.

7 Counterfactual

In this section, I present two sets of counterfactual result. First, I compare the observed network to the national optimal network and highlight the key patterns driven by each inefficiency mechanisms discussed in Section 3. I also decompose the welfare gains in the optimal network into margins from those channels with a first-order approximation. Next, I compute the counterfactual network under different subsidies and Pareto weights in the Nash equilibrium and show their welfare performance.

7.1 Optimal Investment

In the first exercise, I compute the national optimal network according to Definition 3. The equilibrium arising from this network informs us of the welfare loss from decentralized highway investment. In particular, I take the r_{ij} from the estimated residuals in state planners' first-order conditions as detailed in section 6.3.3. I take the vector of keep-tax rates $1 - t_g^{data}$ from the observed equilibrium, which also exactly matches the tax rates in the data, and the national optimal network will be funded by a tax plan that provides keep-tax rates proportional to this vector as detailed in Definition 3.

To solve the high-dimensional non-linear optimization problem, I adopt the Su and Judd (2012) strategy of optimization with equilibrium constraints. In this procedure, the optimization problem takes spatial equilibrium conditions as constraints, and equilibrium variables (prices and population distribution) are searched simultaneously with the decision variables (investments and taxes) until constraints and optimality conditions are both satisfied. This speeds up the optimization by essentially skipping the computation of an exact spatial equilibrium when investments are sub-optimal.[31]

Optimal Investment And Determinants of Distortions

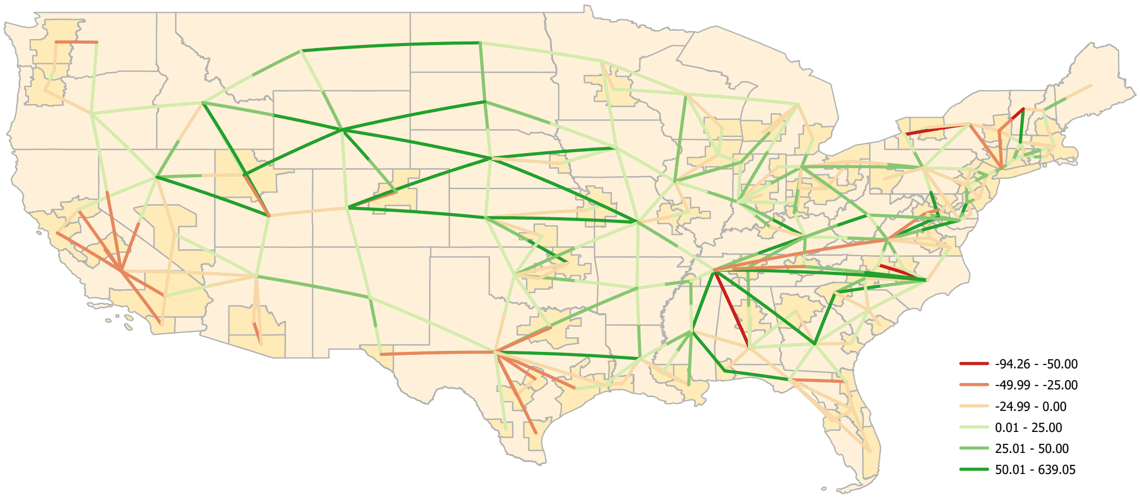
On aggregate, the optimal network delivers a welfare improvement equivalent to an income gain of 0.3 percentage points of GDP, with an increase in aggregate infrastructure spending of 0.19 percentage points of GDP.[32] Figure 3 shows the percentages changes in investment at each highway link in the national optimal network. A salient pattern is that intra-state links tend to receive reduced investments and inter-state links tend to receive more. This reveals the technological externalities from Nash equilibrium: as inter-state links carry way more thoroughfare than the intra-state links, the former is more severely under-invested in a Nash equilibrium if state planners do not perfectly internalize their impact on other states. As a by-product of this mechanism, urban CFS areas (colored in dark shades in the panel on top) tend to receive less investments than they do under the observed network if they are enclosed by the rural area of the same state. Meanwhile, urban areas that touch state borders themselves gain extra investment in the optimal network, especially those that jointly form a metropolitan area. [33]

Another pattern of interest relates the investment patterns with relative market size. In the bottom panel of figure 3, I plot the optimal investment changes against the background colored by market size. Comparing investments of the same state towards different external markets, the links towards destinations towards smaller markets seem to get more investments in the optimal network. Take New Mexico as an example: while investments towards all neighbors are increased, the links towards Rest of Arizona and El Paso-Las Cruces, TX get more additions than those towards larger markets like Rest of Texas and Rest of Colorado. This is suggestive of terms-of-trade externality: reduced

[31]The national planner's problem is not convex, and multiple local optima which satisfy equilibrium constraints and first-order conditions were discovered. Below, I report the result with the highest welfare discovered so far.

[32]These welfare and expenditure changes are predicted under the estimated altruistic weight of 0.56, which is relatively high. In appendix B.1, I show the welfare gains and expenditure changes under alternative calibrations of the altruistic weight. Varying the altruistic weights from 0.05 to 0.95 predicts values of welfare gains ranging from 0.05% to 0.98% of GDP, with lower weights implying greater welfare gains.

[33]Examples include zones that jointly form the metropolitan area around Philadelphia (PA-NJ-DE-MD) and New York (NY-NJ-CT-PA).



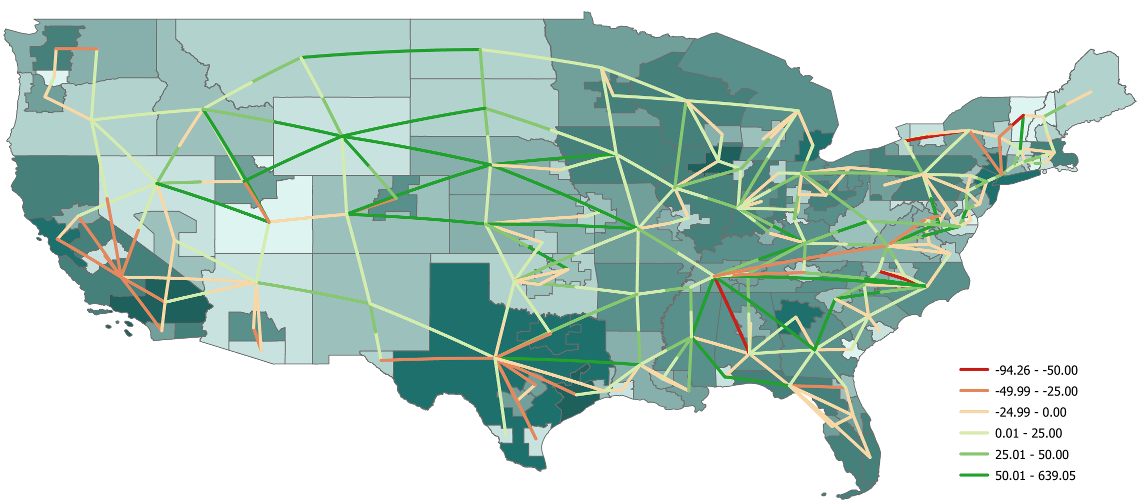


Figure 3: Optimal Investment Changes and Location Fundamentals.

Note: Numbers shown in percentage. In the top panel, darker background colors represent urban CFS areas. In the bottom panel, darker background colors represent CFS areas with larger market size.

