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RAILROADS AND AMERICAN ECONOMIC GROWTH: A "MARKET ACCESS" APPROACH

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ABSTRACT

This paper examines the historical impact of railroads on the American economy. Expansion of the railroad network may have affected all counties directly or indirectly – an econometric challenge that arises in many empirical settings. However, the total impact on each county is captured by changes in that county's "market access," a reduced-form expression derived from general equilibrium trade theory. We measure counties' market access by constructing a network database of railroads and waterways and calculating lowest-cost county-to-county freight routes. As the railroad network expanded from 1870 to 1890, changes in market access were capitalized into county agricultural land values with an estimated elasticity of 1.1. County-level declines in market access associated with removing all railroads in 1890 are estimated to decrease the total value of US agricultural land by 64%. Feasible extensions to internal waterways or improvements in country roads would have mitigated 13% or 20% of the losses from removing railroads.

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During the 19th century, railroads spread throughout a growing United States as the economy rose to global prominence. Railroads became the dominant form of freight transportation and areas around railroad lines prospered. The early historical literature often presumed that railroads were indispensable to the United States' economy or, at least, very influential for economic growth. Our understanding of the development of the American economy is shaped by an understanding of the impact of railroads and, more generally, the impact of market integration.

In *Railroads and American Economic Growth*, Fogel (1964) transformed the academic literature by using a "social saving" methodology to focus attention on counterfactuals: in the absence of railroads, freight transportation by rivers and canals would have been only moderately more expensive along most common routes. Fogel argued that small differences in freight rates caused some areas to thrive relative to others, but that the aggregate economic impact of railroads was small. This social saving methodology has been widely applied to transportation improvements and other technological innovations, though many scholars have discussed both practical and theoretical limitations of the approach (see, e.g., Lebergott, 1966; Nerlove, 1966; McClelland, 1968; David, 1969; White, 1976; Fogel, 1979; Leunig, 2010).[1]

There is an appeal to a methodology that estimates directly the impacts of railroads, using increasingly available county-level data and digitized railroad maps. Recent work has compared counties that received railroads to counties that did not (Haines and Margo, 2008; Atack and Margo, 2010; Atack et al., 2010; Atack, Haines and Margo, 2011), and similar methods have been used to estimate impacts of railroads in modern China (Banerjee, Duflo and Qian, 2012) or highways in the United States (Baum-Snow, 2007; Michaels, 2008). These studies estimate relative impacts of transportation improvements; for example, due to displacement and complementarities, areas without railroads and areas with previous railroads are also affected when railroads are extended to new areas.

This paper develops a methodology for estimating *aggregate* impacts of railroads on the American economy, maintaining Fogel's focus on the agricultural sector. We argue that it is natural to measure how expansion of the railroad network affects each county's "market access," a reduced-form expression derived from general equilibrium trade theory, and then to estimate how enhanced market access is capitalized into each county's value of agricultural land. A county's market access increases when it becomes cheaper to trade with another county, particularly when that other county has a larger population and higher trade costs with other counties. In a wide class of multiple-region models, changes in market access

[1] One alternative approach is to create a computational general equilibrium model, with the explicit inclusion of multiple regions separated by a transportation technology (e.g., Williamson, 1974; Herrendorf, Schmitz and Teixeira, 2009). Cervantes (2013) presents estimates from a calibrated trade model.

summarize the total direct and indirect impacts on each county from changes in the national railroad network. We measure counties' market access by constructing a network database of railroads and waterways and calculating lowest-cost county-to-county freight routes.

As the railroad network expanded from 1870 to 1890, changes in market access were capitalized into agricultural land values with an estimated elasticity of 1.1. This estimate would not reject the coefficient implied by the model (at plausible parameter values), though the empirical analysis does not depend on calibrating the model.

An empirical advantage to estimating the impact of market access, rather than estimating the impact of local railroad density, is that counties' market access is influenced by changes elsewhere in the railroad network. Despite concerns about exacerbating attenuation bias from measurement error, the estimated impact of market access is largely robust to using only variation in access to more-distant markets or to controlling for changes in counties' own railroad track. Another identification approach uses the fact that counties close to navigable waterways are naturally less dependent on expansion of the railroad network to obtain access to markets. The estimated impact of market access is larger when instrumenting for changes in market access with counties' initial market access through waterways only.

The paper then estimates the aggregate impact of railroads on the agricultural sector in 1890, based on the calculated decline in counties' market access without railroads and the estimated impact of market access on agricultural land values. Removing all railroads in 1890 is estimated to lower the total value of US agricultural land by 63.5%. This reduction in agricultural land value generates annual economic losses equal to 3.40% of GNP, which is moderately larger than comparable social saving estimates by Fogel (1964) that are presumed to reflect an upper bound impact. Railroads were critical to the agricultural sector, though the total loss of all agricultural land value would only generate annual economic losses equal to 5.35% of GNP. Reviving the idea that railroads were "indispensable" to American economic growth would require extending our analysis to other economic sectors and/or impacts on technological growth.

