National Transportation Networks, Market Access, and Regional Economic Growth

Ian Herzog*

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Abstract

I estimate interregional transportation's effect on local economic growth by studying the Interstate Highway System. To estimate transportation's effects on county employment and wages, I develop a new instrumental variables strategy: isolating market access growth caused by incidental connections to rural counties. I find that through market access highways increased employment, had small and delayed wage effects, and that instruments correct for downward bias. A structural model interprets reduced-form results as agglomeration and congestion forces strengthening after 1980. Counterfactual simulations suggest that Interstates' effects were highly heterogeneous and that additions to early Interstate plans were less valuable than the system's core. JEL codes: R1, R4, R12, F14

*Department of Economics, University of Toronto, 150 St. George Street, Toronto, Ontario, M5S 3G7, Canada. E-mail ian.herzog@mail.utoronto.ca. I am indebted to Nathaniel Baum-Snow's excellent supervision and comments from Peter Morrow, Robert McMillen, and seminar participants at the University of Toronto. Any remaining errors or omissions are mine.

1 Introduction

Does improving a region's market access improve its economic growth, and at what cost? This question underlies some of the world's most ambitious public works projects. Highway networks such as India's Golden Quadrilateral, China's National Highways, and America's Interstate Highway System all aim to promote national growth, but can concentrate these gains in a handful of cities. To better understand if, when, and how transportation affects regional economic development, I estimate the Interstate Highway System's (IHS) effects on U.S. counties' market access and economic growth.

The Interstate Highway System is an ideal test case for studying transportation infrastructure's long-run effects. It is a comprehensive highway network that greatly improved upon existing roads to reduce both commuting and shipping costs. Both of these channels can cause economic growth directly and by fostering agglomeration economies, but endogeneity concerns and measurement issues have made separating these channels difficult.

I overcome these challenges using panel data on U.S. county incomes and employment, the national highway network, and a measure of market access. Guided by a general equilibrium trade model, I measure each county's market access as a travel time discounted sum of incomes in other counties. In theory, market access captures transportation's equilibrium effects, and I find that its empirical counterpart varies independently of local road density. I use this variation to distinguish the effects of commuter highways and market access on county employment and wage growth. To identify market access' causal effects, I develop a new instrumental variables strategy that uses its weighted average structure to exploit details of early IHS plans. Finally, I calibrate a structural model to investigate changing patterns of agglomeration over time and to assess the value of recent additions to the IHS.

My empirical analysis identifies inter-city highways' local effects using previously unexploited details of early IHS plans.[1] In particular, I use the fact that early IHS plans explicitly prioritize

[1]Baum-Snow (2007) and Duranton and Turner (2012) use planned Interstate mileage within major metropolitan areas to isolate their role as commuting infrastructure. Michaels (2008) uses highway plans to estimate trade's impact on incidentally connected rural counties. In a broader sample of U.S. counties, Frye (2014) uses Interstate plans to isolate plausibly exogenous variation in which counties access the IHS, but most prominent metropolitan areas have at least one highway running through them.

a number of cities. Prioritized cities were disproportionately prosperous and endogenously became Interstate hubs, but their market access varies exogenously with travel times to whichever counties were en-route between them.

To identify causal effects, I control for priority city status and instrument market access with its planned counterpart. Critically, market access' instruments exclude connections between priority cities to adapt the intuition of the inconsequential units approach described by Redding and Turner (2015). Prior applications of the inconsequential units approach can only identify causal effects for rural counties, but my instruments isolate exogenous variation in market access of both rural counties and major cities. For rural counties, these instruments vary with planned highway construction rather than endogenous post-hoc extensions. For major cities, they vary with incidental connections to rural counties. Conditional on observables mentioned in early IHS proposals, these instruments identify market access' effect on economic growth in both rural counties and prioritized cities.

Econometric estimates generate three main conclusions. First, I find that improving a county's market access increases their long run income growth, mostly by increasing employment. Second, comparing alternative instrumental variables strategies suggests that highways improved market access in counties that would have otherwise grown less than average. Third, I find evidence for changing mechanisms over time and argue that local productivity spillovers and housing costs became more important determinants of growth after 1980.

From 1953 to 1980, when most IHS expansion occurred, market access caused substantial employment growth with no effect on county wages. Most of the associated wage growth happened between 1980 and 2010. Combining these periods, I find that market access had large effects on county employment and modest effects on wages in the long run. From 1953 to 2010, a standard deviation increase in an average county's market access growth increased their employment growth by a quarter of a standard deviation and increased their wage growth by just one seventh of a standard deviation.

I interpret these results in a Ricardian trade model featuring mobile labour, agglomeration economies, and endogenous housing costs. In the model, counties produce differentiated goods and draw good-specific productivities from a single distribution as in Eaton and Kortum (2002). Counties differ in which goods they produce most productively and each have a distinct comparative advantage, encouraging trade, but trade is costly. Highways enter the model by reducing trade costs, which depend on inter-county travel times. To consider the role of local externalities, I assume that both housing costs and firm productivity increase with city size.

The model interprets market access' large long run effects on employment and wages as evidence that agglomeration spillovers strengthened and housing supply tightened over time. In this static model, market access' short run effects (from 1953 to 1980) map to structural parameters that are consistent with existing literature (Eaton and Kortum, 2002; Combes and Gobillon, 2015; Donaldson and Hornbeck, 2016) but the model requires large agglomeration and congestion elasticities to rationalize market access' larger long run effects on employment and wages.

The model also reveals substantial heterogeneity in the employment growth counties owe to Interstate Highways. A counterfactual that closes Interstates to inter-city travel dramatically changes equilibrium market access and suggests that the interquartile range of counties' employment attributable to the IHS is 16 percent of 2010's median county employment.

Finally, I ask whether recent additions to the 1947 highway plan benefited households as much as the Interstate Highway System's key routes. These additional highways sometimes cross sparsely populated areas or abruptly become slower secondary roads; studying them gives insight into the political process allocating infrastructure investment and the value of continued highway expansion. Counterfactual welfare simulations suggest that, on a per kilometre basis, extensions to the 1947 highway plan are worth only about one fifth of their planned counterparts. Further, I find that states' counterfactual employment losses from removing unplanned highways are imperfectly correlated with unplanned highway density and are attenuated in states whose neighbours built unplanned roads. This raises the possibility that building highways to improve lagging regions' market access benefits them at the expense of other places.

These findings contribute to the literature studying transportation's role in promoting regional integration and economic growth. In particular, I complement reduced form evidence from Chandra and Thompson (2000), Michaels (2008), and Frye (2014) in the United States, Ghani et al. (2016)

in India, and Faber (2014) in China. These studies have mixed findings, but often suggest that highways redirect economic activity.

I also bring a new identification strategy to the literature studying market access' effect on regional economic growth. Previous studies in this vein include Donaldson and Hornbeck's (2016) analysis of American railroads, Alder et al. (2017) in India, Jaworski and Kitchens (2016) in Appalachia, Jedwab et al. (2017) in Africa, and Baum-Snow et al. (2017) in China. My work builds on Bartelme (2018), who argues that wage and employment elasticities summarise inter-city transportation's economic impacts. To my knowledge, I am the first to use this approach for policy analysis.

Finally, I add to the literature on Interstate Highways' economic effects. Early studies restricted attention to rural counties to identify highways' effect on employment, finding some evidence of spillovers between neighbours (Chandra and Thompson, 2000) and increasing trade related activities (Michaels, 2008). Others find that by improving metropolitan commuting, Interstates caused suburbanization (Baum-Snow, 2007) and employment growth (Duranton and Turner, 2012). This paper complements Duranton et al. (2014), who find that highways effect both the level and composition of trade, and Allen and Arkolakis (2014) whose calibrated model associates large welfare gains with the IHS's construction.

The political economy of Interstate construction is scarcely addressed in economic literature. Redding and Turner (2015) note that studies often find that Interstates were allocated to places that would otherwise grow less than average, and Knight (2002) finds evidence that powerful senate representatives bring states federal highway funds that crowd out their own highway spending. By finding negative selection on market access and associating relatively small welfare gains with unplanned highways, I shed new light on the value and politics of Interstate expansion.

I proceed by discussing relevant details of IHS planning and construction and my data in section 2. Then, section 3 outlines the structural model grounding empirical work. Section 4 describes my econometric approach and section 5 presents results. Finally, section 6 combines empirical results with the structural model to estimate welfare effects.

2 Background and data

2.1 The 1947 Interstate Highway Plan

In the early 20th century, America's highways were mostly independent auto trails. These auto trails varied in quality and were gradually improved and organized into the US numbered highways in the 1920s. Meanwhile, the federal government became increasingly involved in highway financing and planning.

In 1922, General John J. Pershing submitted the first detailed proposal for a national network of limited access highways. The so-called Pershing plan proposed over 30,000 kilometres of highways that the army considered necessary for national defence. The Federal Aid Highway Act initiated the federal government's official role in planning an interregional road network in 1944, and congress published its official plan for the Interstate Highway System in 1947. Interstate Highways were promised federal funding in 1956 and most of the network was built by the early 1980s.

Congress' 1947 highway plan contains a detailed map covering much of the modern Interstate Highway network. The plan describes 41,000 highway miles meant to support America's growing transportation demand and facilitate evacuations and military mobilization "in case of an atomic attack" (Eisenhower, 1955). In addition, the 1947 map includes labelled points on a number of priority cities. It is unclear exactly how these priority points were chosen, but the plan resembles a 1944 proposal to congress recommending a network with direct connections to as many large cities as possible (National Interregional Highway Committe, 1944).

Figure 1 plots the 1947 highway plan, which identifies 211 priority cities (shown as points) and proposes routes between them. Lightly shaded lines show today's Interstate Highway System, which is somewhat more complicated than the planned IHS. It seems that contemporary highways' deviations from initial plans represent local assessments of potential growth and lobbying efforts since 1947. This is consistent with Redding and Turner's (2015) assessment that unplanned highways went to negatively selected places to support their economic development. Priority points labelled on the plan were unanimously connected to actual Interstates and often had unplanned highways built nearby.

2.2 Measuring roads and travel times

Market access, my main explanatory variable, depends on inter-county travel times. I capture variation over time by calculating driving times along America's highways before and after IHS construction. Hypothetical driving times along 1947's planned IHS also play an role in my empirical analysis.

I compute baseline travel times using a 1956 Shell Oil Company road map, which identifies major auto-routes spanning the entire continental United States. I assume a constant speed of 35 mph along auto-routes and connect county centroids by straight lines at 10 mph. My baseline inter-county travel times data are a symmetric matrix of fastest possible driving times between county centroids along this road network.[2]

Data describing Interstate Highways come from the USGS's National Atlas. To model the post Interstate Highway network, I add the IHS to the baseline network and recalculate fastest driving times assuming 65 mph travel along Interstates. Empirical analysis uses these travel times to describe both 1980 and 2010 roads.

Finally, the 1947 highway plan re-routes current Interstate Highways to compute travel times for transportation measures' instruments. Market access instruments replace actual travel times with those computed as if Interstate Highways exactly follow the 1947 plan.

I measure counties' local commuter highways roads as Interstate Highway equivalent kilometres: the weighted sum of Interstate and secondary road kilometres within each county's boundaries where secondary road km each count for 35/65 of an Interstate km. In 1950, this simply amounts to a scaled count of auto-route mileage in each county. I assign counties highway equivalent km using post-Interstate, planned, and baseline highway configurations.