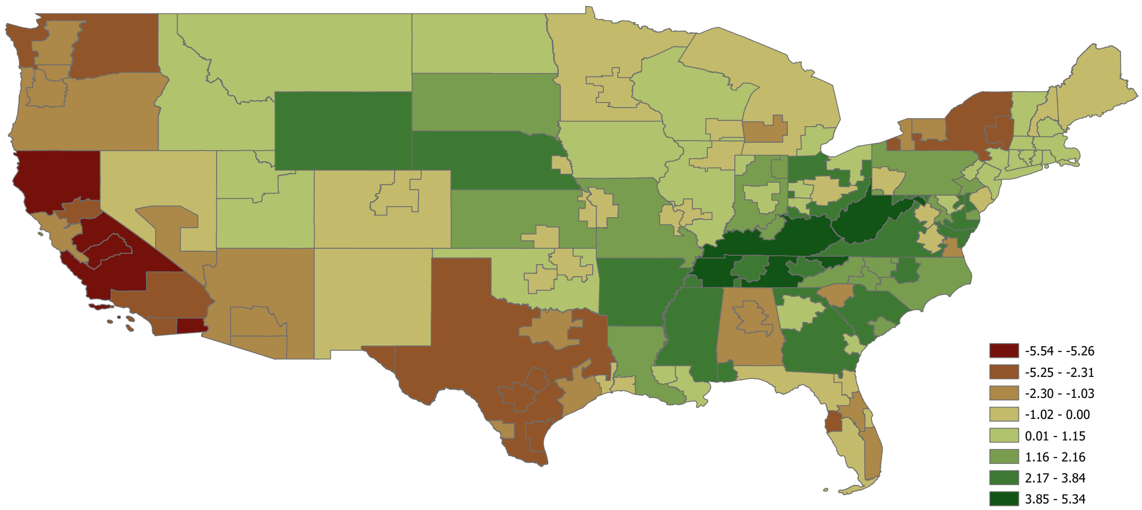


Figure 4: Population Changes Under Optimal Network.

Note: Areas losing population are shaded red; those gaining population are shaded green.

bilateral trade cost towards a relatively small market tends to depreciate the investor's terms of trade, coupled with the appreciation of terms of trade in the destination market, hence discourages investments by a local planner.

Table 5 shows that these patterns are systematic. In this table, I document the correlation between percent changes of investment in the optimal network and local economic characteristics. Column 1 shows that links connecting a pair of zones belonging to the same state (*intrastate links*) on average receive 39% less incremental investment than other links. To further confirm that the gap is driven by technological externalities, Table 6 shows that intrastate links on average carry 29% less external goods flows (column 2) than interstate ones. It further reveals that while the magnitude of investment increase positively correlates with the share of external goods flows for intrastate links (column 3 and 5), the same pattern is not obvious on interstate links (column 4 and 6). As later analysis would show, a more complicated mixture of externalities on interstate links is concealed under this null result.

Relative market size, which determines the size and magnitude of terms-of-trade externality, will contribute negative changes in optimal investment according to the model prediction. Since terms of trade at smaller markets are more elastic than those at larger

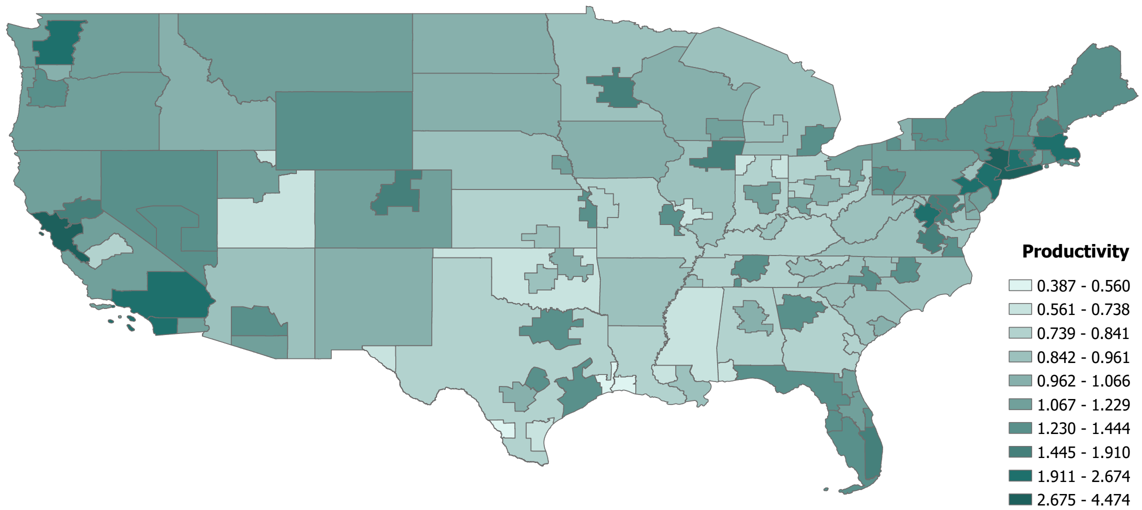


Figure 5: Fundamental Productivity.

Note: Productivity of Birmingham-Hoover-Talladega, AL is normalized to 1.

markets, investments towards the former tend to create positive terms-of-trade externality at the cost of the investor's terms of trade, discouraging investments in a non-cooperative Nash equilibrium. Column 2 in Table 5 verifies this prediction. On inter-state links, investment changes ($\frac{\Delta I_{ij}}{I_{ij}}$) negatively correlates with the market size in the destination relative to the investor's location ($\frac{E_j}{E_i}$). As a placebo test, the same pattern does not show up for internal links, for which terms-of-trade effects on both ends are internalized by state planners (column 3). Column 4 and 5 show that the investor with a comparative advantage in amenity tends to under-invest more severely towards smaller markets, whereas those with a disadvantage in amenity do not seem to inefficiently favor larger markets. This reveals an interaction between incentives from goods market and labor market: while it is tempting to reduce trade costs towards a larger market from the terms-of-trade perspective, the simultaneous reduction in commuting costs to that market could backfire if the latter happens to offer better amenities, as local workers who currently live in the same place may find it more appealing to relocate to the high-amenity area and commute from there.

Finally, we examine how fiscal capacity drives inefficient investment. Column 6 shows that, on interstate links, investments face greater shortfalls if they would cause a larger reduction in investor's keep-tax rate. Specifically, *Tax Response* is computed by the total derivative of local keep-tax rates in response to a marginal increase in investment, accounting for the full adjustment in general equilibrium. Conditional on marginal cost, an additional drop of 1% in keep-tax rate implies an additional 65% underinvestment.[34] This reflects the inefficiency from endogenous fiscal budget: while highway expenditure incurs local fiscal burden and drives emigration with increased tax rates, tax base is transferred towards locations that receive migrants. Without internalizing the transfer, a local planner would under-invest on links that trigger large increases on local tax. Accordingly, intra-state links do not show the same negative effect from *Tax Response* (column 7), confirming that the correlation stems from imperfect internalization.

To further understand how much each of these channels matter, we perform the following decomposition. For the optimal change in investment on link *od*, it induces adjustments in social planner's objective and state planners' objective, the gap between which measures the externality of such a change. We decompose the local-linear approximation of this gap into terms discussed in subsection 4.3:

$$
\begin{aligned}
\Delta_{I,od}W - \Delta_{I,od}W_g \simeq & \sum_{i,j} \omega_{ij}^{od} \Delta_{I,od} U_{ij}, \\
\Delta_{I,od}U_{ij} = & U_{ij} \times \Big(\underbrace{\mathrm{d}_{I,od} \ln p_i - \sum_k S_{ik} \times \mathrm{d}_{I,od} \ln p_k}_{\text{Terms of trade}} \\
& \underbrace{- \sum_k S_{ik} \times \mathrm{d}_{I,od} \ln \tau_{ki}}_{\text{Logistics technology}} - \underbrace{\mathrm{d}_{I,od} \ln \kappa_{ij}}_{\text{Commuting technology}} \\
& + \underbrace{\mathrm{d}_{I,od} \ln(1 - t_i)}_{\text{Fiscal costs+externality}} + \underbrace{a \times \mathrm{d}_{I,od} \ln L_j}_{\text{Agglomeration spillover}} + \underbrace{b \times \mathrm{d}_{I,od} \ln R_i}_{\text{Amenity congestion}} \Big) \\
& \times \Delta I_{od}, \\
\omega_{ij}^{od} = & \frac{W}{U_{ij}} \lambda_{ij} (1 - R_{g(i)} + \varepsilon R_{g(i)} - \varepsilon \mathbb{I}\{o \in J(i)\}),
\end{aligned}
$$

where $\mathrm{d}_{I,od}X$ denotes the total derivative of the equilibrium variable X with respect to I_{od}. We first compute the magnitude of the derivatives in each externality term, then multiply them with the change in investment ΔI_{od} in the optimal network relative to the observed one. Summing these effects across all links yields the first-order welfare impact of each externality.