The paper then considers whether railroads were "irreplaceable" to the agricultural sector, or whether alternative transportation improvements had the potential to substitute for the absence of railroads. First, in the absence of railroads, additional canals might have been constructed to bring many areas closer to low-cost waterways (Fogel, 1964). However, we measure substantial declines in counties' market access when replacing railroads with the extended canal network proposed by Fogel. The proposed canals mitigate only 13% of the losses from removing the railroad network, though the implied annual economic benefits would have exceeded the estimated annual capital costs. Second, in the absence of railroads, country roads might have been improved to reduce the costs of long-distance wagon transportation (Fogel, 1964). Replacing railroads with lower wagon transportation costs would have mitigated roughly 20% of the losses from removing the railroad network. Most of this benefit to improved country roads would have continued in the presence of railroads, however, which suggests that railroads did not substantially discourage improvements in country roads or perhaps even the introduction of motor trucks. The absence of railroads might also have increased waterway shipping rates (Holmes and Schmitz, 2001), which is estimated to exacerbate by 22% the economic losses from removing railroads.

Revisiting the historical impact of railroads on the American economy suggests a larger role for railroads and market integration in economic development. Fogel (1964) calculates the impact of railroads based on willingness to pay for the transportation of agricultural goods, and our methodology is based on a similar willingness to pay for agricultural land. Whereas Fogel adds up the impact of railroads partly by assuming the complete loss of agricultural land more than 40 miles from a natural waterway, we directly estimate the impact of railroads on all counties' agricultural land values.[2] While Fogel frames his social saving estimate as an upper bound due to the potential for adaptation to the absence of railroads, our best estimates neglect potential gains to consumers, other sectors, and/or technological innovation. We hope that the ability to measure and analyze impacts of "market access" will spur a new wave of research on the aggregate impacts of railroads throughout the American economy.[3]

More broadly, this paper takes on the general methodological challenge of estimating aggregate treatment effects in empirical settings with substantial treatment spillover effects. Railroads affect all areas to some degree through interlinked trade networks. If railroads' impacts were locally confined, then the unit of analysis might be aggregated (e.g., Miguel and

[2]We see our methodology as a natural extension of Fogel's intuition, drawing on recent advances in trade theory, county-level data, and spatial computational tools.

[3]In related work using a similar model, Redding and Sturm (2007) estimate the impact on population from changes in market access following the division and reunification of Germany, Hanson (2005) studies the correlation between US county-level wages and county-level market access from 1970 to 1990, and Redding and Venables (2004) and Head and Mayer (2011) study the relationship between national GDP and country market access. Donaldson (forthcoming) estimates the income benefits from India's railroads and shows that these are consistent with an Eaton and Kortum (2002) model similar to that used here. In contrast to Donaldson (forthcoming), this paper measures the impact of railroads on market access (as derived from an Eaton-Kortum model extended to allow for labor mobility) to estimate the aggregate impact of railroads and to evaluate the impact of counterfactual scenarios. This paper's methodological approach is more suited to settings with high mobility of labor, which appears to reflect the historical US economy more than the Indian economy. The concept of "market access" has been useful for empirical work (surveyed by Redding (2010)), though this paper is the first to leverage the concept of "market access" to estimate aggregate effects of place-based treatments (such as transportation infrastructure) from spatial comparisons using micro-geographical data. Redding (2010) highlights the surprising absence of research in this field that uses the price of an immobile factor, such as our use of land values, to estimate the benefits to each location in the presence of mobile factors.

Kremer, 2004). As in many empirical settings, however, sufficient aggregation is empirically intractable. Our proposed solution uses economic theory to characterize how much railroads change each area's market access; once the intensity of treatment is defined to reflect both direct and indirect impacts, relative empirical comparisons estimate the aggregate treatment effect of railroads.[4] Using economic theory as a guide, but without relying on calibration, it is possible to estimate aggregate treatment effects in a reduced-form manner using relative variation. Empirical research is increasingly estimating relative magnitudes by comparing areas more affected or less affected by some plausibly exogenous treatment; we hope to encourage an extension of this research agenda to address the many important questions that are more aggregate in nature.

I American Railroads and "Social Saving" Estimates

By 1890, expansion of the railroad network had enabled a dramatic shift westward in the geographic pattern of agricultural production. Large regional trade surpluses and deficits in agricultural goods reflected the exploitation of comparative advantage. Fogel (1964) develops a "social saving" methodology for calculating the aggregate impact of railroads on the agricultural sector. We develop a different "market access" methodology for estimating the aggregate impact of railroads on the agricultural sector, though some aspects of our approach are rooted in Fogel's analysis. It is therefore useful to begin with a summary of Fogel's social saving analysis. We also take the opportunity to extend some of Fogel's calculations in minor respects, using modern spatial analysis tools and digitized county-level data.