Table 1 summarises the baseline and post-Interstate road networks. Hours between counties are calculated for fastest routes between county centroids using Dijkstra's algorithm, and change in log highway equivalent kilometres is set to zero in counties without highways in the 1956 Shell road map. The IHS implied substantial road building, an average increase of 0.43 log equivalent km with substantial variation across counties. The data associate dramatic travel time reductions

[2] I identify minimum travel times using Dijkstra's shortest path algorithm, implemented in the ArcGIS Network Analyst toolbox.

with IHS construction—average pairwise trip time fell by thirty eight percent. Reduced cross-trip variance occurred as the longest trips saw the largest travel time reductions.

2.3 Outcomes and controls

My main outcomes are long differences in county populations, employment, and payrolls between 1950 and 2010. I focus on counties with constant boundaries throughout the study period and merge these data with 1990 definitions of commuting zones.[3] I convert all dollar values to 2010 United States dollars using the Bureau of Labour Statistics' Consumer Price Index for All Urban Consumers. Going forward, the distinction between real and nominal incomes refers to cost of living differences across counties rather than years.

Population, demographic, and housing data come from the decennial censuses.[4] Payrolls, total employment, and establishment counts from the County Business Patterns (CBP).[5] Since no CBP data exist for 1950, I use 1953 data in its place. Critically, census data are measured by county of residence while CBP data track workplaces.

In some cases, the 1953 CBP reported employment and payrolls for county groups rather than individual counties. To compute 1953 payrolls for each group's constituent counties, I assume per-employee payrolls are constant within a county group and assign counties employment counts in proportion to their 1950 populations.

Table 2 summarises growth in key outcomes across the 2,978 counties included in CBP data. Note that 1950 CBP data actually refer to 1953 while population, taken from the census, refers to 1950. The data reflect America's rapid economic growth in the mid twentieth century. And while growth slowed for the average county in the latter period, cross-county variance in growth rates persisted.

[3]Using county boundary shapefiles for 1940 and 2010 from NHGIS, I drop counties that experienced greater than ten percent change in area. This procedure retains 3047 of the 3109 counties and county equivalent units in the contiguous United States (excluding Hawaii and Alaska) as of the 2010 census. Boundary changes are concentrated in Virginia where county boundaries are less stable than is typical.

[4]1940 and 1950 census data and other controls (excluding population) come from county databooks. Population data and outcomes come from decennial censuses are accessed via NHGIS.

[5]Early CBP data come from the 1956 county databook, which reports CBP data without industry breakdowns for most counties. A small number of counties are mis-coded in the county databook; I correct this using scans of the 1953 CBP source material. Recent CBP data come from NHGIS and American Fact Finder.

3 A model of regional trade and market access

I now present a simple model of trading counties in the spirit of Eaton and Kortum (2002). The model extends Roback's (1982) classic local labour markets model to include costly trade and gains from regional integration. The model emphasizes local comparative advantage and is isomorphic to several views of regional trade including New Economic Geography models with local increasing returns to scale (Allen and Arkolakis, 2014).

The model features land as an input to producing both traded goods and housing. Since I fix counties' residential land supply, rents increase with total incomes and households trade off endogenous housing costs and wages when choosing their location.[6] I also assume households enjoy an amenity value from local roads similar to Duranton and Turner's (2012) model of highways' commuter benefits. Finally, firms' productivity increases in local employment, a constant elasticity agglomeration benefit capturing efficiencies from increasing returns in local input services, thick labour markets, or knowledge spillovers (Duranton and Puga, 2004).

The model delivers a simple market access measure to summarise transportation's effect on regional development and provides a framework for estimating transportation's aggregate implications.

3.1 Households

The model features many trading counties, indexed by i when producing or sending goods and n when receiving goods. I assume the United States is populated by $\bar{L}$ identical and mobile households, each inelastically supplying a single unit of labour and receiving w_n in income. Households have Cobb-Douglas preferences represented by $U_n = \frac{A_n}{\tau_n} C_n^{\mu} H_n^{1-\mu}$ where A_n is a local public good, τ_n is a representative commute's dis-utility, H_n is housing, and C_n is a bundle of traded goods.[7]

I assume households' tastes imply a constant elasticity of substitution σ across traded goods so that an ideal price index P_n summarises the traded bundle's cost in each county. Households also

[6] Endogenous housing costs create a mobility friction that is isomorphic to idiosyncratic moving costs, urban crowding, or commute congestion. Allen and Arkolakis (2014) offer a formal discussion of several related models.

[7] Note that this model is isomorphic to one in which households pay an iceberg commute cost, so that their take home income is some fraction τ_n of their market income.

pay an endogenous user cost of ρ_n per unit of housing.

I use a stylized model of commuting to capture local roads' effects. I assume roads per capita decrease commute times with constant returns to scale and write speed supply as $\tilde{\tau^s}\left(\frac{L_n}{R_n}\right)^{\tilde{\delta^s}}$ where L_n is total county employment and R_n is a measure of local road mileage. Assuming τ_n is a constant elasticity function of commute time and abstracting from differences in commute distances, I can write commute costs as $\tau_n = \tau\left(\frac{L_n}{R_n}\right)^{\delta}$ where δ combines households' preference for shorter commutes with roads' marginal effect on commute times.[8]

These assumptions culminate in each county's residents achieving utility levels

$$u_n = \tau\mu^{\mu}(1-\mu)^{(1-\mu)}A_n\left(\frac{R_n}{L_n}\right)^{\delta}\frac{w_n}{P_n^{\mu}\rho_n^{1-\mu}} \tag{1}$$

and households choose to live and work in the highest utility location.

3.2 Production, trade, and labour demand

In each county i, a continuum of perfectly competitive firms produce varieties (indexed by ν) combining labour, land, and perfectly mobile capital in a Cobb-Douglas production function with total factor productivity $\tilde{T}_i z_i(\nu)$ so that each variety's marginal cost is $\frac{q_i^{\gamma}w_i^{\alpha}r^{1-\alpha-\gamma}}{\tilde{T}_i z_i(\nu)}$. Capital rents at a constant price r and firms pay endogenous local prices w_i and q_i for labour and land respectively.[9]

Following Eaton and Kortum (2002), firms draw idiosyncratic productivity components, $z_i(\nu)$, from a common Frechet distribution with the cumulative density $F(z) = \exp(-z^{-\theta})$. I assume that θ exceeds one and call it the trade elasticity because it is inversely proportional to the scope for comparative advantage. Firms also enjoy an agglomeration spillover so that $\tilde{T}_i = T_i L_i^{\zeta}$. Finally, goods shipped from county i to county n pay iceberg trade costs $\tau_{in} > 1$ so that p_{in} dollars spent in county n brings the county i's seller p_{in}/τ_{in} dollars of net revenue.

This production structure implies that in zero-profit equilibrium, variety ν ships from i's pro-

[8]Empirical work excludes counties with changing boundaries and measures local roads in as a speed weighted sum of county road mileage, so commute times, rather than distances, are a reasonable way to interpret local roads' effect on households.

[9]I equate local incomes and expenditure in equilibrium; equivalent to assuming land and capital rents are spent where they are earned. I discuss rentiers in more detail when I introduce housing production.

ducers to n's consumers at prices

$$p_{in}(\nu) = \alpha^{\alpha}\gamma^{\gamma}\frac{q_i^{\gamma}w_i^{\alpha}r^{1-\alpha-\gamma}}{L_i^{\zeta}T_i z_i(\nu)}.$$

Eaton and Kortum (2002) show that these prices imply that county n's price index is $P_n = \kappa_1 CMA_n^{-\frac{1}{\theta}}$, where $CMA_n = \sum_j \left[\frac{q_j^{\gamma}w_j^{\alpha}}{L_j^{\zeta}T_j}\tau_{jn}\right]^{-\theta}$ captures each county's access to low cost producers and is often called consumer market access.[10] Further, the total value of goods i sells to n is

$$X_{in} = \left[\frac{q_i^{\gamma}w_i^{\alpha}}{L_i^{\zeta}T_i}\right]^{-\theta}\frac{\tau_{in}^{-\theta}}{CMA_n}Y_n. \tag{2}$$

where Y_n is county n's total output. Summing (2) across county i's trading partners and assuming balanced trade shows that aggregate incomes satisfy

$$Y_i = \left[\frac{q_i^{\gamma}w_i^{\alpha}}{L_i^{\zeta}T_i}\right]^{-\theta}\sum_n \frac{Y_n\tau_{in}^{-\theta}}{CMA_n} \tag{3}$$

where $\sum_n \frac{Y_n\tau_{in}^{-\theta}}{CMA_n}$ captures firms' access to large export markets and is often called firm market access. As in Donaldson and Hornbeck (2016), symmetric trade costs imply that firm and consumer market access are equal. Therefore, I define structural market access as

$$MA_i \equiv CMA_i = \sum_n \frac{Y_n\tau_{in}^{-\theta}}{CMA_n}. \tag{4}$$

With a single market access term and Cobb-Douglas production, equation (3) reduces to $Y_i^{1+\theta(\alpha+\gamma)} = T_i^{\theta}L_i^{\theta(\zeta+\alpha)}S_i^{\theta\gamma}MA_i$ where S_i is a county's productive land endowment. Substituting $Y_i = \frac{w_iL_i}{\gamma}$ gives local labour demand as a constant elasticity function of wages, fundamental productivity, land area, and market access:[11]

$$L_i = \kappa_2 T_i^{\frac{\theta}{1+\theta(\gamma-\zeta)}} S_i^{\frac{\gamma\theta}{1+\theta(\gamma-\zeta)}} MA_i^{\frac{1}{1+\theta(\gamma-\zeta)}} w_i^{-\frac{\theta(\alpha+\gamma)+1}{1+\theta(\gamma-\zeta)}}. \tag{5}$$

[10] $\kappa_1 = \alpha^{\alpha}\gamma^{\gamma}r^{1-\alpha-\gamma}\left[\int_0^{\infty} x^{\frac{1-\sigma}{\theta}}e^{-x}dx\right]^{\frac{1}{1-\sigma}}$.

[11] $\kappa_2 = \alpha^{\frac{1}{1+\theta(\gamma-\zeta)}}$

Note that the local labour demand elasticity's relationship with non-traded inputs' share of production depends critically on the scope for comparative advantage.[12] Further, growing market access shifts local labour demand upwards, and this effect is strongest when land is a small share of costs or the scope for comparative advantage is large. Finally, agglomeration benefits offset local input costs.[13]

3.3 Housing

I capture endogenous housing costs with a stylized housing supply model. First, I assume that competitive developers combine traded capital and land to produce housing with a Cobb Douglas technology. Marginal cost pricing implies that each county's residents face housing prices $\rho_i = (q_i^R)^\eta r^{1-\eta}$ where η is land's share in housing production and q_i^R is residential land rent. For simplicity, I assume developers use different land than traded good producers, but pay proportional rents $q_i^R = \phi q_i$. Cobb-Douglas traded good production then implies $q_i^R = \phi q_i = \phi\gamma\frac{Y_i}{S_i} = \phi\frac{\gamma w_i L_i}{\alpha S_i}$ and the (inverse) housing supply function is:

$$\rho_i = \left(\phi\frac{\gamma w_i L_i}{\alpha S_i}\right)^\eta r^{1-\eta}. \tag{6}$$

In equilibrium, I assume all land rents are bundled with capital rents and distributed to absentee landlords. Landlords live where they own land, receive income in proportion to their county's output, and spend all of this income on traded goods.