Table 4 reveals that the aggregate welfare loss masks quantitatively important roles

[34]The standard deviation in keep-tax rate response is 0.107%.

of each externality channel, which largely offset one another. Column 1 shows that, switching from the observed network to an optimal one, host states receive transfers through terms-of-trade adjustments, which amount to 14% of the total gains accruing to the rest of the nation. Columns 2 and 3 confirm the positive spillover from serving through traffic, for both freights and passengers. Because of a relatively high share of interstate trade flows compared to commuting traffic, cross-border freights account for the bulk of such spillovers. Column 4 shows that, after accounting for cross-state cost sharing implicit from the federal subsidy, optimal investments would make non-investor states marginally more attractive to taxpayers as their tax rates fall relative to the investor state; failing to internalize this fiscal spillover accounts for 46% of the gap between investor payoffs and the national return. Finally, local spillovers induced by population mobility matters: shifts in amenities reduce the rest of the nation's welfare gains by 47.2%, while productivity shifts raise them by 13.6%.

Terms of Trade	Thoroughfare		Fiscal	Spillovers		Total
	Goods	Commuters		Amenity	Productivity	
-14.4%	93.1%	8.8%	46.0%	-47.2%	13.6%	100%

Table 4: Decomposition of Strategic Inefficiency

Impact on Population Distribution

Figure 4 shows the redistribution of population across CFS zones. As the surrounding rural area tends to get more investments than the enclosed urban area, the latter tends to lose population and the former tends to gain.[35] In states with many urban areas (so that the rural area is divested), urban zones that touch state borders tend to gain population; but in states where few urban area exists, even if an urban area touches the border and gets additional investment, the surrounding rural area tends to gain much more investment as they share state borders with more locations, hence attract population from the urban zone.

Another intriguing pattern is the apparently progressive nature of population relocation. Among the rural locations that gain additional investment in the optimal network, those with lower productivity (illustrated in figure 5) seem to experience more sizable immigration, for instance, in the Appalachian Mountains. One driver behind this pattern

[35]Rest of CA, TX and NY are obvious exceptions to this pattern – these rural areas had too much intra-state investment towards a multitude of urban areas to start with, and investments are withdrawn from them in the optimal network.

is that workers have idiosyncratic preferences over locations, and on aggregate, the average utility exhibits love of variety. A national planner thus has an incentive to harmonize the value of all varieties so that more individuals with extreme preferences can be satisfied. In addition, technological externalities and fiscal constraint are also dominant drivers for some specific cases. We discuss several cases in Appendix D.

	Dependent variable:						
	Percent Changes in Optimal Investment						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Intrastate Links	-39.260^{***}						
	(4.321)						
Dest. Rel. Market Size		-3.924^{**}	-1.325	-19.033^{**}	-2.320		
		(1.794)	(1.107)	(9.398)	(2.753)		
Tax Response						-63.043^{**}	-43.484
						(29.854)	(36.582)
Marginal Cost						-0.492	-3.088^{***}
						(3.353)	(0.895)
Constant						26.071^{***}	-11.628^{***}
						(5.209)	(1.776)
Origin FE	Yes	Yes	Yes	Yes	Yes	No	No
Sample	All	External	Internal	Ext, ui>uj	Ext, ui<uj	External	Internal
Observations	502	302	200	151	151	302	200
R^2	0.301	0.224	0.515	0.266	0.329	0.015	0.049
Adjusted R^2	0.059	-0.191	-0.149	-0.265	-0.438	0.009	0.039

Note: Dest. Rel. Market Size represents the ratio between market sizes of investment destination and origin. Market size is proxies by total inbound trade flows in CFS 2017. *Tax Response* represents the changes in local keep-tax rates in response to a marginal unit of investment on a given link. A 0.01 reduction in this variable represents an extra 1% raise in local tax. *Marginal Cost* is the cost shifter $\delta^I_{ij|i}$. *Internal* and *External* represent the subsample of intrastate and interstate links, respectively. $ui > uj$ represents a subsample of interstate links where the origin has better fundamental amenity than the destination, and $ui < uj$ represents the reverse. Standard errors clustered by origin FAF zone. $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$.

Table 5: Optimal Percent Changes in Investments and Fundamentals

	Dependent variable:					
	$\Delta I^{opt}(\%)$	Share of External Goods Flow	$\Delta I^{opt}(\%)$			
	(1)	(2)	(3)	(4)	(5)	(6)
Intrastate Links	-39.260^{***}	-0.291^{***}				
	(4.321)	(0.013)				
Share of External Goods Flow			56.980^{***}	9.804	80.475^{***}	20.166
			(4.564)	(39.997)	(12.612)	(112.216)
Constant			-29.667^{***}	25.575		
			(1.572)	(26.606)		
Origin FE	Yes	Yes	No	No	Yes	Yes
Sample	All	All	Internal	External	Internal	External
Observations	502	502	200	302	200	302
R^2	0.301	0.868	0.398	0.0003	0.667	0.221
Adjusted R^2	0.059	0.822	0.395	-0.003	0.212	-0.196

Note: Internal and *External* represent the subsample of intrastate and interstate links, respectively. Standard errors clustered by origin FAF zone. *p<0.1; **p<0.05; ***p<0.01.

Table 6: Optimal Percent Changes in Investments and Share of External Goods Flows

7.2 Alternative Subsidies and Altruistic Weights

In this section, I present Nash equilibrium under counterfactual subsidies implemented in the Northeast Census Region, assuming the area forms a closed economy with a fixed total population; the "federal" policy in this case corresponds to a self-liquidating combination of a uniform regional tax (on top of state taxes) and a fixed reimbursement rate for states' highway construction costs. I compare the baseline equilibrium with those under multiple alternative subsidy rates to assess the efficacy of uniform national highway subsidies in addressing the strategic inefficiencies. I also show that the welfare gains from cooperation are concave, and the equilibrium would be much less efficient if no cooperation were in place.

Aggregate Changes

Table 7 shows the percent changes in welfare and infrastructure expenditure under various alternative subsidy rates. Relative to the prevailing 34.5% subsidy, moderately increased subsidies improves welfare. This is consistent with the finding that the optimal network overall demands more investment than the observed level. When the subsidy rate rises to 90%, however, welfare drops relative to the Nash equilibrium under a lower subsidy while investment keeps growing. Two forces are at work here. First, since the investment technology exhibits decreasing returns to scale, returns diminish as investment accumulates. Second, as the subsidy shifts much of the cost to the rest of the economy, only a small share of the cost is internalized by the local government, while much of the benefits accrue only locally. In the language of the model, when the bulk of costs are funded by the uniform federal tax, any local investment triggers only a mild rise in local tax, unlike the case with a smaller federal contribution. This reduces incentives for residents to emigrate in response to the rise in local tax, lowering the perceived cost from the local planner's perspective. On the other hand, improved infrastructure disproportionately improves market access in goods and labor for the local economy, which implies higher real wages and lower commuting costs, and attracts immigration as a result. This combination of concentrated benefits and diffused costs generates the observed over-investment under high subsidies.