Fogel (1964) estimates that the social saving from railroads in the agricultural sector in 1890 was no more than 2.7% of GNP. He divides this impact into that coming from interregional trade (0.6%) and intraregional trade (2.1%). For interregional trade, defined as occurring from 9 primary markets in the Midwest to 90 secondary markets in the East and South, freight costs were only moderately cheaper with the availability of railroads than when using only natural waterways and canals. Multiplying the difference in freight costs (with and without railroads) by the quantity of transported agricultural goods (in 1890), Fogel calculates the annual interregional social saving from railroads to be no more than \$73 million or 0.6% of GNP. This number is proposed as an upper bound estimate because the approach assumes perfectly inelastic demand for transport, whereas the quantity of transported goods should be expected to decline with increased transportation costs.[5]

[4] In the absence of an economic model, the spatial econometrics literature provides estimators for when treatment spillovers are a known function of geographic or economic distance Anselin (1988). Estimation of aggregate treatment effects requires a cardinal ranking of how much areas (or people) are exposed to the treatment, whereas an ordinal ranking is insufficient.

[5] Indeed, the total cost of agricultural interregional shipments would have nearly doubled in the absence of railroads.

For intraregional trade, defined as the trade from farms to primary markets, the impact of railroads was mainly to reduce distances of expensive wagon transportation. In the absence of railroads, farms would have incurred substantially higher costs in transporting goods by wagon to the nearest waterway to be shipped to the nearest primary market. In areas more than 40 miles from a waterway, wagon transportation may have become prohibitively expensive; indeed, Fogel refers to all land more than 40 miles from a navigable waterway as the "infeasible region" because it may have become infeasible for agricultural production if railroads were removed. Figure 1, panel A, largely reproduces Fogel's map of areas within 40 miles of a navigable waterway (shaded black), with the addition of areas within 40 miles of a railroad in 1890 (shaded light gray). Fogel bounds the economic loss in the "infeasible region" by the value of agricultural land in areas more than 40 miles from a waterway, which he calculates to generate approximately $154 million in annual rent. Adding the additional increase in transportation costs within the feasible region, which is bounded by $94 million using a similar approach to the interregional analysis, Fogel calculates the total annual intraregional impact to be no more than $248 million or 2.1% of GNP.

Fogel's total social saving estimate of $321 million or 2.7% of GNP is generally interpreted as indicating a limited impact of the railroads, though the total loss of all agricultural land could only generate annual losses of $642 million or 5.35% of GNP. Fogel's methodology is typically associated with the interregional social saving calculation and the analogous approach for the intraregional impact in the feasible region, though the annual rents from land in the infeasible region is the largest component of the total estimate. Fogel emphasizes that losses in the infeasible region may well be overstated, as the railroad network could have been replaced with an extended canal network to bring most of the infeasible region (by value) within 40 miles of a waterway. Figure 1, panel B, shows that much of the area beyond 40 miles from a navigable waterway would be within 40 miles of canals that might plausibly have been built if railroads did not exist (shaded dark gray). Fogel estimates that these canals would mitigate 30% of the intragional impact from removing railroads.

Fogel faced a number of challenges in calculating the intraregional impact of railroads, some of which can be partly overcome by using modern computer software and digitized county-level data. One challenge was in measuring the area of the infeasible region, which is much more accurate with the benefit of modern computer software. Using digitized maps of Fogel's waterways and county-level data on agricultural land values (as opposed to state-level averages), we calculate a $181 million annual return on agricultural land in the infeasible region that is only moderately larger than Fogel's approximation of $154 million.[6] It was

[6]Throughout the paper we use Fogel's preferred mortgage interest rate (7.91%) to convert agricultural land values to an annual economic value. We also express annual impacts as a percent of GNP, using Fogel's

impractical for Fogel to calculate the area within 40 miles of a railroad in 1890, but, consistent with 40 miles being a reasonable cutoff distance for the infeasible region, we calculate an annual return of only $4 million on agricultural land more than 40 miles from a waterway or railroad in 1890.

Fogel faced another challenge in calculating the intraregional social saving in the feasible region. Data limitations require a number of practical approximations and there are theoretical concerns about whether an upper bound estimate is meaningful given the potentially large declines in transported goods without railroads. An alternative approach, extending Fogel's treatment of the infeasible region, is to assume that agricultural land declines in value the further it is from the nearest waterway or railroad. A simple implementation of this idea, though computationally infeasible in Fogel's era, is to assume that land value decays linearly as it lies between 0 miles and 40 miles from the nearest waterway or railroad. Using modern computer software, we can calculate the fraction of each county within arbitrarily small distance buffers of waterways and/or railroads.[7] Implementing this approach, we calculate the annual intraregional impact of removing railroads to be $319 million or 2.7% of GNP.