3.4 Labour supply

Goods and housing market equilibria admit substituting $P_i = \kappa_1 MA_i^{-\frac{1}{\theta}}$ and $\rho_i = \phi\left(\frac{\gamma w_i L_i}{\alpha S_i}\right)^\eta r^{1-\eta}$ into (1) to get local utility in terms of market access and population. In spatial equilibrium, mobile households arbitrage away utility differences across counties so that $\bar{u} = u_i \forall i$ and (inverse) local

[12] As θ grows, the Frechet dispersion becomes less disperse and firms within a county become more interchangeable, eroding productivity advantage gained from specializing in producing a small set of their varieties.

[13] I model production congestion via firms use of land in production at a fixed share γ of output, but land can generalize to any fixed non-traded but costly input.

labour supply is[14]

$$w_i = (\bar{u}\kappa_3)^{\frac{1}{1-\eta(1-\mu)}} A_i^{-\frac{1}{1-\eta(1-\mu)}} S_i^{-\frac{\eta}{1-\eta(1-\mu)}} R_i^{-\frac{\delta}{1-\eta(1-\mu)}} MA_i^{-\frac{\mu}{\theta}\frac{1}{1-\eta(1-\mu)}} L_i^{\frac{\eta(1-\mu)+\delta}{1-\eta(1-\mu)}}. \tag{7}$$

Note that since market access reduces the price index, it shifts labour supply towards lower wages. So if θ is small, market access acts as a local amenity, as do commuter roads if δ is large.

3.5 Equilibrium

Combining labour demand (equation (5)) and supply (equation (7)) gives equilibrium wages and labour allocations as log-linear functions of local fundamentals, road allocations, and market access:

$$\ln w_i = \ln \kappa^w + \delta_u^w \ln \bar{u} + \beta^w \ln MA_i + \delta_R^w \ln R_i + \ln \chi_i^w \tag{8}$$

$$\ln L_i = \ln \kappa^L + \delta_u^L \ln \bar{u} + \beta^L \ln MA_i + \delta_R^L \ln R_i + \ln \chi_i^L \tag{9}$$

$$MA_i = \frac{1}{\alpha}\sum_j \frac{w_j L_j \tau_{ij}^{-\theta}}{MA_j} \tag{10}$$

$$\bar{L} = \sum_i L_i \tag{11}$$

where χ_i^w and χ_i^L are functions of exogenous local productivity, amenities, and land endowments; and κ^w and κ^L depend on the interest rate. Given model parameters, capital's rental rate (r), total national employment ($\bar{L}$), local fundamentals (χ_i^w, χ_i^L), and bilateral trade costs (τ_{in}), an equilibrium is county employment, wages, market access, and national utility so that (8), (9), (10), and (11) hold.[15] Arguments developed by Bartelme (2018) imply that a unique equilibrium exists whenever $\beta^w + \beta^L \leq 2$. Crucially, market access summarises inter-city roads' effects on local wage and employment patterns and I assume trade costs grow log-linearly with inter-county travel times.

The equilibrium conditions (8) and (9) form the basis for my empirical task of identifying market access elasticities β^w and β^L. These elasticities identify key model parameters, summarise

[14] $\kappa_3 = \kappa_1 \tau \mu^\mu (1-\mu)^{(1-\mu)} \left((\frac{\phi\gamma}{\alpha})^\eta r^{1-\eta} \right)^{1-\mu}$

[15] Model parameters are standard production function and preference parameters $\{\alpha, \gamma, \mu\}$, externality elasticities $\{\zeta, \eta\}$, the commute costs elasticity δ, and the trade elasticity θ.

the effects of counterfactual road configurations, and are interesting in their own right.

Elasticities in equations (8) and (9) are complicated functions of model parameters (specified in appendix table A.1) and I differentiate local labour supply and demand to map reduced form elasticities to structural parameters and develop intuition. Taking logarithms of (5) and (7) and differentiating with respect to market access yields

$$\beta^L = \frac{1}{1+\theta(\gamma-\zeta)} - \beta_w \frac{\theta(\alpha+\gamma)+1}{1+\theta(\gamma-\zeta)} \text{ and} \tag{12}$$

$$\beta^w = \beta^L \frac{\eta(1-\mu)+\delta}{1-\eta(1-\mu)} - \frac{\mu}{\theta}\frac{1}{1-\eta(1-\mu)}. \tag{13}$$

The demand shift, equation (12), increases the equilibrium employment elasticity when agglomeration forces offset firms' local input costs and housing costs The supply shift, equation (13), can cause a negative equilibrium wage elasticity if gains from trade (which grow as θ shrinks) offset housing costs and road congestion (captured by η and δ). Finally, given assumptions about the agglomeration elasticity (ζ) and production shares (γ and α), local wage and employment elasticities identify the trade elasticity. Then, adding estimates of housing's expenditure share ($1-\mu$) and local roads' reduced form elasticities (δ_R^w and δ_R^L) identifies the congestion parameters (η and δ) and differences in household welfare across equilibria.

Equations (8) and (9) also show how unobserved local fundamentals complicate econometric estimates. Local productivity, amenities, and land endowments are exogenous but jointly determine market access and labour market outcomes.[16] And since a county's market access also reflects their neighbours' productivity and amenities, spatially clustered shocks, such as southern states' post-war growth, are particularly problematic.

[16] To see this, note that $MA_i = \frac{1}{\alpha}\sum_n \frac{w_n L_n \tau_{in}^{-\theta}}{MA_n} = \frac{1}{\alpha}\kappa^w \kappa^L \bar{u}^{\delta_u^w+\delta_u^L} \sum_n \tau_{in}^{-\theta} MA_n^{\beta^w+\beta^L-1}\chi_n^w \chi_n^L$.

4 Empirical strategy

4.1 Measuring market access

My econometric analysis measures market access by omitting recursive terms following Donaldson and Hornbeck (2016). This approximation is less model dependent than equation (10) and summarises each county's economic centrality as a travel time discounted sum of other counties' incomes. To focus on inter-city roads, I assume trade costs are a constant elasticity function of driving times $\tau_{ijt} = \tau_0 time_{ijt}^{\tau_1}$. Then, county i's market access in year t is

$$MA_{it} = \tilde{\tau} \sum_{j \neq i} w_{jt} L_{jt} time_{ijt}^{-\tilde{\theta}} \tag{14}$$

where $w_{jt}L_{jt}$ are county j's total payrolls, $\tilde{\theta} = \tau_1 \theta$ is the decay parameter, and $\tilde{\tau} = \frac{\tau_0^{-\theta}}{\alpha}$ is a scale parameter I normalize to one since it does not affect growth rates. I set the decay parameter to 1.5 to match estimates of regional trade flows' elasticity of highway distance, as suggested by the model's gravity equation. Specifically, equation (2) can be written as

$$\begin{aligned} \ln X_{ij} &= \alpha_i + \alpha_j - \theta \tau_{ij} \\ &= \alpha_i + \alpha_j - \theta \tau_1 \ln time_{ij} + \varepsilon_{ij} \end{aligned}$$

where X_{ij} is value shipped from region i to j, α_i and α_j are origin and destination fixed effects, and ε_{ij} captures approximation error arising from measuring trade costs as a constant elasticity function travel times.

Duranton et al. (2014) estimate inter-city trade's elasticity with respect to highway distance using 2007 Commodity Flow Survey (CFS) data describing bilateral trade flows between 66 American regions. Their elasticity estimates range from -1.63 to -1.91 for weight traded and -1.17 to -1.41 for value traded. I aggregate my county level travel times to payroll weighted average travel times between CFS region pairs and find 2007 inter-regional trade value's elasticity of bilateral driving times is -1.57.[17]

Table 3 summarises market access growth using total county payrolls in 2010 and 1953 as weights and $\tilde{\theta} = 1.5$. The data imply substantial market access growth, but it is not all the direct result of new highways. The following decomposition apportions market access growth between direct effects of road improvements and income growth:

$$\Delta \ln MA_{it} = \Bigg(\overbrace{\ln \sum_{j \neq i} w_{jt} L_{jt} time_{ijt}^{-\tilde{\theta}} - \ln \sum_{j \neq i} w_{j0} L_{j0} time_{ijt}^{-\tilde{\theta}}}^{\text{income growth}} \Bigg) + \Bigg(\underbrace{\ln \sum_{j \neq i} w_{j0} L_{j0} time_{ijt}^{-\tilde{\theta}} - \ln \sum_{j \neq i} w_{j0} L_{j0} time_{ij0}^{-\tilde{\theta}}}_{\text{road improvements}} \Bigg).$$

The final column of table 3 shows that both factors were important. Computing market access growth with payrolls held at baseline levels suggests that income growth accounts for about 60 percent of the mean and half of the variance of market access growth in my data.

Figure 2 plots changes in log market access across U.S. counties. Solid lines indicate existing Interstates, dotted lines indicate secondary roads (built before 1956), and darker colours indicate more growth. Figure 2 reveals that Interstates caused market access growth in many counties that were not directly connected to the IHS and were particularly important for many western and southern hubs.

4.2 Econometric model

I estimate Interstate Highways' effect on local economic outcomes through their effects on market access and commuter roads. The main estimating equation is an empirical counterpart to equations (8) and (9),

$$\Delta \ln y_i = \kappa + \beta_1 \Delta \ln MA_i + \beta_2 \Delta \ln R_i + X_i' \Gamma + \epsilon_i, \tag{15}$$

[17] I define a CFS region pair's weighted average travel time as the sum of travel times between county pairs weighted by each county pair's share of all county pairs' payrolls. Regressing log bilateral trade values on origin and destination fixed effects and weighted average travel times yields an elasticity of -1.574 by OLS and -1.573 instrumenting travel times with planned counterparts. IV estimates using a cubic specification of log travel times give a mean elasticity of -1.45, bolstering the assumption of log-linear trade costs.

where $\Delta \ln y_i$ is a county's change in log total employment or payroll per employee from 1953 to 2010 in the main specification. Regressions using outcomes from decennial censuses use 1950 as the base year and some regressions separately consider growth from 1950 to 1980 and 1980 to 2010. Market access growth varies alongside falling driving times and growing market sizes between 1953 and 1980 or 2010 depending on the time horizon of interest.[18] The parameter of interest is market access' elasticity β_1, which summarises the Interstate Highway Network's local effects.

Highways also improve counties' local roads, increasing R_i. Holding constant within city roads separates highways' effects on commuting from market access. Identifying β_1 using market access growth unrelated to local infrastructure suits the relevant counterfactual: re-configuring roads to alter trade costs without affecting other local factors.

The vector of baseline controls, X_i, contains 1940 and 1950 log manufacturing and agricultural employment shares, 1940 and 1950 log sales per farm, log dollar values of wartime industrial and military facilities financed between 1940 and 1945, dummies for positive wartime investment, a third order polynomial in 1940 and 1950 log population, census division fixed effects, log land area, longitude and latitude, and dummies indicating counties within 50 km of a coast, all interacted with dummies for commute zones identified as prioritized by the 1947 plan.[19] The priority city dummy plays an important role in my identification strategy. Residuals capture measurement error and unobserved determinants of growth including local productivity and amenities. I assume ϵ_i cluster by commute zone and base all inference on 1990 commute zone clustered standard errors.[20]

Since market access should increase both labour supply and labour demand, I expect it to increase employment. Effects on per-employee payroll are ex-ante ambiguous. Market access increases wages if it improves local labour demand and households demand compensation for moving. On the other hand, market access can improve local amenities and provide wide variety of low cost consumption goods, increasing labour supply and reducing wages.

[18]Market access growth from 1953 to 2010 is only considered for long-run outcomes (growing from 1950 to 2010). Otherwise, I consider growth until 1980 to ease interpretation of results. Market access growth from 1980 to 2010 is not directly of interest since the IHS was largely complete by 1980, so I cannot identify subsequent market access growth's causal effects.