Subsidy Rate	10%	30%	34.5%	50%	70%	90%
ΔU (% GDP)	-0.197	-0.036	0.000	0.121	0.248	0.099
ΔG (% GDP)	-0.08	-0.02	0.000	0.09	0.25	0.73

Table 7: Changes in Welfare and Infrastructure Expenditure Under Alternative Subsidies, Northeast

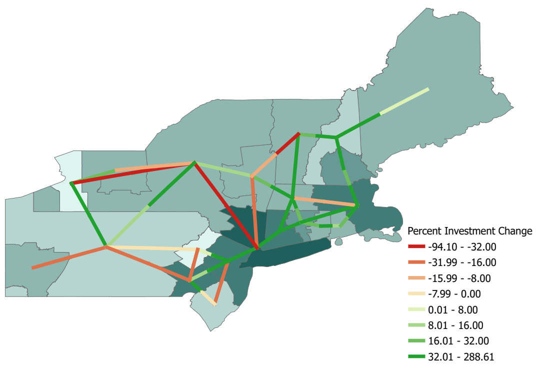
Table 8 compares the welfare implication of different levels of cooperation between states. Starting from the baseline in the Northeast, where the altruistic weight is estimated at 0.28, moving toward deeper cooperation ($\Omega = 0.5$) would bring welfare gains equivalent to 0.46% of regional income, while reverting to zero cooperation would incur losses more than twice as large, equivalent to 1.04% of regional income. Comparing the last two columns, most of the welfare gap between the observed and optimal networks stems from the absence of cooperation; the national planner's ability to reallocate fiscal revenue plays a relatively marginal role in improving efficiency. However, such flexibility does improve cost effectiveness, as total infrastructure spending rises less under the global optimum than the fully cooperative Nash equilibrium ($\Omega = 1$).

Altruism	$\Omega = 0$	$\Omega = 0.28$	$\Omega = 0.5$	$\Omega = 1$	Global Planner
ΔU (% GDP)	-1.04	0.00	0.46	1.02	1.04
ΔG (% GDP)	-0.11	0.00	0.11	0.32	0.31

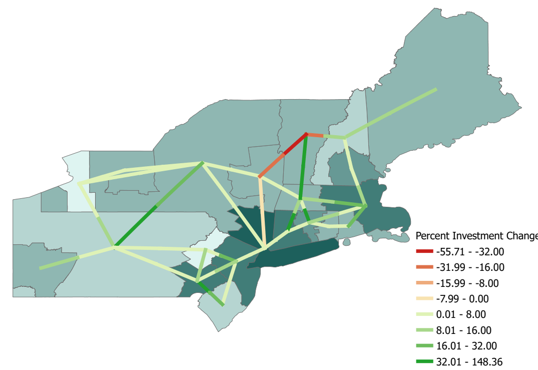
Table 8: Changes in Welfare and Infrastructure Expenditure Under Alternative Altruistic Weights, Northeast

Distributive Changes

To further understand the effect of subsidy policy changes, we now explore how states respond to increased subsidy and how these responses reallocate economic activities. Figure 6 shows the comparison between the percent investment changes demanded by the optimal network and those arising from a Nash equilibrium with 60% subsidy. With few exceptions, increased subsidies invite more investments by local governments on almost all linkages, whereas the optimal network requires reduction on many links especially intra-state ones. This explains the limited improvement of efficiency offered by subsidy – while the network overcomes the overall under-investment, misallocation across links due to strategic incentives are not targeted by a uniform subsidy.



(a) Optimal Network, $\Delta U = 1.036\%$ GDP



(b) Nash Under 60% Subsidy, $\Delta U = 0.194\%$ GDP

Figure 6: Percent Investment Changes Relative to Observed Network.

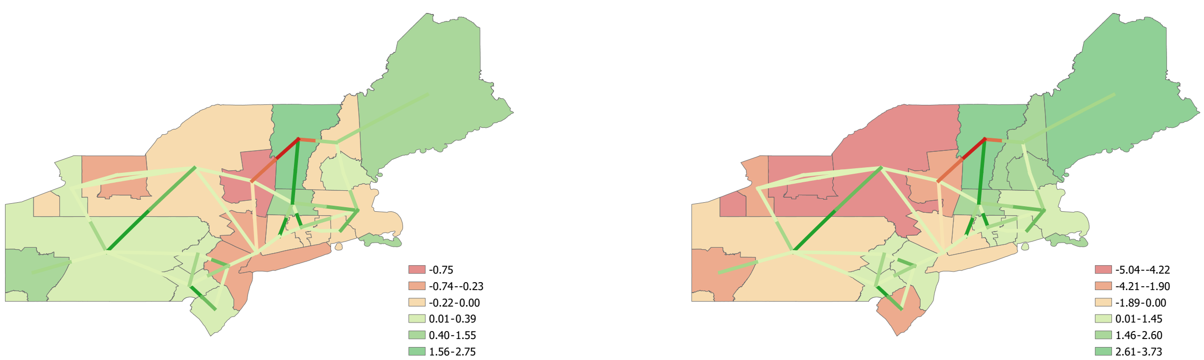
Note. Areas are shaded by fundamental productivity. Numbers in legend denote changes in investments on each link by percentage points of the observed investment on the same link.

How does the increase in federal subsidy reallocate economic activities through the endogenous changes in highway network? Figure 7 shows the reallocation of residents and workers in the counterfactual Nash equilibrium under a moderately raised, 60% federal highway subsidy. Their fundamental productivity and amenity are plotted in panels (a) and (b) in figure 9. Perhaps surprisingly, locations with high productivity did not necessarily gain more workers with the extra subsidy available. In contrast, locations with mediocre productivity and amenity like Vermont and Rest of Massachusetts gained both workers and residents. This emphasizes the importance to take into account of states' strategic reactions to subsidies, which will bring different spatial reallocation than a uniform reduction of transportation costs across the space.

In particular, we highlight that lowering import costs and manipulating terms of trade are important considerations behind states' strategic reactions. To see this, compare figure 7 and figure 8. In figure 8, we show the percent changes in output prices – depicting terms-of-trade adjustments – and reductions in local consumer price indices in the counterfactual. Compared to figure 7, locations that experienced improvement in terms of trade tend to gain workers, and locations with relatively large reductions in price indices tend to gain residents.[36] These gains are achieved by markets of relatively

[36]One noticeable exception is Remainder of New Hampshire, which did not rank high in either terms-of-trade gains or price index reduction but still had mild gains in residents. Notice the other part of New Hampshire (the NH part of Boston metropolitan) gained much in price index and becomes more attractive to residents, which implied that state tax only need to be raised by very little relative to other states. This gives an advantage to Remainder of New Hampshire.