Figure 1, panel C, shows smaller geographic buffers around waterways and railroads. In contrast to the 40-mile buffers in panel A, panel C shows 10-mile buffers that reflect the average wagon haul from a farm to a rail shipping point in 1890. The comparative advantage of railroads' high density is more apparent at smaller distance buffers. Panel D adds 10-mile buffers around the proposed canals, which mainly run through sections of the Midwest and Eastern Plains. Replicating the above analysis of distance buffers, we calculate an annual loss of $221 million or 1.8% of GNP when replacing railroads with the proposed canals. This preliminary exercise finds that the proposed canals mitigate 31% of the intraregional impact from removing railroads, which is very close to Fogel's original estimate of 30%.

The waterway network, particularly with extended canals, is moderately effective in bringing areas near some form of low-cost transportation. Construction of railroads was hardly limited to providing a similarly sparse network, however, and our main estimates will

preferred measure of GNP in 1890 ($12 billion).

[7]In practice, we take a discrete approximation to this linear decay function and assume that agricultural land loses 100% of its value beyond 40 miles, 93.75% of its value between 40 and 35 miles, 81.25% of its value between 35 and 30 miles, and so forth until losing 6.25% of its value between 5 and 0 miles. We calculate the share of each county that lies within each of these buffer zones (e.g., between 40 miles and 35 miles from a waterway or railroad). In addition, to avoid overstating the impact of railroads, we modify Fogel's calculation of the infeasible region to also reflect counties' imperfect access to railroads: since no county has all of its land within 0 miles of a waterway or railroad, all 1890 county land values already capitalize some degree of imperfect access. To calculate percent declines off the correct base, we adjust observed county agricultural land values to reflect their implied value if not for distance to a waterway or railroad. In the end, we calculate the implied decline in land value based on each county's land share within each 5-mile distance buffer of a waterway and subtracting the county's land share within that buffer of a waterway or railroad.

show that high density railroad construction was particularly effective in providing nearby low-cost routes to markets.

Our main empirical analysis will extend much of Fogel's intuition for evaluating the aggregate impact of railroads in 1890.[8] We maintain Fogel's focus on the agricultural sector, as non-agricultural freight was geographically concentrated in areas with low transportation costs along waterways. We build on Fogel's intuition that the value of agricultural land, as an immobile factor, should reflect the cost of getting agricultural goods to market. We choose transportation cost parameters to be comparable to Fogel's chosen values (discussed in Section II.A), but explore robustness to these parameter choices in Section V.B. Rather than follow Fogel in assuming a relationship between agricultural land values and the transportation network, we estimate this relationship. Rather than follow Fogel in assuming where goods are transported, we use qualitative insights from a general equilibrium trade model to help measure how counties value the transportation network. In particular, we measure how expansion of the railroad network affects counties' market access and then estimate the impact of market access on agricultural land values. We then calculate the implied economic impact of decreased market access if railroads were eliminated, if railroads were replaced with the proposed canals, or under other counterfactual scenarios.

II Data Construction

This paper uses a new dataset on predicted county-to-county freight transportation costs, calculated using a newly-constructed geographic information system (GIS) network database that we describe in this section. This network database shares some similarities to a hypothetical historical version of Google Maps—a digital depiction of all journeys that were possible in 1870 and 1890 using available railroads, canals, natural waterways, and wagons. Our goal is not to obtain the best possible measure of actual freight costs, which might draw on published freight costs, but rather an econometrically useful proxy for changes in freight costs due to expansion of the railroad network.

Our measurement of market access relies on three components: (1) transportation cost parameters that apply to a given unit length of each transportation mode (railroad, waterway, and wagon); (2) a transportation network database that maps where freight could move along each transportation mode; and (3) the computation of lowest-cost freight routes along the network for given parameters. In this section, we describe the construction of these components and some data limitations.

[8] There has been extensive debate—surveyed by Fogel (1979)—regarding the social saving methodology and its application to evaluating the aggregate impact of railroads. We do not relitigate these issues, as most do not relate directly to our alternative methodological approach. Where relevant, we address some of the associated issues.

II.A Transportation Cost Parameters

Our guiding principle in choosing transportation cost parameters has been to follow Fogel's choice of these same parameters. We therefore set railroad rates equal to 0.63 cents per ton-mile and waterway rates equal to 0.49 cents per ton-mile.[9] Transshipment costs 50 cents per ton, incurred whenever transferring goods to/from a railroad car, river boat, canal barge, or ocean liner.[10] Wagon transportation costs 23.1 cents per ton-mile, defined as the straight line distance between two points.[11] The empirical analysis explores the results' robustness to alternative transportation cost parameters.

Because wagon transportation is much more expensive than railroad or waterway transportation, the most important aspects of network database construction concern the required distances of wagon transportation. Indeed, Fogel (1964) and Fishlow (1965) both emphasize that railroads mainly lowered transportation costs by decreasing expensive wagon transportation through the interior of the United States.