[19]I add one to employment shares, farm sales and war facility investments before taking logarithms.

[20]The spatial autocorrelation consistent variance-covariance matrix suggested by Kelejian and Prucha (2007) and Conley (1999) produces similar results.

4.3 Identification strategy

Deliberate highway planning and general equilibrium feedbacks make highway and market access variables endogenous. Further, equations (8) and (9) suggest that unobserved productivity and quality of life trends may bias estimates of equation (15) if they are correlated with market access. Baseline controls partially alleviate this concern, but are not sufficient to credibly identify transportation's effects. So I build instruments for market access and local roads based on the 1947 highway plan and knowledge that many counties were incidentally connected to the IHS.

Following Duranton and Turner (2012), I use planned road building to instrument local road growth. Specifically, local roads' instruments are the growth in highway equivalent km each county would have seen if the IHS followed the 1947 plan. I also use planned travel times between counties to build instruments for market access, which warrant further discussion.

Since market access is weighted by city incomes, the exclusion restriction is twofold. First, I require that changing trade costs are unrelated to residual growth. This restriction would be violated if the IHS made major hubs of cities expected to grow most. Second, I require that partner county incomes—which weight trade costs—are unrelated to unobserved determinants of local outcomes.

My instruments for market access have three important features. First, instruments only use 1953 payrolls as weights and grow only as travel times fall. This addresses mechanical problems of regressing a county's employment growth on a function of other counties' growth. Second, instruments exclude contributions from counties within a 100 km radius. This doughnut form makes instruments unrelated to regional radial highways, which may improve market access most in large IHS hubs. Third, instruments compute travel times assuming Interstates precisely follow the 1947 plan, ignoring potentially endogenous additions to and deviations from this plan.

The simplest instrument for market access growth is then:

$$\Delta \ln MA_i^{plan} = \ln \sum_j D_{ij}^{far} w_{j0} L_{j0} time_{ijplan}^{-1.5} - \ln \sum_j D_{ij}^{far} w_{j0} L_{j0} time_{ij0}^{-1.5}$$

where $time_{ijplan}^{-1.5}$ are planned travel times and $D_{ij}^{far} = 1$ if counties i and j are at least 100 km apart. To exploit incidental connections to the IHS, I introduce the indicator D_i^{inc} for plausibly incidentally connected counties and define market access growth caused by incidental connections to the IHS as $\Delta \ln \widetilde{MA}_i^{inc} = \ln \sum_j D_j^{inc} D_{ij}^{far} w_{j0} L_{j0} time_{ijplan}^{-1.5} - \ln \sum_j D_j^{inc} D_{ij}^{far} w_{j0} L_{j0} time_{ij0}^{-1.5}$. If the set of incidentally connected counties is properly defined, it is reasonable to expect that $\text{Cov}\left(\Delta \ln \widetilde{MA}_i^{inc}, \epsilon_i\right) = 0$ given controls for priority city status.

Early highway plans detail federal priorities and provide insight into which counties were incidentally included. Federal plans allocated 40,000 highway miles to support national defence, population centres, agricultural hubs, and manufacturing clusters (National Interregional Highway Committe, 1944). I capture direct effects of these factors with controls for baseline employment mixes, farm sales, wartime investment, and population. I also observe the set of cities the 1947 plan prioritized.[21] So, I define incidentally connected counties as those not sharing commute zones with any of the 211 cities named in the 1947 plan and control for an indicator of counties sharing a commute zone with any prioritized city.

However, differences in planned market access growth among prioritized cities might reflect differences in potential productivity or amenity growth. In particular, direct routes between priority cities might reflect their relative growth potential. Figure 3 depicts a stylized example of this issue. Initial plans gave Dallas a direct connection to Memphis, but nearby Shreveport's planned Intestate connection to Memphis routes through Jackson, Mississippi, in a right angle.[22] All three of these cities are labelled as priorities in the 1947 plan, but Dallas' market access grew more than Shreveport's. This difference mechanically reflects Dallas' significance as an Interstate hub, which was likely encouraged by its own potential productivity growth. To avoid inducing correlation between priority cities' market access and unobserved fundamental growth, I explicitly eliminate variation in market access instruments driven by connections between counties in priority commute zones, but allow priority cities to affect incidentally connected ones.

[21] The 1947 IHS plan explicitly names 211 cities whose places in the network seem quite deliberate.

[22] As of March 2019, the fastest route from Shreveport to Memphis takes an unplanned portion of I-49 conceived in the late 90s that gradually opened to traffic over the 2000s and 2010s. However, the Shreveport-Memphis drive remains less direct than the Dallas-Memphis drive.

Specifically, I specify the first stage equation

$$\Delta \ln MA_i = \alpha^{MA} + \beta_1^{MA} \Delta \ln \widetilde{MA}_i^{inc} + \beta_2^{MA} D_i^{inc} \Delta \ln \widetilde{MA}_i^{hub} + \beta_3 \Delta \ln \tilde{R}_i + X_i' \Gamma^{MA} + \epsilon_i^{MA}$$

where $\Delta \ln \widetilde{MA}_i^{hub}$ is planned market access to priority cities and $\Delta \ln \tilde{R}_i$ is planned local highway efficiency km growth.[23] This specification considers priority cities' effect on incidentally connected counties' market access and omits potentially endogenous variation in priority cities' market access growth.

5 Effects on local economic activity

5.1 First stage results

Table 4 presents first stage estimates associated with alternative instrument sets. Column 1 presents each instrument's standard deviation and the remaining columns present ordinary least squares (OLS) regressions of infrastructure measures on instruments and controls. Columns 2 through 5 are first stage results for reduced form market access growth from 1953 to 2010, column 6 uses structural market access, defined in equation 10, and column 7 presents estimates for local road density. The candidate instrument in the first row is market access growth with observed highways and baseline income, while instruments in the second through fourth rows use planned Interstates, baseline incomes, a 100 km donut around each county, and distinguish between access to incidentally connected counties and major hubs.

All instrument sets have intuitive coefficient estimates and produce strong first stages, Angrist and Pischke (2008) partial F-statistics are large. Reassuringly, market access' instruments consistently predict its growth better than planned local roads. For example, column 4 associates a standard deviation increase in planned access to incidentally connected counties with over 10 times more market access growth than a standard deviation increase in planned local road density. Further, incidental market access growth is negatively correlated with local road growth conditional on controls and planned local road building.

[23] $\Delta \ln \widetilde{MA}_i^{hub} = \ln \sum_j (1 - D_j^{inc}) D_{ij}^{far} w_{j0} L_{j0} time_{ijplan}^{-1.5} - \ln \sum_j (1 - D_j^{inc}) D_{ij}^{far} w_{j0} L_{j0} time_{ij0}^{-1.5}$

5.2 Long run effects

Table 5 presents long-run elasticities of employment and payroll per employee with respect to market access and local roads. Growth is measured from 1953 to 2010 and all regressions include a full set of controls. Column 1 presents OLS estimates, columns 2 through 5 present TSLS estimates with alternative instrument sets, and column 6 uses structural market access as the independent variable. Market access instruments based on the 1947 plan all take a doughnut form, excluding counties within a 100 km buffer, and each TSLS regression corresponds to a first stage presented in 4.

Least squares estimates in column 1 overstate market access' importance since market access both causes and is caused by regional income growth. Column 2 shows that fixing instruments' weights at 1953 payrolls attenuates market access elasticities and attributes more growth to local road building. Column 3 uses plan-based instruments for market access and local road growth. Accounting for unplanned infrastructure placement increases market access elasticities and attenuates local road elasticities for both outcomes. Column 4 excludes connections to major hubs from market access' instruments, further increasing employment elasticities. Column 5 presents my preferred specification, which exploits variation in incidentally connected counties' connections to major hubs and vice-versa. These estimates resemble column 4, which ignore major hubs' effects on incidentally connected places.

Preferred estimates suggest that a ten percent increase in market access causes an 8.4 percent increase in employment. This means that moving one standard deviation up in market access growth delivers 24 extra percentage points of employment growth, about one quarter of the standard deviation of counties' employment growth rates. Average payrolls also respond to market access, but less than employment. A standard deviation market access growth causes a 4 percentage point increase in per employee payroll growth, just over one seventh of its cross-county standard deviation. Column 6 shows that using the structural model's recursive market access terms yields similar elasticity estimates.

The online appendix presents several additional results. Appendix table A.2 reports TSLS estimates of equation (15) interacting market access growth with indicators of counties above or below median on measures of 1950 city status. Non-metropolitan counties and those starting less-dense exhibit the largest employment responses to improved market access. Results for average payrolls are noisy, but provide some evidence that market access' effects on wages are bigger in counties with more educated residents. Appendix table A.3 considers change in log median dwelling values, detached home shares, and log establishment counts as additional outcomes. Results suggest that market access growth pushed households into pricier and smaller dwelling on average, but lack of quality adjusted house price data make these results difficult to interpret. I also find that market access increases establishment counts, but with a smaller elasticity than employment, giving some evidence that market access increases establishment size.

Overall, results suggest that market access caused by highways increases local income growth and that this effect is driven primarily by employment growth. Wages also grow in response to market access, but this effect is quantitatively less important. In addition, given a county's place in the national highway network, local road density has little effect on long-run employment and incomes. Finally, applying increasingly stringent identification assumptions suggests that unplanned highways gave additional market access growth to places that would otherwise have grown less—additions to early IHS plans generally favoured lagging regions.

5.3 Effects over time

Table 6 presents highways' effects on county employment, average payroll, and population growth from 1950 to 1980 in panel A, the period of active road building, and from 1980 to 2010 in panel B. Regardless of outcome year, the main explanatory variable is market access growth from 1953 to 1980 and each column presents TSLS estimates using incidental connection instruments.

In early decades, market access causes population and employment growth with no discernible effect on average payrolls. In latter decades, market access increases average payrolls and causes additional employment growth. Local roads also become more important determinants of labour market outcomes after 1980. On average, a standard deviation increase in local road growth caused a 3 percentage point increase in 1980 to 2010 employment growth.

These results have two key implications. First, in the short run, Interstate Highways had little effect on average incomes but were an important determinant of employment and population growth. This suggests labour was relatively mobile across counties during IHS construction, and the changing distribution of market access guided local economic development without closing regional wage gaps. Second, IHS construction continued causing employment and payroll growth even after 1980, when Interstate expansion slowed dramatically. Wage gains in latter years may have been offset by increased housing costs, but nevertheless could reflect dynamic agglomeration externalities, path dependence, or endogenous complementary investments such as local collector roads, housing, or warehouses.

5.4 Robustness tests

I begin assessing the validity of my identification strategy by testing whether my market access instruments are correlated with population growth before the IHS was built. Specifically, I draw on a limited sample of counties where historic population data are available and run TSLS regressions of the form

$$\ln pop_{it} - \ln pop_{i1880} = \beta_t \Delta \ln MA_i + (X_i^{geo}\gamma_t + \alpha_{d(i)t}) \cdot (1 + D_i^{hub}) + e_{it}$$

where ΔMA_i is market access growth from 1950 to 2010, $\alpha_{d(i)t}$ are census division by year fixed effects, and X_i^{geo} is a vector of pre-determined geographic controls.[24] Consistent with my identification strategy, I interact controls with a major hub dummy D_i^{hub}.

Figure 4 presents TSLS estimates of β_t using incidental connections instruments. While confidence intervals are wide, figure 4 brings some concerns that the instruments endow more market access to counties that suffered in the early 1900s and began rebounding early in the IHS planning process. This highlights the importance of economic and demographic controls included in all regressions discussed so far.