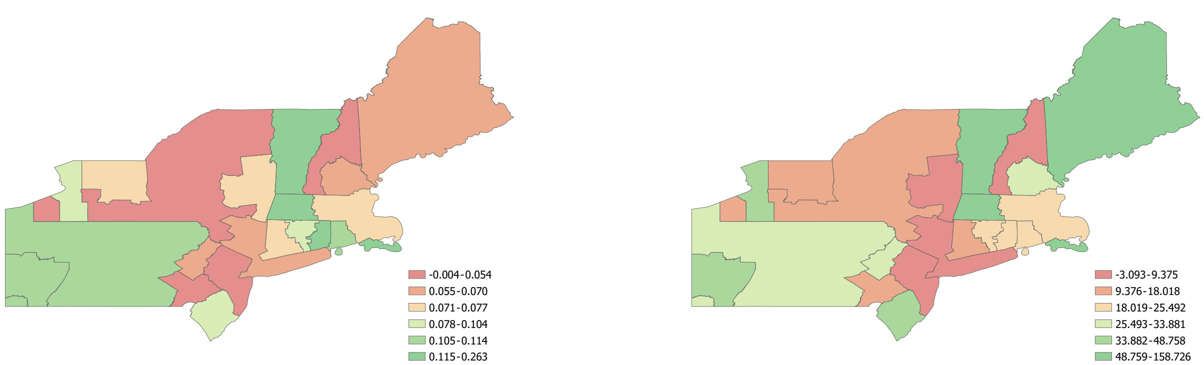
small size aggressively increase investments on roads connecting to larger markets. Such investments improve their terms of trade, owing to the large share of sales towards the latter, and lower their price index, given the large share of expenditure devoted to them. For instance, while not a top productive location by its own, Vermont strategically increased investments towards Rest of Massachusetts, a relatively large market among its neighbors (shown in panel (c) of figure 9, which also indirectly lowers the trade costs with Connecticut and New York city, a few big markets in some distance. The reduction in trade costs increases Vermont's sales towards those large markets and reduces the importing costs from them, bringing gains both in terms of trade and price index.



(a) Percentage Changes in Workers

(b) Percentage Changes in Residents

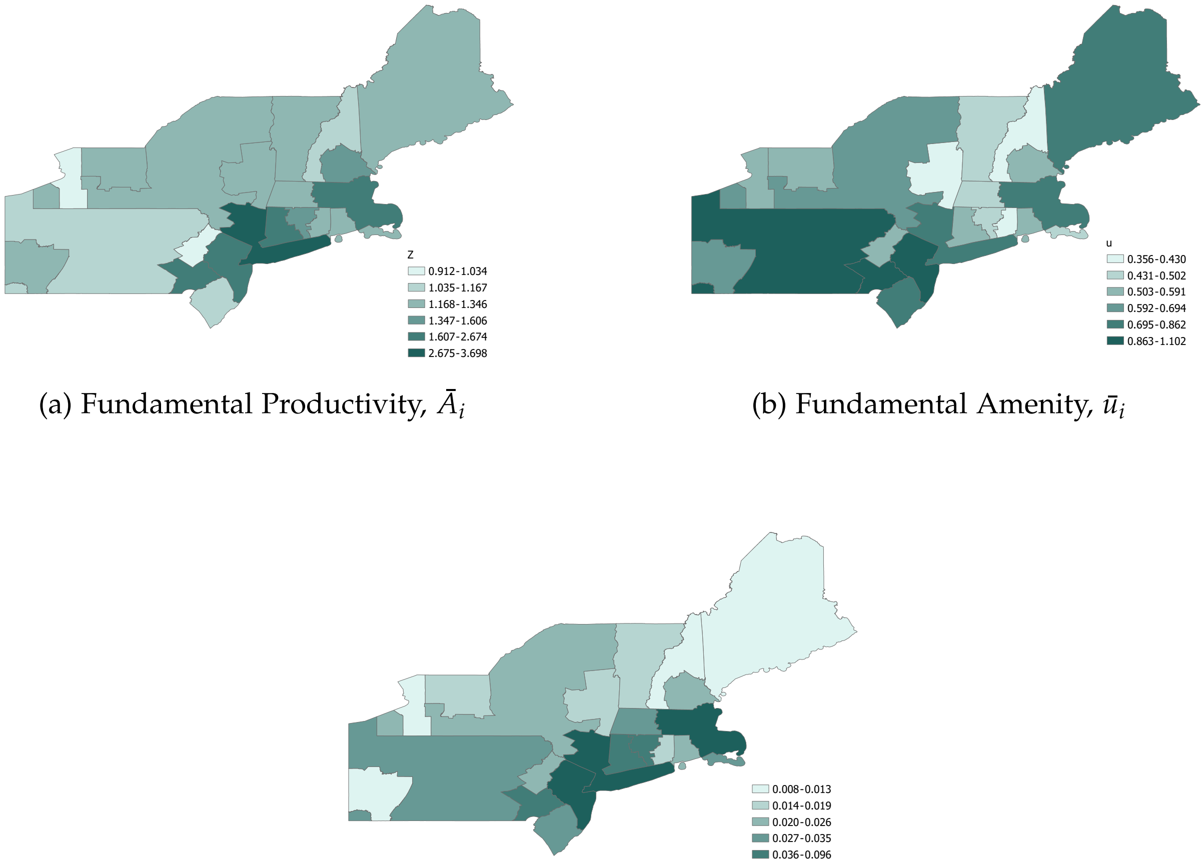
Figure 7: Population Redistribution Under 60% Subsidy.



(a) Percent Increase in Output Price

(b) Percent Reductions in Price Index

Figure 8: Price Changes Under 60% Subsidy.



(a) Fundamental Productivity, $\bar{A}_i$

(b) Fundamental Amenity, $\bar{u}_i$

(c) Market Size, E_i (Observed Equilibrium)

Figure 9: Economic Characteristics of Northeast Region.

8 Conclusion

This paper studies the inefficiencies brought by decentralized investments in the U.S. highway network, and assesses the implications of federal highway subsidies given this institution. It first documents empirical patterns in the U.S. highway system illustrating that state borders negatively impacts time to travel, availability of direct highway connections, and quality of roads. Beginning by developing a general theoretical framework, this study highlights three origins of inefficiency brought by strategic investments of non-cooperative state planners: through-traffic externality, terms-of-trade externality, and fiscal externality.

The paper proceeds to parameterize the model for a quantitative application on the U.S. highway system, which features state-driven investment decisions and a locationblind federal highway subsidy. Accounting for the potential imperfect coordination between states, the paper estimates a Pareto weight of 0.56, a ratio by which states value the welfare of constituents of other jurisdictions relative to their own. Under the estimated parameters, the lack of cooperation between states incurred a welfare loss equivalent to 0.3% of GDP relative to a nationally optimal network. The observed network is overall under-invested, and interstate linkages on average face a greater shortfall compared to intrastate ones, highlighting the role of externalities due to through-traffic. Furthermore, linkages tend to be most severely under-invested if they connect the investor towards a smaller market, a consequence of terms-of-trade externalities, and if they trigger a sensitive reaction in state taxes, manifesting the effect of fiscal externalities.

Further counterfactual exercises show that raising subsidies can at best partially overcome the strategic inefficiency, but overdoing it can backfire due to the diffused fiscal cost that states fail to internalize. Finally, forces driving strategic inefficiencies also play a role when states respond to subsidy adjustments by their investments. When considering the distributive effect of raising subsidies, policy makers should take into account the endogenous reallocation of states investments, which may predict a reallocation of economics activities that differ substantially from those implied by simplified assumptions, such as a uniform reduction in transportation costs.

References

Adão, R., Becko, J. S., Costinot, A., and Donaldson, D. (2024). A world trading system for whom? evidence from global tariffs.

Allen, T. and Arkolakis, C. (2014). Trade and the topography of the spatial economy *. *The Quarterly Journal of Economics*, 129(3):1085–1140.

Allen, T. and Arkolakis, C. (2022). The Welfare Effects of Transportation Infrastructure Improvements. *The Review of Economic Studies*, 89(6):2911–2957.

Allen, T., Arkolakis, C., and Li, X. (2024). On the equilibrium properties of spatial models. *American Economic Review: Insights*, 6(4):472–89.

Allen, T., Arkolakis, C., and Takahashi, Y. (2020). Universal gravity. *Journal of Political Economy*, 128(2):393–433.

Almagro, M., Barbieri, F., Camilo Castillo, J., Hickok, N. G., and Salz, T. (2024). Optimal urban transportation policy: Evidence from chicago. Working Paper 32185, National Bureau of Economic Research.