II.B Transportation Network Database

Creation of the network database begins with digitized maps of constructed railroads around 1870 and 1890. We are grateful to Jeremy Atack and co-authors for providing these initial GIS railroad files (Atack, 2013).[12] These railroad files were originally created to define mileage of railroad track by county and year; by contrast, for our purposes, railroad lines are modified to ensure that GIS software recognizes that travel is possible through the railroad network.[13]

The second step adds the time-invariant locations of canals, navigable rivers, and other

[9]Rates reflect an output-weighted average of rates for transporting grain and meat. Waterway rates include insurance charges for lost cargo (0.025 cents), inventory and storage costs for slower transport and non-navigable winter months (0.194 cents), and the social cost of public waterway investment (0.073 cents).

[10]Fogel considers transshipment charges as a sub-category of water rates, but our modeling of transshipment points allows for a unified treatment of Fogel's interregional and intraregional scenarios. Fogel's sources record higher railroad freight costs per ton-mile for shorter routes, but we approximate these higher costs with a 100 cent fixed fee and a 0.63 cent fee per mile.

[11]This rate reflects a cost of 16.5 cents per mile traveled and Fogel's adjustment factor of 1.4 between the shortest straight line distance and miles traveled.

[12]First, year-specific maps of railroads are "georeferenced" to US county borders. Second, railroad lines are hand-traced in GIS software to create a digital map of railroad line locations. The best practical approach has been to trace railroad lines from excellent maps in 1911 (Whitney and Smith, 1911), and then remove lines that do not appear in maps from 1887 (Cram, 1887) and 1870 (Colton, 1870).

[13]We use GIS topology tools to ensure exact connections between all railroad line segments. Hand-traced railroad lines often contain small internal gaps that we have "snapped" together, though we have tried to maintain these gaps when appropriate (e.g., across the Mississippi river in the absence of a railroad bridge). The default option in GIS is for intersecting lines to reflect an overpass without a connection, but we have broken the network into segments that permit turns at each intersection. These modifications to the railroad network have little effect on total railroad track mileage by county and year. To minimize measurement error in changes, we created a final 1890 railroad file and modified that file to create a version for 1870 that omits lines constructed between 1870 and 1890.

natural waterways. We use Fogel's definition of navigable rivers, which are enhanced to follow natural river bends.[14] For lakes and oceans, we saturate their area with "rivers" that allow for a large number of possible routes.[15] Transshipment costs are incurred whenever freight is transferred to/from one of the four transportation methods: railroad, canal, river, and lake or ocean.[16]

The third step connects individual counties to the network of railroads and waterways. We measure average travel costs between counties by calculating the travel cost between the geographical center (or centroid) of each pair of counties. County centroids must be connected to the network of railroads and waterways; otherwise, lowest-cost travel calculations assume that freight travels freely to the closest railroad or waterway. We create wagon routes from each county centroid to each nearby type of transportation route in each relevant direction.[17] Because the network database only recognizes lines, we also create direct wagon routes from every county centroid to every other county centroid within 300km.[18]

The fourth step refines centroid-to-network connections due to the importance of wagon distances to overall freight costs. For example, when a railroad runs through a county, the centroid's nearest distance to a railroad does not reflect the average distance from county points to a railroad.[19] We create 200 random points within each county, calculate the distance from each point to the nearest railroad, and take the average of these nearest distances. We then adjust the cost of travel along each centroid connection to within-county railroads to reflect that county's average travel cost to a railroad. We then repeat this procedure for centroid connections to navigable rivers and canals. This refinement to the network database allows the empirical analysis to exploit precise variation on the intensive margin of county access to railroads and waterways as the density of the railroad network increases from 1870

[14] Fogel's classification of "navigable" rivers may be overly generous in some cases (Atack, 2013).

[15] We do not permit direct access to lakes and oceans at all points along the coast; rather, we restrict access to "harbors" where the coast intersects interior waterways. We create additional "harbors" where the railroad network in 1911 approaches the coastline, which also permits direct "wagon" access to the coast at these points.

[16] Overlapping railroads and waterways do not connect by default; instead, we create connections among railroads and waterways to allow for fixed transshipment costs. The need to include transshipment costs is the main reason why it is not possible to model the network using a raster, assigning travel costs to each map pixel.

[17] Many such connections were created by hand, which raises the potential for errors, but we have used GIS topology tools to ensure that these connections are exactly "snapped" and classified correctly by type (centroid-to-railroad, centroid-to-river, etc.).

[18] The direct wagon routes are restricted to be over land, but there is no adjustment for mountains or other terrain; in practice, the long-distance wagon routes are already very costly.

[19] Fogel recognized the importance of measuring this within-county distance and his ideal solution was to break each county into small grids and take the average of nearest distances from each grid to a railroad. However, due to technical limitations, Fogel approximated this average distance using one-third of the distance from the farthest point in a county to a railroad.

to 1890.

Figure 2 shows part of the created network database. Panel A shows natural waterways, including the navigable rivers and routes within lakes and oceans. Panel B adds the canal network, which is highly complementary with natural waterways. Panel C adds railroads constructed in 1870, and then Panel D adds railroads constructed between 1870 and 1890. Early railroads were complementary with the waterway network; by 1870 and especially by 1890, however, the railroad network is more of a substitute for the waterway network.