Appendix table A.4 presents results of TSLS regressions of baseline covariates on market access growth. Market access growth is associated with higher baseline manufacturing share, high school graduate share, and population. In addition, there is a positive but imperfect relationship between

[24] Geographic controls or longitude, latitude, a coastal dummy, and log land area.

market access and local road growth. Finally, appendix tables A.5 and A.6 show that results are generally robust to altering the control vector and market access' decay parameter.

6 Model calibration and counterfactuals

In this section, I use the structural model to quantitatively assess mechanisms driving reduced form results. First, I estimate the model's central parameters to assess local externalities' role in long-run outcomes. Second, I calibrate the model and simulate the IHS's effect on America's employment distribution. Third, I investigate the reduced form finding that unplanned highways went to negatively selected places by comparing the utility of the complete IHS to a smaller system that exactly follows the 1947 plan.

6.1 Identifying model parameters

Reduced form results are consistent with market access growth improving shipping opportunities initially, and causing additional growth as agglomeration forces strengthen over time. To quantitatively assess this claim, I calibrate the model in two steps. In the first step I estimate the trade elasticity and an initial housing supply elasticity using short-run estimates of equations (8) and (9). The second step takes this trade elasticity and asks what agglomeration and housing supply elasticities rationalize market access' long-run effects on employment and wages.

6.1.1 Trade and the short run

I estimate the trade elasticity (θ) using market access and local roads elasticities of employment and wage growth until 1980 presented in panel A of table 6. Throughout, I assume housing is 25 percent of spending and labour and land shares in production are 0.65 and 0.15. I estimate the model for a range of initial agglomeration elasticities, taking a baseline value of 0.05 from relevant empirical estimates (Combes and Gobillon, 2015).

Combining the baseline agglomeration elasticity with short-run wage and employment elasticities and re-arranging equation (12) delivers an estimate of the trade elasticity (θ). Then, combining the trade elasticity with equation (13) delivers estimates of the inverse housing supply elasticity (η)

and local roads' marginal utility (δ), which is near zero due to local roads' null effects on outcomes until 1980.[25] Intuitively, this procedure uses the firm's problem to estimate the trade elasticity, and then uses the household's problem to identify congestion effects. Finally, wage and employment responses to local road mileage separate congestion between housing costs and traffic congestion.

Table 7 presents structural parameter estimates for a range of initial agglomeration elasticities. A baseline agglomeration elasticity of 0.05 suggests the trade elasticity is approximately 8.1, in line with conventional estimates (Eaton and Kortum, 2002; Donaldson and Hornbeck, 2016). Trade elasticity estimates fall alongside the starting agglomeration elasticity, but remain near the range identified by prior literature. Given the trade elasticity, I estimate a short run inverse housing supply elasticity between 0.24 and 0.68, with estimates shrinking as the baseline agglomeration elasticity grows.

6.1.2 Agglomeration and the long run

To explain wage and employment growth Interstates caused after 1980, I take the initial trade elasticity as given and estimate long run agglomeration and housing supply elasticities based on long run market access elasticities, the sum of elasticities in panels A and B of table 6.

In this step, I maintain the intuition of sequentially estimating production parameters from the firm's problem and congestion parameters from the household's problem. Specifically, I re-arrange equation (12) to compute the long run agglomeration elasticity as a function of the trade elasticity and long run market access elasticities. I then use long run elasticities and equation (13) to calculate a new housing supply elasticity.

The results, presented in the final 2 rows of table 7, suggest that agglomeration and congestion forces both strengthened over time. Specifically, I find that an agglomeration elasticity of about 0.29 rationalizes market access' long run effects on wages and employment. This agglomeration elasticity is large relative to empirical estimates (Combes and Gobillon, 2015) but the model requires

[25] Combining labour supply and demand give solutions for reduced form wage and employment responses to local roads, which must satisfy $\delta_R^L = \varepsilon^{LD}\delta_R^w$ and $\delta_R^w = -\frac{\delta}{1-(1-\mu)\eta} + \frac{\delta+(1-\mu)\eta}{1-(1-\mu)\eta}\delta_R^L$. Re-arranging the second equation yields $\delta = \frac{(1-\mu)\eta\delta_R^L-(1-(1-\mu)\eta)\delta_R^w}{\delta_R^L-1}$, which I solve jointly with equation (13) to isolate δ and η as functions of housing's expenditure share, the trade elasticity, and the reduced form elasticities β^w, β^L, δ_R^L, and δ_R^w.

strong agglomeration forces to rationalize long run market access elasticities. Taking a long run agglomeration elasticity of 0.10, on the high end of empirical estimates, is consistent with a negative trade elasticity, equivalent to rejecting the model's production function.[26]

The model also suggests that the long-run inverse housing supply elasticity increased to somewhere between 0.54 and 0.77. As in the first step, variation across estimates comes from baseline agglomeration's effect on trade elasticity estimates. This tightening housing supply represents substantial growth in the elasticity of housing costs with respect to local population.

6.2 Counterfactual procedure

This section describes how I calibrate the model and simulate inter-city transportation's effects on county employment and household welfare.

I begin by using market access' relationships with employment and wages to identify the distribution of fundamental productivities and amenities. First, I iteratively solve (4) for 2,978 market access terms that summarise 2010's actual inter-city roads and payrolls.[27] I then invert equilibrium conditions (8) and (9) and plug in 2010 wages, employment, and market access to identify exogenous amenity and productivity composites χ_i^L and χ_i^w up to scale.[28] I set scale parameters κ_L and κ_w so that equations (8) and (9) are consistent with 2010 average wages and total employment.[29] Note that counties' amenities include commuter roads, which remain present when I change inter-county travel times in counterfactual simulations.

With fixed amenities and productivities in hand, counterfactual simulations change inter-county travel times and jointly solve equilibrium conditions (4), (8), and (9) for new market access terms. I hold total national employment at its 2010 level so that household utility adjusts to satisfy the equilibrium migration condition. This step delivers counties' equilibrium employment shares with counterfactual highway networks.

[26] In gravity trade models, a negative trade elasticity would suggest that bilateral trade costs increase trade between counties. My Ricardian trade model requires $\theta > 1$ to guarantee that productivity shocks have a positive expected value.

[27] All counterfactuals are limited to counties with no missing CBP data and computations are preformed using R's BBsolve function.

[28] In the model, local fundamentals' scale is determined by the aggregate terms κ_L and κ_w, which capture exogenous factors affecting aggregate income such as capital's rental rate.

[29] This choice of scale parameters is consistent with an equilibrium utility of one in 2010.

For welfare estimates, I normalize 2010 utility to one, change inter-county travel times, and solve for counterfactual utility consistent with labour market clearing: $\bar{u}_c = \left(\frac{\bar{L}_{2010}}{\sum_i \kappa_L MA_{icounter}^{\beta_L} \chi_i^L} \right)^{\frac{1}{\delta_u}}$. Critically, the model's structure implies that $\delta_u^L = \frac{\varepsilon^{LD}}{1-\eta(1-\mu)-\varepsilon^{LD}\left[(1-\mu)\eta+\delta\right]}$, where the labour demand elasticity $\varepsilon^{LD} = -\frac{\theta(\alpha+\gamma)+1}{1+\theta(\gamma-\zeta)}$ captures transportation's effect on production.

Welfare estimates exclude land rents and should be interpreted as direct gains to workers. However, the model's structure implies that aggregate land rents are proportional to labour income and total output.[30] I refrain from quantifying land rents because the model's congestion force can isomorphically represent other fixed factors, urban externalities, and idiosyncratic location preferences (Allen and Arkolakis, 2014).

6.3 Economic geography

Figure 5 plots percent change in counties' employment shares from removing the IHS in 2010. Darker colours indicate larger employment losses, lighter colours indicate employment gains relative to actual 2010 levels,[31] and white shaded counties are excluded from the sample due to data limitations. Variation in market access makes highways' effects differ dramatically across counties, employment losses' interquartile range is 16 percent of 2010's median employment share. Losses are heaviest in northern and central parts of the country and near major highways. Many counties in southern California fare particularly well without Interstate Highways, perhaps reflecting attractive amenities.

6.4 Valuing additions to initial plans

I now ask whether additions to the 1947 highway plan benefited households as much as the Interstate Highway System's key routes. Figure 1 shows that nearly every route in the initial plan was eventually built, and that additions sometimes cross sparsely populated areas or abruptly become slower secondary highways. In the North-East, unplanned Interstates tend to cross regions that were already well served by initial plans. Estimating the incremental value of unplanned highways

[30] Households' preferences and land market structure implies that $(1-\mu)\sum_i w_i L_i$ is spent on housing, a fixed share of which is paid to land, and firms' technology implies commercial land rents equal $\frac{\gamma}{\alpha} n \sum_i w_i L_i$.

[31] The distinction between gains and below average losses depends on my assumption of exogenous equilibrium aggregate employment.

is informative about the political process that built them and the potential value of continued IHS expansion.

To estimate unplanned highways' value, I calibrate the model to 2010 fundamentals and run two counterfactual simulations. First I estimate the utility loss associated with removing the entire IHS and reverting to 1956 travel times. This step delivers an estimate of the entire IHS's value $u_{ihs} = 1 - u_{56}$. Next, I return to 2010 and simulate moving to planned inter-city travel times to estimate additional highways' value $u_{unpl} = 1 - u_{plan}$. Then, unplanned highways' relative value is the benefit ratio $\frac{u_{unpl}}{u_{ihs}}$.[32] Since the 1947 plan contains approximately three quarters of current IHS mileage, I focus on unplanned highways' relative value per kilometre $\frac{u_{unpl}/km_{unpl}}{u_{ihs}/km_{ihs}}$.

Table 8 presents estimates of unplanned highways' relative value. Each row assumes a different combination of long run trade and agglomeration elasticities, including my estimates of 8.11 and 0.29, and maintains the same fundamentals and counterfactual employment allocations. Results show that the utility loss associated with removing either system depends on model parameters, but the distance adjusted benefit ratio remains between 0.175 and 0.195. Even after adjusting for mileage, planned highways were substantially more valuable than ensuing additions.

It is important to note two caveats to this measure of the relative values of planned and unplanned highways. First, these welfare calculations cannot distinguish the possibility of diminishing returns to new highway construction from unplanned routes' negative selection. On the other hand, welfare calculations implicitly account for complementary road investments and attribute complementarities between the planned and unplanned highways to unplanned highways.

To ascertain whether unplanned highways benefited the states that built them, I consider the distribution of employment losses associated with removing unplanned highways. Figure 6 plots percent change in states' employment shares from removing unplanned highways against log unplanned highway density. The plot omits Nebraska, which lacks unplanned highways, and Georgia, a high outlier which contains several IHS hubs, including Atlanta and Savannah, and has neighbours that built a number of unplanned highways. Losses are slightly worse in states with more unplanned roads, but the relationship is far from perfect.[33]

[32]Since the model features homothetic preferences, the benefit ratio directly maps into a monetary value.

[33]The correlation coefficient associated with 6 is -0.32.

Moreover, states that built unplanned highways appear to have shifted employment away from their neighbours. Regressing standardised percent employment changes from removing unplanned highways on standardized logarithms of own and mean of neighbours' unplanned highway density yields $\frac{\%\Delta L_i}{SD(\%\Delta L_i)} = -0.53 \frac{\text{ln unplanned density}_i}{SD(\text{ln unplanned density}_i)} + 0.35 \frac{\text{ln unplanned density}_{n(i)}}{SD(\text{ln unplanned density}_{n(i)})}$ where $n(i)$ are state i's adjacent states.[34] Removing all unplanned highways might decrease national employment, but the model suggests that employment losses would be smallest in states whose neighbours built the most unplanned highways.[35]

7 Conclusion

This paper presents new estimates of national transportation's effects on regional economic growth. To produce these estimates, I develop a broadly adaptable identification strategy: isolating market access growth driven by incidental connections to rural counties. I then calibrate a general equilibrium trade model to assess mechanisms underlying empirical results, simulate aggregate effects, and discuss policy implications.