Bagwell, K. and Staiger, R. W. (1999). An economic theory of gatt. *American Economic Review*, 89(1):215–248.

Barrow, R. V. (1967). *The Politics Of Interstate Route Selection: A Case Study Of Interest Activities In A Decision Situation*.

Baum-Snow, N. (2007). Did highways cause suburbanization?*. *The Quarterly Journal of Economics*, 122(2):775–805.

Baum-Snow, N., Brandt, L., Henderson, J. V., Turner, M. A., and Zhang, Q. (2017). Roads, railroads, and decentralization of chinese cities. *The Review of Economics and Statistics*, 99(3):435–448.

Baum-Snow, N., Henderson, J. V., Turner, M. A., Zhang, Q., and Brandt, L. (2020). Does investment in national highways help or hurt hinterland city growth? *Journal of Urban Economics*, 115:103124. Cities in China.

Bonadio, B. (2024). Ports vs. roads: Infrastructure, market access and regional outcomes. CESifo Working Paper Series 11383, CESifo.

Bordeu, O. (2023). Commuting infrastructure in fragmented cities. Working paper.

Brancaccio, G., Kalouptsidi, M., and Papageorgiou, T. (2024). Investment in infrastructure and trade: The case of ports. Working Paper 32503, National Bureau of Economic Research.

Davis, J. (2022). A history of the secretary's ability to approve (or disapprove) highway projects. Technical report. Eno Center for Transportation.

Donaldson, D. and Hornbeck, R. (2016). Railroads and american economic growth: A "market access" approach *. *The Quarterly Journal of Economics*, 131(2):799–858.

Duranton, G. (2015). Roads and trade in colombia. *Economics of Transportation*, 4(1):16–36. Special Issue on Collective Contributions in the Honor of Richard Arnott.

Duranton, G., Morrow, P. M., and Turner, M. A. (2014). Roads and Trade: Evidence from the US. *The Review of Economic Studies*, 81(2):681–724.

Duranton, G. and Turner, M. A. (2012). Urban Growth and Transportation. *The Review of Economic Studies*, 79(4):1407–1440.

Egger, P. H., Loumeau, G., and Loumeau, N. (2023). China's dazzling transport-infrastructure growth: Measurement and effects. *Journal of International Economics*, page 103734.

Faber, B. (2014). Trade Integration, Market Size, and Industrialization: Evidence from China's National Trunk Highway System. *The Review of Economic Studies*, 81(3):1046–1070.

Fajgelbaum, P. D., Gaubert, C., Gorton, N., Morales, E., and Schaal, E. (2023). Political preferences and transport infrastructure: Evidence from california's high-speed rail. Working Paper 31438, National Bureau of Economic Research.

Fajgelbaum, P. D. and Schaal, E. (2020). Optimal transport networks in spatial equilibrium. *Econometrica*, 88(4):1411–1452.

Federal-Aid Highway Act (1944). Federal-aid highway act of 1944. `https://govtrackus.s3.amazonaws.com/legislink/pdf/stat/58/STATUTE-58-Pg838a.pdf`. Public Law 78-521; 58 Stat. 838.

Federal Highway Administration (2017). From names to numbers: The origins of the u.s. numbered highway system. Technical report, U.S. Department of Transportation, Federal Highway Administration.

Federal Highway Administration (2023). Designating the urban interstates. Technical report, U.S. Department of Transportation, Federal Highway Administration.

Felbermayr, G. and Tarasov, A. (2022). Trade and the spatial distribution of transport infrastructure. *Journal of Urban Economics*, 130(C):S009411902200050X.

Ferrari, A. and Ossa, R. (2023). A quantitative analysis of subsidy competition in the u.s. *Journal of Public Economics*, 224:104919.

Greenstone, M., Hornbeck, R., and Moretti, E. (2010). Identifying agglomeration spillovers: Evidence from winners and losers of large plant openings. *Journal of Political Economy*, 118(3):536–598.

Head, K. and Ries, J. (2001). Increasing returns versus national product differentiation as an explanation for the pattern of u.s.-canada trade. *American Economic Review*, 91(4):858–876.

Hierons, T. (2024). Spreading the jam: Optimal congestion pricing in general equilibrium. *Working Paper*.

Hornbeck, R. and Rotemberg, M. (2024). Growth off the rails: Aggregate productivity growth in distorted economies. *Journal of Political Economy*, 132(11):3547–3602.

Kanbur, R. and Keen, M. (1993). Jeux sans frontières: Tax competition and tax coordination when countries differ in size. *The American Economic Review*, 83(4):877–892.

Keen, M. and Konrad, K. A. (2013). Chapter 5 - the theory of international tax competition and coordination. In Auerbach, A. J., Chetty, R., Feldstein, M., and Saez, E., editors, *handbook of public economics, vol. 5*, volume 5 of *Handbook of Public Economics*, pages 257–328. Elsevier.

Kornfeld, R. and Fraumeni, B. M. (2022). How should we measure infrastructure? the case of highways and streets. Working Paper 30045, National Bureau of Economic Research.

Kreindler, G., Gaduh, A., Graff, T., Hanna, R., and Olken, B. A. (2023). Optimal public transportation networks: Evidence from the world's largest bus rapid transit system in jakarta. Working Paper 31369, National Bureau of Economic Research.

Loumeau, G. (2023). Regional borders, commuting and transport network integration. *The Review of Economics and Statistics*, pages 1–45.

Ma, L. and Tang, Y. (2024). The distributional impacts of transportation networks in china. *Journal of International Economics*, 148:103873.

Michaels, G. (2008). The effect of trade on the demand for skill: Evidence from the interstate highway system. *The Review of Economics and Statistics*, 90(4):683–701.

Monte, F., Redding, S. J., and Rossi-Hansberg, E. (2018). Commuting, migration, and local employment elasticities. *American Economic Review*, 108(12):3855–90.

Muñoz, M. (2023). How much are the poor losing from tax competition? NBER Working Paper 31920, National Bureau of Economic Research.

Nagy, D. K. (2023). Hinterlands, city formation and growth: Evidence from the u.s. westward expansion. *The Review of Economic Studies*, 90(6):3238–3281.

Oates, W. E. (1999). An essay on fiscal federalism. *Journal of Economic Literature*, 37(3):1120–1149.

Ossa, R. (2011). A "new trade" theory of gatt/wto negotiations. *Journal of Political Economy*, 119(1):122–152.

Ossa, R. (2018). A quantitative analysis of subsidy competition in the u.s. Working Paper 20975, National Bureau of Economic Research.

Redding, S. and Turner, M. (2015). Transportation costs and the spatial organization of economic activity. In *Handbook of Regional and Urban Economics*, volume 5, chapter Chapter 20, pages 1339–1398. Elsevier.

Redding, S. J. (2016). Goods trade, factor mobility and welfare. *Journal of International Economics*, 101:148–167.

Redding, S. J. and Rossi-Hansberg, E. (2017). Quantitative spatial economics. *Annual Review of Economics*, 9(Volume 9, 2017):21–58.

Redding, S. J. and Sturm, D. M. (2008). The costs of remoteness: Evidence from german division and reunification. *American Economic Review*, 98(5):1766–97.

Santamaria, M. (2021). *Reshaping Infrastructure: Evidence from the division of Germany*. University of Warwick, Centre for Competitive Advantage in the Global Economy.

Su, C.-L. and Judd, K. L. (2012). Constrained optimization approaches to estimation of structural models. *Econometrica*, 80(5):2213–2230.

Tsivanidis, N. (2023). Evaluating the impact of urban transit infrastructure: Evidence from bogotá's transmilenio. *University of California, Berkeley*.

Weiwu, L. (2024). Unequal access: Racial segregation and the distributional impacts of interstate highways in cities. Working paper.