II.C Limitations of the Network Database

There are several limitations of the constructed network database. First, the constructed network database is mainly restricted to transportation linkages within the United States.[20] The data only include US counties' access to other US counties. As a robustness check, however, we proxy for the impact of international markets by assigning additional product demand and supply to US counties with major international ports.

Second, freight rates are held constant throughout the network database. Freight rates may vary with local demand and market power in the transportation sector, and may also vary by direction due to back-haul trade relationships. Local variation in freight rates is partly endogenous to local economic outcomes, however, so there are advantages to using Fogel's average national rates for estimation purposes. We hold rates fixed in 1890 and 1870, such that measured changes in trade costs and market access are determined by variation in the location of transportation routes rather than prices. In extensions to the baseline analysis, we examine whether particular regions are driving the results by allowing the impact of market access to vary by region.

Third, there are no congestion effects or economies of scale in transporting goods. We do not restrict locations where trains can turn or switch tracks, so actual railroad transportation routes may be less direct. We also do not measure differences in railroad gauges, which required some additional costs in modifying railroad cars and tracks. In robustness checks, we allow for higher railroad costs that reflect less-direct routes or periodic transshipment within the railroad network.

Overall, we should expect that measurement of transportation costs will be robust to even large percent differences in the chosen railroad and waterway rates. Recall that 10 miles of wagon transportation are roughly equivalent to $375 - 475$ miles of railroad or waterway transportation. Thus, estimated transportation costs are dominated by the order-of-magnitude

[20] There are two exceptions. First, the network database includes a Canadian railroad line between New York and Michigan. Second, the database includes a waterway route from the Pacific Ocean to the Atlantic Ocean (i.e., around Cape Horn or through Panama by railroad), and the empirical analysis explores the results' robustness to varying the cost of this waterway connection.

difference between wagons and railroads or waterways. In robustness checks, we allow for lower transportation costs by wagon and waterway.

II.D Transportation Route Cost Calculations

We use the complete network database to calculate the lowest-cost route between each pair of counties, i.e., 5 million calculations.[21] Initially, we calculate the lowest-cost routes under two scenarios: (1) the wagon, waterway, and railroad network in 1870, and (2) the wagon, waterway, and railroad network in 1890.[22] These transportation costs are used to calculate counties' market access in 1870 and 1890, so that we can estimate the impact of changing market access on changes in land values. The created data are not our best predictions of actual freight routes and costs, but an econometrically useful proxy for differences over space and time due to differences in the location of railroads and waterways.

II.E County-level Census Data

County-level data are drawn from the US Censuses of Agriculture and Population (Haines, 2005). The two main variables of interest are: (1) total value of agricultural land, and (2) total population. Census data include only the combined value of agricultural land, buildings, fences, and other land improvements, but we follow Fogel in adjusting these data to reflect the "pure" value of agricultural land (Fogel, 1964, pp. 82-83).[23] We also adjust data from 1870 to reflect 1890 county boundaries (Hornbeck, 2010).

III A "Market Access" Approach to Valuing Railroads

The empirical analysis is guided by a model of trade among US counties that specifies how each county is affected by changes in the national matrix of county-to-county trade costs. The model contains thousands of counties, each with interacting goods markets and factor markets, that generate positive and negative spillovers on other counties. Under a set of assumptions that are standard among modern trade models, all direct and indirect impacts of changing trade costs are reflected, in equilibrium, in changes to a county's "market

[21] In principle, it is a daunting task to find the optimal route between two points on such a dense network; in practice, the computation is improved dramatically by applying Dijkstra's algorithm (see, e.g., Ahuja, Magnanti and Orlin, 1993, for a textbook treatment).

[22] For the later analysis, we calculate the lowest-cost routes under counterfactual scenarios: removing the 1890 railroad network; replacing the 1890 railroad network with an extended canal network; replacing the 1890 railroad network with improved country roads (decreased wagon freight rates); and removing the 1890 railroad network and increasing water freight rates (due to decreased competition).

[23] Fogel reports the "pure" value of agricultural land by state, after subtracting estimates for the value of agricultural buildings, fences, and other land improvements. We multiply counties' reported Census data by Fogel's estimated "pure" value of agricultural land (in their state) divided by the Census's reported value of agricultural land, buildings, fences, and other land improvements (in their state). This adjustment reduces the total value of agricultural land in our sample by 39%, which is the main factor decreasing the magnitude of the estimated dollar impact of railroads in this paper as compared to preliminary versions of our analysis.

access."[24]

The model implies a simple log-linear relationship between county agricultural land values and county market access, appropriately defined. While the model requires particular assumptions to arrive at this parsimonious solution to the challenges posed by general equilibrium spatial spillovers, the predicted relationship also has an atheoretical appeal in capturing the impact of railroads. County market access increases when it becomes cheaper to trade with another county, particularly when that other county has a larger population. Guided by the model, we regress county agricultural land value on county market access and a set of control variables.