Interstate highways caused differences in market access that led to substantial variation in counties' employment and had small effects on relative wages. These effects compounded over time and market access only began causing wage growth years after the Interstate's construction, when commuter highway availability also began determining growth. This evolution is consistent with local agglomeration and housing costs becoming stronger forces shaping America's economic geography over time.

To better understand the value of continued Interstate expansion, I proceed to study highways that were omitted from early federal plans. I find that market access caused by unplanned highways is correlated with adverse economic conditions, that these unplanned highways provided limited economic value, and that they drew economic activity away from certain places. This suggests that given the institutions currently guiding Interstate expansion, new inter-city highways might add

[34] This regression uses the same sub-sample of states shown in figure 6 and subtracts the mean of each variable so that the constant is mechanically equal to zero.

[35] The market clearing assumption implies does not imply competition among immediate neighbours, this is a feature of the data. Market clearing only imposes that employment changes are zero sum nationally.

less value than the Interstate Highway System's core routes.

These results are useful for understanding national transportation networks' current and historical role in determining regional growth. In particular, it seems that estimates of this infrastructure's value could benefit from closely studying the political economy at play. Additional research could also improve our understanding of density's role in determining the regional and aggregate effects of national transportation, and the extent to which these investments close regional wage gaps. Finally, future work could bridge the gap between the market access approach taken here and the model based approaches of Fajgelbaum and Schaal (2017) and Allen and Arkolakis (2019) to learn more about the implications of increasing traffic congestion.

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8 Tables

Table 1: Summary of the roads data by county

	Travel time (hours)		Change in log highway equivalent km
	Pre interstate	Post interstate	
Mean	32.1	19.8	0.43
Std. Dev.	17.3	9.9	0.62

Table 2: Cross-county economic growth

Log change in	Payroll per Employee	Employment	Population
Panel A: 1950/53 to 1980			
Mean	0.320	0.617	0.213
Std. Dev.	0.208	0.755	0.437
Panel B: 1980 to 2010			
Mean	0.040	0.349	0.174
Std. Dev.	0.203	0.464	0.351
Panel C: 1950/53 to 2010			
Mean	0.359	0.965	0.386
Std. Dev.	0.259	0.979	0.722

Employment and payrolls come from county business patterns databases in 1953, 1980, and 2010. County populations come from 1950, 1980, and 2010 decennial censuses.

Table 3: Summary of market access measures

	$\Delta ln(MA)$	$ln(MA, 1953\text{ payrolls})$
Mean	1.87	0.721
Std. Dev.	0.284	0.139

Market access growth from 1953 to 2010 is weighted by each year's payrolls (from County Business Patterns) in column 1 and only 1953 payrolls in column 2.

Table 4: First stage results

	Std.Dev.	$\Delta \ln MA$					$\Delta \ln Roads$
			Reduced form			Recursive	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$\Delta \ln MA$ (fixed income)	0.14	1.090 (0.027)					
$\Delta \ln \widetilde{MA}^{inc}$	0.13		0.358 (0.076)	0.848 (0.039)	0.750 (0.066)	0.777 (0.058)	-0.286 (0.110)
$\Delta \ln \widetilde{MA}^{hub}$	0.14		0.500 (0.076)				
$D^{inc} \Delta \ln \widetilde{MA}^{hub}$	0.36				0.142 (0.073)	0.064 (0.065)	0.174 (0.111)
$\Delta \ln Roads$	0.62	0.012 (0.005)					
$\Delta \ln \widetilde{Roads}$	0.52		0.013 (0.007)	0.018 (0.008)	0.018 (0.008)	0.014 (0.007)	0.877 (0.023)
Observations	2,978	2,978	2,978	2,978	2,978	2,978	2,978
Dep.Var. St.Dev.	–	0.28	0.28	0.28	0.28	0.20	0.62
R^2	–	0.898	0.773	0.764	0.765	0.571	0.650
A-P F-Stat	–	1156.27	351.92	399.91	308.37	281.6	325.59

Commute zone clustered standard errors in parenthesis, A-P F-statistics are partial first stage F-statistics for market access computed following Angrist and Pischke (2008) using clustered variance matrices, and all regressions include a full set of controls. Column 1 presents each instrument's standard deviation and the remaining columns present OLS regressions of infrastructure measures on instruments and controls.

Table 5: Long run effects on county outcomes

	OLS (1)	Fixed income (2)	Plan (3)	Inc. Connect (4)	Inc. Connect (5)	Inc. Connect (6)
Panel A: Employment						
$\Delta \ln MA$	0.737	0.413	0.695	0.849	0.843	0.876
	(0.136)	(0.140)	(0.197)	(0.218)	(0.213)	(0.222)
$\Delta \ln Roads$	0.073	0.116	0.035	0.014	0.015	0.017
	(0.030)	(0.032)	(0.043)	(0.043)	(0.043)	(0.043)
Panel B: Payroll per employee						
$\Delta \ln MA$	0.104	0.086	0.135	0.138	0.137	0.142
	(0.031)	(0.034)	(0.048)	(0.054)	(0.053)	(0.055)
$\Delta \ln Roads$	0.010	0.013	0.011	0.011	0.011	0.011
	(0.008)	(0.008)	(0.011)	(0.012)	(0.012)	(0.012)
Observations	2,978	2,978	2,978	2,978	2,978	2,978
Market access type	Reduced Form	Reduced Form	Reduced Form	Reduced Form	Reduced Form	Recursive
Excluded instruments	None	$\Delta \ln MA_i$	$\Delta \ln \widetilde{MA}_i^{inc}$ $\Delta \ln \widetilde{MA}_i^{hub}$ $\Delta \ln \widetilde{R}_i$	$\Delta \ln \widetilde{MA}_i^{inc}$ $\Delta \ln \widetilde{R}_i$	$\Delta \ln \widetilde{MA}_i^{inc}$ $D_i^{inc} \Delta \ln \widetilde{MA}_i^{hub}$ $\Delta \ln \widetilde{R}_i$	$\Delta \ln \widetilde{MA}_i^{inc}$ $D_i^{inc} \Delta \ln \widetilde{MA}_i^{hub}$ $\Delta \ln \widetilde{R}_i$
Instrument payrolls	Changing	Fixed	Fixed	Fixed	Fixed	Fixed
Instrument travel times	Actual	Actual	Plan	Plan	Plan	Plan

Commute zone clustered standard errors in parenthesis. Each column corresponds to an OLS or TSLS regression of 1953 to 2010 log change employment and payroll per-employee growth on market access, local road density, and controls.

Table 6: Short run and continued effects

	Payroll per Employee	Employment	Population
	(1)	(2)	(3)
Panel A: 1950/53 to 1980			
$\Delta \ln MA$	0.001	0.548	0.274
	(0.046)	(0.180)	(0.084)
$\Delta \ln Roads$	0.0003	−0.036	0.001
	(0.009)	(0.034)	(0.015)
Panel B: 1980 to 2010			
$\Delta \ln MA$	0.145	0.346	0.237
	(0.047)	(0.107)	(0.074)
$\Delta \ln Roads$	0.010	0.050	0.015
	(0.010)	(0.026)	(0.016)
Observations	2,978	2,978	2,978

Commute zone clustered standard errors in parenthesis. Each column corresponds to an TSLS regression using full set of controls, incidental connections instruments for market access, and the 1947 plan local road instruments. Panel A differences in log outcomes from 1950 (or 1953 for employment and payrolls) to 1980, and panel B differences them from 1980 to 2010.

Table 7: Structural parameter estimates

ζ_{SR}	0.10	0.05	0
$\hat{\theta}$	15.99	8.11	5.43
$\hat{\eta}_{SR}$	0.24	0.46	0.68
$\hat{\eta}_{LR}$	0.54	0.66	0.77
$\hat{\zeta}_{LR}$	0.28	0.29	0.29

Table 8: Welfare effects of removing unplanned highways

θ	ζ	u_{ihs}	u_{unpl}	$\frac{u_{unpl}}{u_{ihs}}$	$\frac{u_{unpl}/km_{unpl}}{u_{ihs}/km_{ihs}}$
10	0.29	0.132	0.017	0.129	0.176
10	0.1	0.232	0.031	0.136	0.186
10	0.05	0.257	0.035	0.137	0.188
10	0	0.281	0.039	0.139	0.191
8.11	0.29	0.145	0.019	0.130	0.177
8.11	0.1	0.241	0.033	0.136	0.187
8.11	0.05	0.265	0.037	0.138	0.189
8.11	0	0.289	0.040	0.140	0.192
6	0.29	0.168	0.022	0.131	0.179
6	0.1	0.258	0.035	0.138	0.188
6	0.05	0.280	0.039	0.139	0.191
6	0	0.302	0.043	0.141	0.193
4	0.29	0.206	0.028	0.134	0.183
4	0.1	0.285	0.040	0.140	0.191
4	0.05	0.305	0.043	0.141	0.193
4	0	0.324	0.046	0.143	0.196