A Details and Derivations of The General Model

A.1 Primitives of Stylized Examples

A.2 Derivations for Utility Decomposition

By envelope theorem, the derivative of price index at location i with respect to prices of imports from location k is

$$\frac{\mathrm{d}P_i}{\mathrm{d}p_{ik}} = \frac{c_{ij,k}}{C_i\left(\left\{c_{ij,k}\right\}_k\right)} \forall j, \tag{35}$$

which says that the derivative of price index with respect to price of any commodity equals the unit demand of commodity.

Worker's expenditure can be written as a function of fundamental utility, prices, local amenity and commuting costs:

$$e_{ij} = e\left(U_{ij}, \left\{p_{ji}\right\}_j, u_i(R_i), \kappa_{ij}\right).$$

Let $Y_X = \frac{\partial Y}{\partial X}$ and $Y_{X,ij} = \frac{\partial Y_{ij}}{\partial X_{ij}}$. Take total differentiation and apply Shephard's Lemma,

$$\mathrm{d}e_{ij} = e_U \mathrm{d}U_{ij} + \sum_k c_{ij,k}\left(\tau_{ki}\mathrm{d}p_k + p_k \mathrm{d}\tau_{ki}\right) - U_{e,ij}^{-1} U_{u_i} u_i'(R_i)\mathrm{d}R_i - U_{e,ij}^{-1} U_\kappa \mathrm{d}\kappa_{ij}. \tag{36}$$

On the other hand, differentiate workers' and local governments' budget constraints (2)(3),

$$\mathrm{d}e_{ij} = y_j(L_j)\mathrm{d}p_j + p_j \mathrm{d}y_j(L_j) - P_i\left(K_i \mathrm{d}R_i^{-1} + R_i^{-1} dK_i\right) - T_i \sum_k \frac{\mathrm{d}P_i}{\mathrm{d}p_{ik}}\left(\tau_{ki}\mathrm{d}p_k + p_k \mathrm{d}\tau_{ki}\right). \tag{37}$$

Combining equations (35), (36) and (37), we can rewrite changes in indirect utility U_{ij} as

$$\begin{aligned} U_{e,ij}^{-1}\mathrm{d}U_{ij} = & -\underbrace{\sum_k m_{ij,k} p_k \mathrm{d}\tau_{ki}}_{\text{import technology}} + U_{e,ij}^{-1} \underbrace{U_{comm,ij}\mathrm{d}\kappa_{ij}}_{\text{commuting technology}} - \underbrace{R_i^{-1} P_i \mathrm{d}K_i}_{\text{direct fiscal costs}} \\ & -\underbrace{\sum_k m_{ij,k}\tau_{ki}\mathrm{d}p_k}_{\text{terms of trade}} + \underbrace{\left(T_i P_i \mathrm{d}R_i\right)}_{\text{fiscal externality}} + \underbrace{p_j \mathrm{d}y_j(L_j)}_{\text{productivity spillover}} + \underbrace{U_{e,ij}^{-1} U_{amen,ij} u_i'(R_i)\mathrm{d}R_i}_{\text{amenity congestion}} \end{aligned} \tag{38}$$

where $m_{ij,k}$ is the quantity that choice ij imports (exports if negative) from k for each individual, inclusive of consumption and tax contribution:

$$m_{ij,k} = c_{ij,k} + \frac{T_i}{C\left(\left\{c_{ij,k}\right\}_k\right)} c_{ij,k} - \mathbb{I}\left\{j = k\right\} y_j.$$

B Robustness Checks on Calibration

B.1 Alternative Calibrations of Altruistic Weights

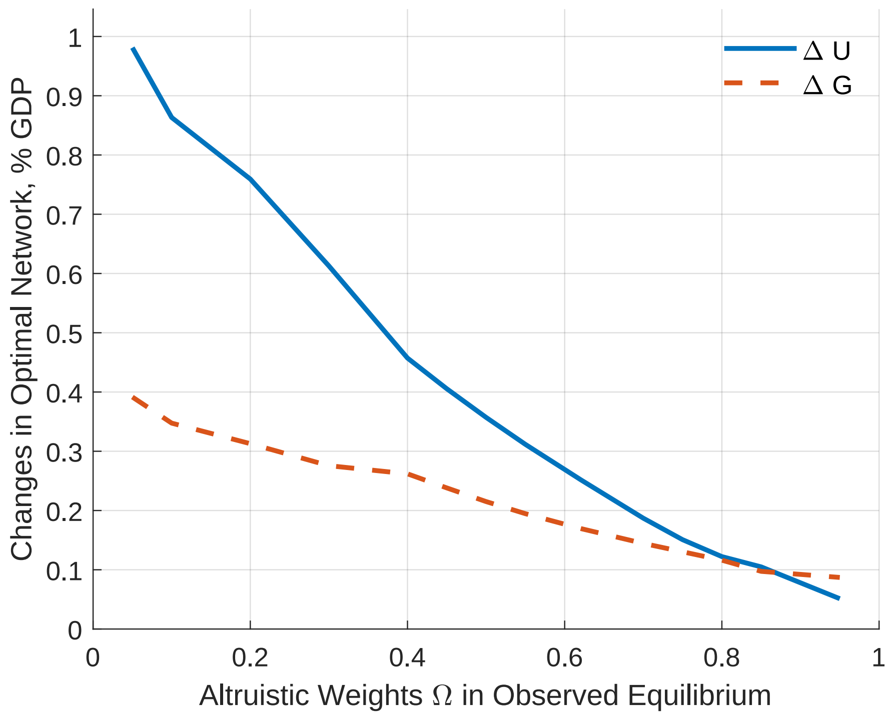


Figure 10: Welfare Gains And Spending Increases Under Optimal Network Under Different Calibrations of Ω

Table 9: Estimates of Altruistic Preference Weight

	Dependent variable:				
	Private Returns to Investment				
	(1)	(2)	(3)	(4)	(5)
Externality	-0.621^{***}				
	(0.205)				
Instrumented Externality		-0.549^{**}	-0.490^{**}	-0.550^{***}	-0.564^{***}
		(0.215)	(0.217)	(0.188)	(0.192)
Constant	0.001^{***}	0.001^{***}	0.001^{***}	0.001^{***}	0.001^{***}
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
First-stage F		80	29	119	423
Instrument	No	Cfc 1	Cfc 2	Cfc 3	Cfc Mean
Observations	502	502	502	502	502
R^2	0.200	0.197	0.191	0.197	0.198
Adjusted R^2	0.198	0.196	0.189	0.196	0.197
Note:					*p<0.1; **p<0.05; ***p<0.01
					Standard errors clustered by origin FAF zone.

Table 9 shows the estimated altruistic weights, Ω, under different specifications. Coefficients for externalities equal to the negative of altruistic weights, $-\Omega$. Column (5) shows the main specification used in the paper. Column (1) shows the result without accounting for the correlation between observed investment and political payoffs, where altruistic weights are biased away from zero. Without accounting for the correlation between observed investment and realized political payoffs, the direction of bias in the estimated Ω is ambiguous *a priori* because payoff functions are not guaranteed to be monotonic with respect to investments. On one hand, gains from reducing trade costs increase with the amount of trade flows; all else equal, they increase with investment. On the other hand, the construction technology features decreasing returns to scale, and the marginal unit of investment brings less reduction in trade costs as investment piles up. Therefore, while the observed investments and political payoffs are positively correlated, the sign of the correlation between the externality term and political payoffs are ambiguous.

Columns (2)-(4) shows results from alternative IV constructions. In each column, one particular set of externalities from randomized investments are used, instead of the mean of 100 sets of externalities. Across all IV specifications, the coefficients are consistently closer to 0 than column (1).