III.A A Model of Trade Among US Counties

The economy consists of many trading counties, each indexed by o if the origin of a trade and by d if the destination. People consume a continuum of differentiated goods varieties (indexed by j), and tastes over these varieties take a CES form (with elasticity σ).[25] A consumer living in county o, who faces a vector of prices $\mathbf{P_o}$ and receives income Y_o, experiences indirect utility:

$$V(\mathbf{P_o}, Y_o) = \frac{Y_o}{P_o}, \tag{1}$$

where P_o is a standard CES price index.[26]

Counties use a Cobb-Douglas technology to produce varieties from labor, capital, and land. The marginal cost of producing goods of variety j in county o is:

$$MC_o(j) = \frac{q_o^{\alpha} w_o^{\gamma} r_o^{1-\alpha-\gamma}}{z_o(j)}, \tag{2}$$

where q_o is the agricultural land rental rate, w_o is the wage rate, r_o is the capital rental rate, and $z_o(j)$ is a Hicks-neutral productivity shifter that is exogenous and local to county o. We follow Eaton and Kortum (2002) in modeling these productivity shifters by assuming that each county draws its productivity level, for any given variety j, from a Fréchet (or Type II

[24] These modeling assumptions are used extensively in the fields of international trade and economic geography, and reflect recent best practice to gain traction in general equilibrium spatial settings with many regions that trade subject to trade costs.

[25] Note that the elasticity of substitution is not restricted; that is, σ could be high if varieties are similar. Anderson, de Palma and Thisse (1992) provide an attractive microfoundation for aggregate-level CES preferences: if individual agents desire only one variety of the good (their "ideal variety") and agents' utilities from their ideal varieties are distributed in a Logit fashion, then aggregate consumption data from a population of many such agents behaves as though all agents have CES preferences over all varieties (where, in such an interpretation, σ indexes the inverse of the dispersion of agents' utilities from their ideal varieties).

[26] That is, $P_o = \left[\int_0^n (p_o(j))^{1-\sigma} dj\right]^{1/(1-\sigma)}$, where n denotes the (exogenous) measure, of varieties available to consumers.

extreme value) distribution with CDF given by: $F_o(z) = 1 - \exp(-T_o z^{-\theta})$, with $\theta > 1$.[27,28] This distribution captures how productivity differences across counties give incentives to specialize and trade, where these incentives are inversely related to θ.[29] We assume perfect competition among producers.[30]

Trading goods is costly. Remote locations pay high prices for imported goods and receive low prices for goods they produce, as this is the only way locations can be competitive in distant markets. We model trade costs using a simple and standard "iceberg" formulation. When a variety is made in county o and sold locally in county o, its price is $p_{oo}(j)$; but when this same variety is made in county o and shipped to county d, it will sell for $p_{od}(j) = \tau_{od} p_{oo}(j)$. A proportional trade cost τ_{od} is applied to each unit of the variety shipped.[31] Trade is potentially costly, so $\tau_{od}^k \geq 1$.

Land is fixed by county, but capital is assumed to be perfectly mobile such that $r_o = r$ for all counties o.[32] We also assume that workers are perfectly mobile across counties, at least over a period of many years. As a result of workers' endogenous option to work in other counties, workers' utility levels are equalized across counties in equilibrium and wages satisfy:

$$w_o = \bar{U} \times P_o, \tag{3}$$

where $\bar{U}$ is the endogenous level of utility obtained by workers in each county. People in particular counties will not benefit disproportionately when expansion of the railroad network decreases transport costs; rather, in equilibrium, everyone benefits by the same amount.

[27]Following Eaton and Kortum (2002), an intuitive rationale for this particular functional form for the distribution of productivities is that it reflects the limiting distribution when producers receive technologies from any distribution and discard all but the best.

[28]An additional parameter restriction, $\theta > \sigma - 1$, is required for the integral in P_o to be finite. However, Eaton, Kortum and Sotelo (2012) demonstrate how this restriction is no longer required when there are a finite number of varieties, as in reality. Our continuum of varieties assumption can be thought of as an analytically convenient approximation to the true finite number of varieties.

[29]More specifically, the parameter T_o captures county-specific (log) mean productivity, which corresponds to each county's level of absolute advantage. The parameter θ captures, inversely, the (log) standard deviation of productivity, which corresponds to the scope for comparative advantage. A low θ means county productivity draws are dispersed, creating large incentives to trade on the basis of productivity differences.

[30]An alternative (and observationally equivalent) formulation, following Melitz (2003), would assume that firms compete monopolistically with free entry such that all firms' expected profits are zero and draw their productivity levels z, following Chaney (2008) and others, from a Pareto distribution $G_o(z) = 1 - (z/T_o)^{-\theta}$, as seen in many firm-level datasets (e.g., Axtell, 2001).