9 Figures

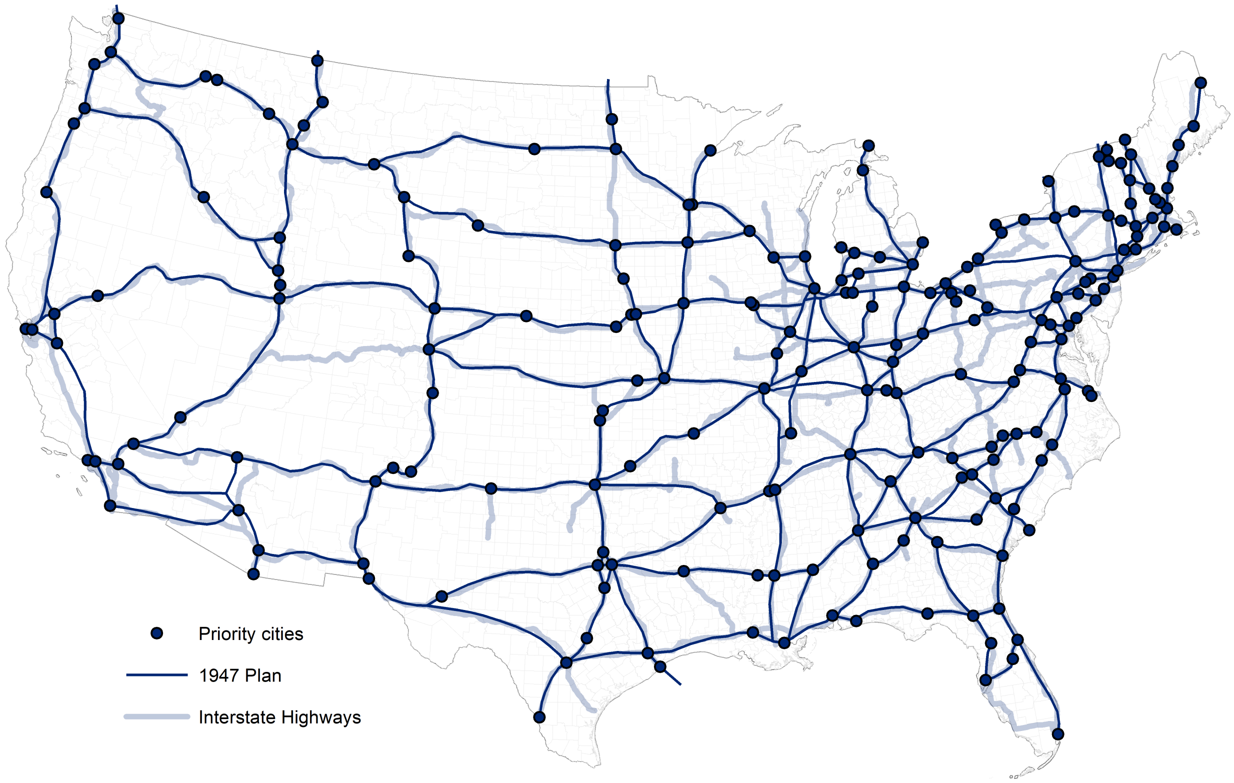
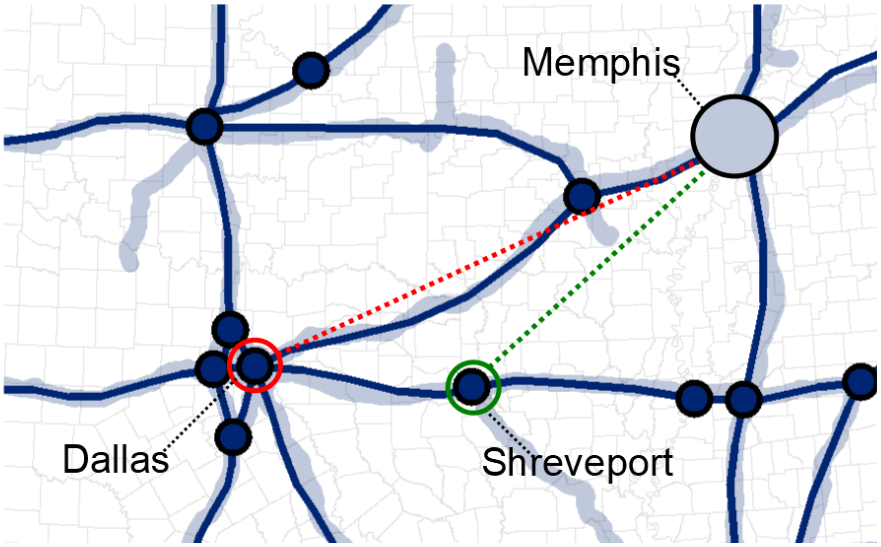


Figure 1: The 1947 Interstate plan (dark lines) and modern Interstate Highways (light lines)

Figure 3: A stylized example of the priority hierarchy



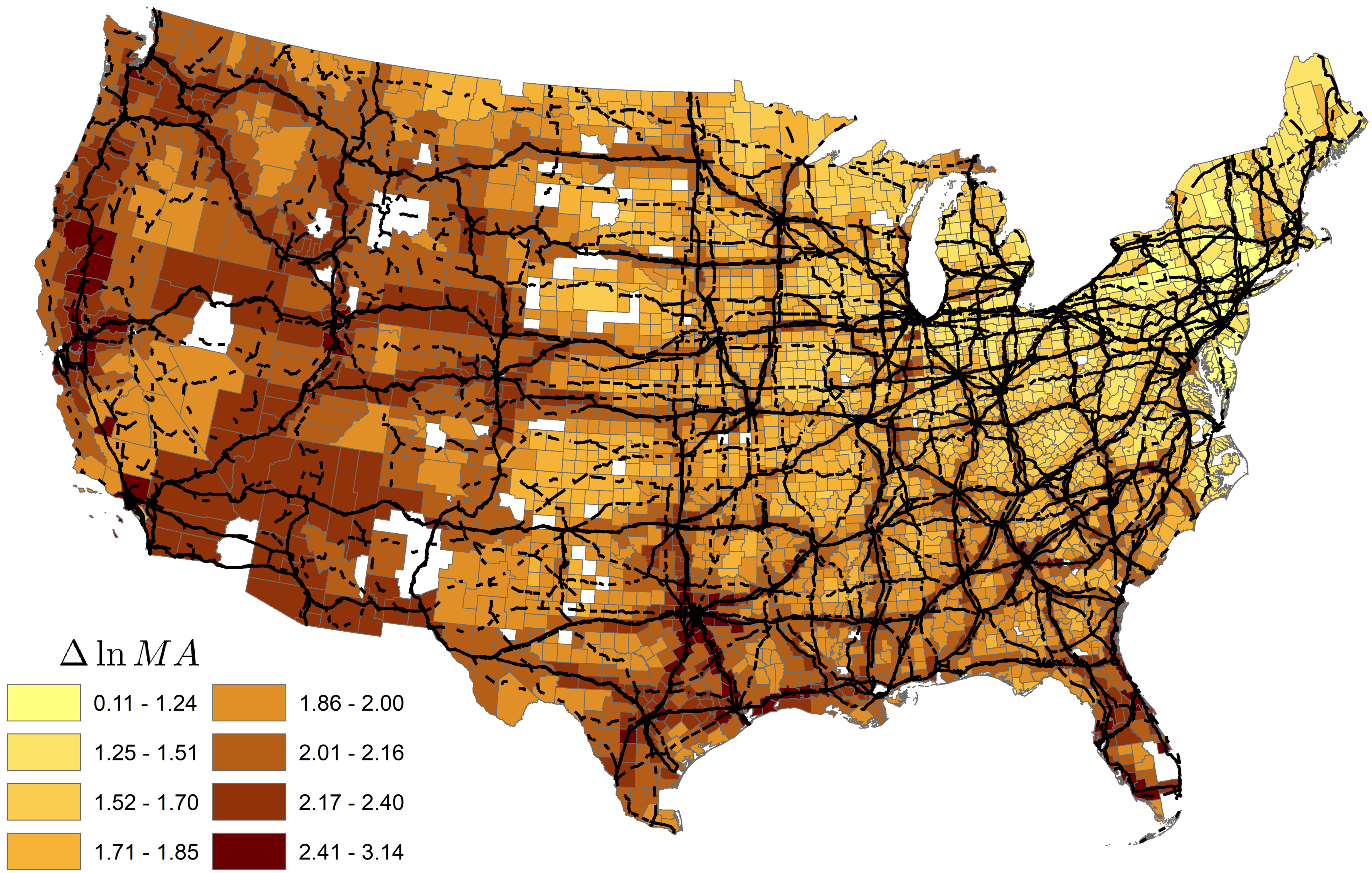


Figure 2: Change in log market access for U.S. counties

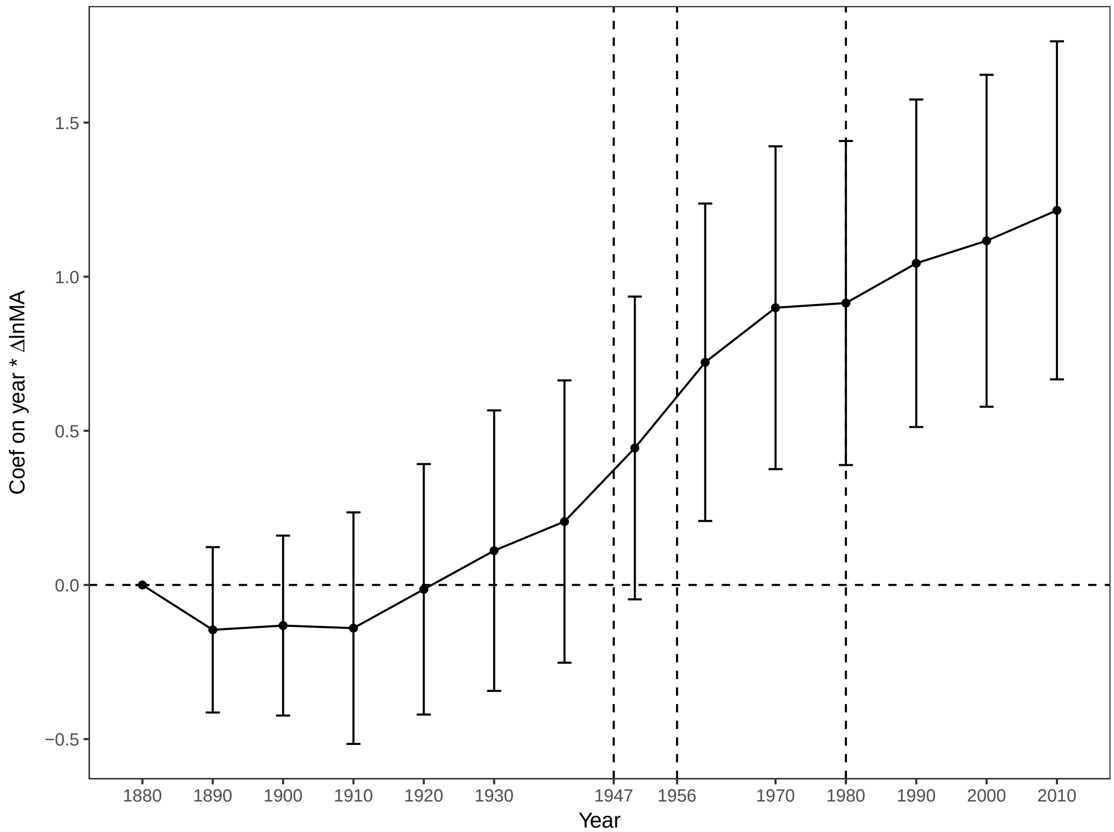


Figure 4: Market access, incidental connections, and population growth from 1880 (error bars represent 95 percent confidence intervals based on commute zone-clustered standard errors)