B.2 Alternative Calibration of Construction Costs

C Robustness Tests with Construction Technology Estimation

Table 10 reports the estimation results for parameters in the construction technology under trucking mode. An obvious omitted variable concern is that investments (captured in *Lanes*) negatively respond to terrain ruggedness, while rugged terrain also increases the time to travel. This would bias the OLS towards zero. Comparing column (1) with (3), the addition of ruggedness moved the OLS estimate on the investment elasticity by 0.002, which is an order of magnitude smaller than the standard deviation 0.021. Similarly, from column (2) to column (4), controlling for ruggedness moved the OLS estimate by 0.001, an order of magnitude smaller than the standard deviation 0.026. We therefore conclude that the omission of ruggedness from the estimation did not create a quantitatively significant bias.

Table 10: Investment and Truck Travel Time

	Dependent variable:			
	Log (Travel Time)			
	OLS	*felm*	*OLS*	*felm*
	(1)	(2)	(3)	(4)
Log (Lanes)	-0.171^{***}	-0.183^{***}	-0.172^{***}	-0.184^{***}
	(0.020)	(0.026)	(0.020)	(0.026)
Log (Miles)	0.892^{***}	0.933^{***}	0.889^{***}	0.931^{***}
	(0.007)	(0.015)	(0.007)	(0.015)
Ruggedness			0.042^{***}	0.041^{*}
			(0.012)	(0.023)
Constant	0.695^{***}		0.706^{***}	
	(0.040)		(0.040)	
Origin FE	*No*	*Yes*	*No*	*Yes*
Observations	502	502	502	502
R^2	0.974	0.991	0.975	0.991
Adjusted R^2	0.974	0.987	0.975	0.987

Note: Variables *Travel Time, Lanes* and *Ruggedness* are measured from the optimal routes connecting the centroids for a pair of FAF zones that share borders. *Travel Time* represents the minutes of travel on the optimal route spent within the jurisdiction of the origin FAF zone. *Lanes* is measured by the mileage-weighted average number of lanes on the optimal route within the jurisdiction of the origin FAF zone. *Miles* measures the driving distance on the optimal route within the jurisdiction of the origin FAF zone. *Ruggedness* is the mileage-weighted average grade on the optimal route. Standard errors clustered by origin FAF zone. *p<0.1; **p<0.05; ***p<0.01.

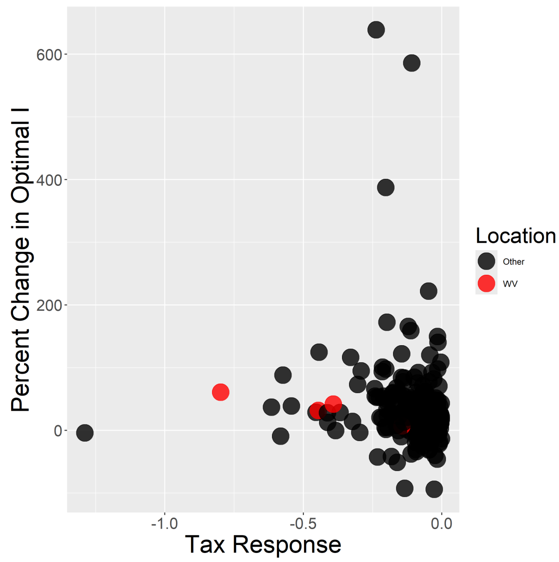
	Linear	Second Moment	IV Alignment + Distance
ζ_1	0.121	0.097	0.126
	(0.001)	(0.001)	(0.001)
ζ_2	0.558	0.332	0.428
	(0.009)	(0.003)	(0.003)
ψ	0.143	0.224	0.215
	(0.003)	(0.000)	(0.001)
ρ_m	35.274	37.257	33.983
	(0.779)	(0.615)	(0.942)

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$

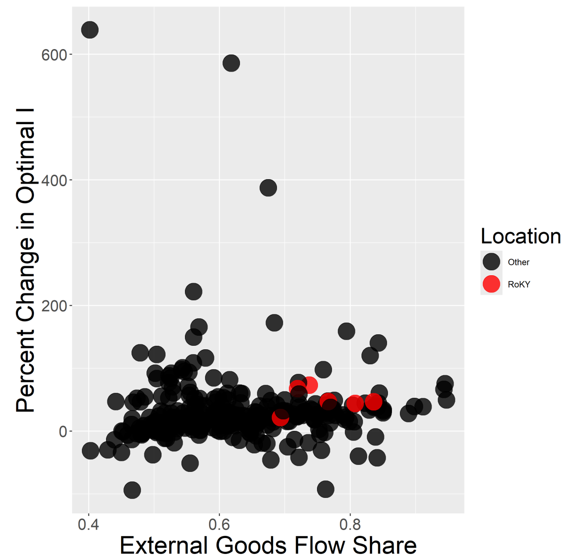
Table 11: GMM Estimates for Parameters in Construction Technology

D Special Cases of Rural Area Gaining Population

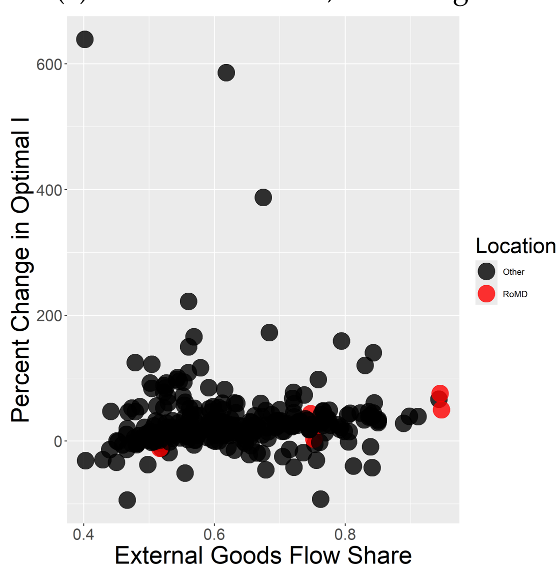
In figure 11, we highlight the links of several rural areas in the Appalachian Mountains that gained population. Panel (a) shows that West Virginia's investments generate larger local tax increases than other links, suggestive of extra-stringent fiscal constraints that drove greater under-investment. Panel (b)-(d) show three relatively low-productivity locations in the Appalachian Mountains that received immigration: Rest of Kentucky, Rest of Maryland and Rest of Virginia. Their links lie to the right of the distribution of external goods flow share, suggestive of stronger technology externalities that drive excessive underinvestment.



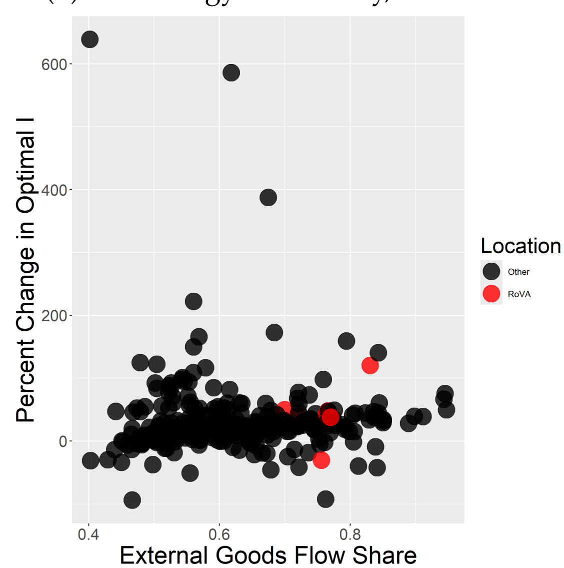
(a) Fiscal Constraints, West Virginia



(b) Technology Externality, Rest of KY



(c) Technology Externality, Rest of MD



(d) Technology Externality, Rest of VA

Figure 11: Optimal Investment Changes, Tax Responses and External Goods Flow Share