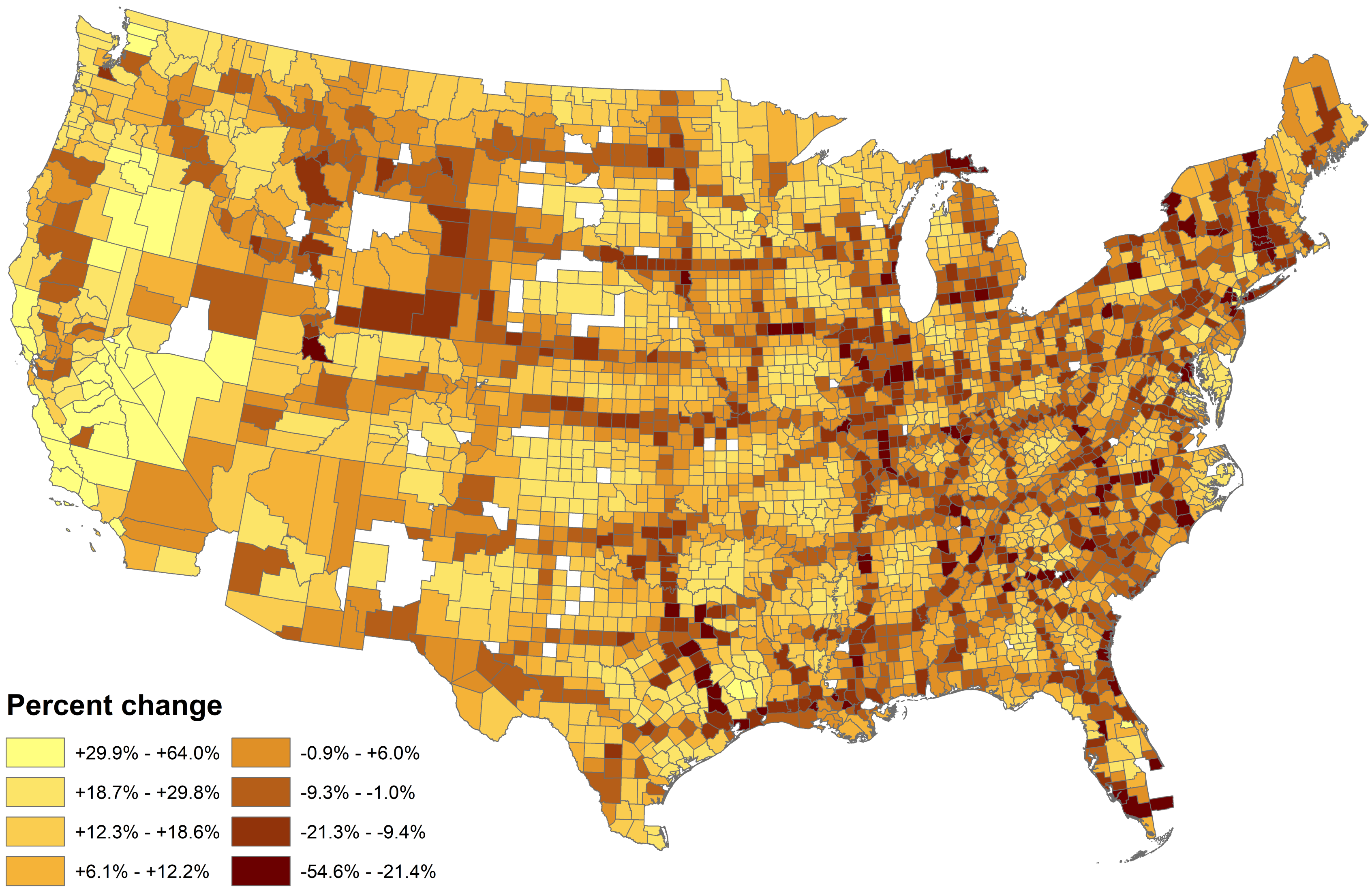


Figure 5: Lost employment from removing the IHS

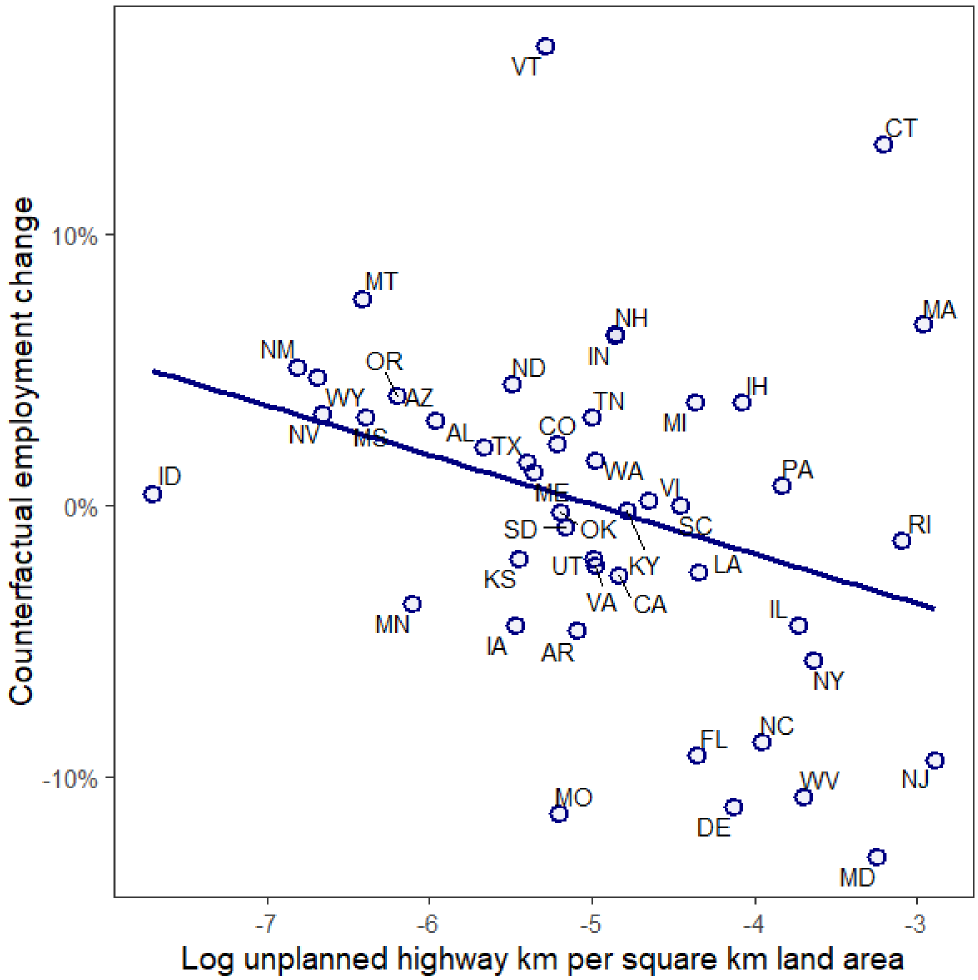


Figure 6: State employment change from removing unplanned highways

A Additional tables

Table A.1: Structural parameters underlying reduced form elasticities

$\beta^w =$	$\frac{1}{1-\varepsilon^{LD}\varepsilon^{LS}}\left[\frac{\varepsilon^{LS}}{1+\theta(\gamma-\zeta)} - \frac{\mu}{\theta}\frac{1}{1-\eta(1-\mu)}\right]$
$\beta^L =$	$\frac{1}{1-\varepsilon^{LD}\varepsilon^{LS}}\left[\frac{1}{1+\theta(\gamma-\zeta)} - \frac{\mu}{\theta}\frac{\varepsilon^{LD}}{1-\eta(1-\mu)}\right]$
$\delta_u^L =$	$\frac{1}{1-\varepsilon^{LD}\varepsilon^{LS}}\left[\frac{\varepsilon^{LD}}{1-\eta(1-\mu)}\right]$
$\delta_u^w =$	$\frac{1}{1-\varepsilon^{LD}\varepsilon^{LS}}\left[\frac{1}{1-\eta(1-\mu)}\right]$
$\delta_R^L =$	$-\frac{1}{1-\varepsilon^{LD}\varepsilon^{LS}}\left[\frac{\varepsilon^{LD}\delta}{1-\eta(1-\mu)}\right]$
$\delta_R^w =$	$-\frac{1}{1-\varepsilon^{LD}\varepsilon^{LS}}\left[\frac{\delta}{1-\eta(1-\mu)}\right]$
$\varepsilon^{LD} =$	$-\frac{\theta(\alpha+\gamma)+1}{1+\theta(\gamma-\zeta)}$ (labour demand elasticity)
$\varepsilon^{LS} =$	$\frac{\eta(1-\mu)+\delta}{1-\eta(1-\mu)}$ (inverse labour supply elasticity)

Table A.2: Long run heterogeneous effects

	1950 interaction variable:			
	MSA	Population density	High school share	Market access
Panel A: Employment				
Above median	-0.221	0.491	0.86	0.79
	(0.539)	(0.21)	(0.278)	(0.225)
Below median	0.913	1.31	0.813	1.037
	(0.226)	(0.349)	(0.288)	(0.315)
Difference	-1.133	-0.819	0.047	-0.247
	(0.585)	(0.369)	(0.373)	(0.338)
Panel B: Payroll per employee				
Above median	0.205	0.091	0.198	0.141
	(0.121)	(0.057)	(0.068)	(0.061)
Below median	0.108	0.194	0.074	0.123
	(0.057)	(0.083)	(0.072)	(0.073)
Difference	0.096	-0.103	0.125	0.018
	(0.13)	(0.09)	(0.09)	(0.077)
Observations	2,978	2,978	2,978	2,978

Commute zone clustered standard errors in parenthesis. Each column corresponds to an interacted TSLS regression using full set of controls plus the interaction variable of interest, incidental connections instruments for market access, and the 1947 plan local road instruments. All regressions include interactions with the baseline variable of interest and incidental connections instruments to the first stage. The dependent variable is change in log employment in panel A and change in log payroll per-employee in panel B.

Table A.3: Additional outcomes

	Dependent variable:			
1950 to 2010 change in	Log median dwelling value	Detached homes' share	Log establishment count	Log employees per establishment
	(1)	(2)	(3)	(4)
$\Delta\ln(MA)$	0.147	−5.701	0.702	0.141
	(0.100)	(2.002)	(0.186)	(0.081)
$\Delta\ln(Roads)$	0.001	0.227	−0.007	0.022
	(0.018)	(0.451)	(0.036)	(0.020)
Observations	2,963	2,978	2,978	2,978

All regressions include a full set of controls, are fit by TSLS using incidental connections instruments for market access and the 1947 plan for local roads, and commute-zone clustered standard errors are in parenthesis. Median dwelling values and detached home shares are as reported to 1950 and 1980 decennial censuses, establishment counts and employees per establishment come from the CBP.

Table A.4: Market access, incidental connections, and covariates

	Dependent variable:			
	$\Delta\ln(Roads)$	1950 manufacturing employment share	1950 high school share	$\ln(pop_{1940})$
	(1)	(2)	(3)	(4)
$\Delta\ln(MA)$	2.325	0.101	0.117	0.864
	(0.236)	(0.045)	(0.344)	(0.311)
Observations	2,978	2,978	2,978	2,978

Commute zone clustered standard errors in parenthesis. Each column is a TSLS regression of a covariate on market access growth and a constant using the incidental connections instruments. $\Delta\ln(Roads)$ is change in efficiency road km within each county. Manufacturing employment share, high school graduate share, and population come from the decennial census.

Table A.5: Market access elasticities from 1950 to 2010 with alternative controls

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Employment	0.843	0.759	0.654	1.055	1.412	0.745	1.019
	(0.213)	(0.337)	(0.247)	(0.234)	(0.292)	(0.212)	(0.185)
Payroll per employee	0.137	0.106	0.103	0.157	0.152	0.142	0.158
	(0.053)	(0.084)	(0.054)	(0.056)	(0.063)	(0.045)	(0.044)
$\Delta \ln(Roads)$	Y	Y	Y	Y	N	N	N
Geog. ctrls.	Y	N	N	Y	N	N	Y
Demog. ctrls.	Y	N	Y	N	N	Y	N

Commute zone clustered standard errors are in parenthesis and each cell presents a coefficient on market access from a different TSLS regression using incidental connections instruments and including local roads instruments in columns 1 through 4. Rows denote outcome variables and columns denote combinations of control variables. Geographic controls are longitude, latitude, log land area, coastal, and census division all interacted with a major city dummy. Demographic controls are county manufacturing and agriculture shares in 1950, population controls, military facilities, log sales per farm, and interactions with major city.

Table A.6: Market access elasticities from 1950 to 2010 with alternative decay parameters

Decay:	0.5	1	1.5	2	2.5	3
Employment	3.292	1.450	0.843	0.534	0.350	0.239
	(0.946)	(0.389)	(0.213)	(0.133)	(0.090)	(0.066)
Payroll per employee	0.617	0.255	0.137	0.083	0.055	0.040
	(0.240)	(0.098)	(0.053)	(0.033)	(0.023)	(0.017)
$SD(\Delta lnMA)$	0.095	0.189	0.284	0.393	0.525	0.679

Commute zone clustered standard errors are in parenthesis and each cell presents a coefficient on market access from a different TSLS regression using incidental connections instruments and full set of controls, including instrumented local roads. Rows denote outcome variables and columns market access' decay parameter.