[31]For simplicity, we assume that all goods are tradable at the cost τ_{od}. A version of the model with some non-tradable goods would simply reduce the predicted elasticity with which market access affects land values, which is a parameter that we estimate anyway.

[32]Landowners are not restricted to own land in their county of residence. Because we do not observe land ownership by county, we assume that land is owned in proportion to county populations.

III.B Solving the Model

Prices and trade flows: First, we solve for goods' trade flows from each origin county o to each other destination county d. Due to perfect competition, the marginal cost of producing each variety is equal to its price. Substituting marginal costs from each supply location o (equation 2) into the demand for agricultural varieties in county d, and allowing consumers to buy goods, in equilibrium, from their cheapest source of supply, Eaton and Kortum (2002) derive two important results for our application. The first is that the consumer price in destination location d is given by:[33]

$$P_d^{-\theta} = \kappa_1 \sum_o T_o (q_o^\alpha w_o^\gamma)^{-\theta} \tau_{od}^{-\theta} \equiv CMA_d. \quad (4)$$

We follow Redding and Venables (2004) in referring to this price index as CMA_d or "consumer market access." Consumer market access in county d represents its access to cheap products: it is a weighted sum of productivity-adjusted costs of production in each origin market o that could supply market d, with weights declining in the cost of trading from o to d (i.e., τ_{od}).

A second important result from Eaton and Kortum (2002) describes X_{od}, the value of total exports from o to d, as:

$$X_{od} = \kappa_1 T_o (q_o^\alpha w_o^\gamma)^{-\theta} \tau_{od}^{-\theta} CMA_d^{-1} Y_d. \quad (5)$$

From equation (5), county o sends more goods to county d if county o is relatively productive (high T_o) or relatively low cost (low w_o or low q_o). County o also sends more goods to county d if county d has high total income (high Y_d) or low overall consumer market access (low CMA_d), meaning that county o faces less competition when selling to market d.

Equation (5) is known as a gravity equation, which governs trade flows in this model. The gravity equation is appealing because it dramatically simplifies a complex general equilibrium problem of spatial competition. In addition, an empirical appeal of the gravity equation is that it appears to provide a strong fit for trade-flow data in many contexts (e.g., Anderson and van Wincoop, 2003, 2004; Combes, Mayer and Thisse, 2008; Head and Mayer, forthcoming).

Land rental rate: While trade flows between 19th century US counties are unobserved, the gravity equation implies tractable and empirically useful expressions for the land rental rate (q_o). Under the assumption of Cobb-Douglas technology, land is paid a fixed share of total output Y_o, so $q_o L_o = \alpha Y_o$ where L_o is the fixed quantity of land in county o. Goods markets clear, so all produced goods are bought ($Y_o = \sum_d X_{od}$). Thus, using equations (3)

[33] Here, κ_1 is a constant defined by $\kappa_1 = \left[\Gamma\left(\frac{\theta+1-\sigma}{\theta}\right)\right]^{-\theta/(1-\sigma)} r^{-(1-\alpha-\gamma)\theta}$, where $\Gamma(\cdot)$ is the Γ function.

and (4) and taking logs, equation (5) implies:[34]

$$(1+\alpha\theta)\ln q_o = \ln \kappa_2 + \ln\left(\frac{T_o}{L_o}\right) - \gamma\theta \ln \bar{U} + \gamma \ln CMA_o + \ln FMA_o, \tag{6}$$

where FMA_o refers to "firm market access" for goods from origin o and is defined as:

$$FMA_o \equiv \sum_d \tau_{od}^{-\theta} CMA_d^{-1} Y_d. \tag{7}$$

Firm market access (FMA_o) is a sum of terms over all destination counties d to which county o tries to sell its goods. These terms include the size of the destination market (given by total income, Y_d) and the competitiveness of the destination market (given by its CMA_d term). All terms are inversely weighted by the cost of trading with each distant market (i.e., by $\tau_{od}^{-\theta}$).

Firm market access is conceptually similar to consumer market access, as both are increasing in cheap access to large markets with few trade partners. To see this similarity explicitly, note that it is possible to write CMA_d as:[35]

$$CMA_d = \sum_o \tau_{od}^{-\theta} FMA_o^{-1} Y_o. \tag{8}$$

Under the additional restriction that trade costs are symmetric (i.e., $\tau_{od} = \tau_{do}$ for all counties d and o), which holds in our empirical application, it can be shown that any solution to equations (7) and (8) must satisfy $FMA_o = CMA_o$, such that FMA and CMA are equal to one another.[36] Therefore, we simply refer to "market access" (MA) to reflect both concepts of market access. Formally, we let $MA_o = FMA_o = CMA_o$ for all counties o. Using the fact that $\gamma Y_d = w_d N_d$, where N_d refers to the (endogenous) number of residents in each county d, as well as equation (3), equation (7) implies that:[37]

$$MA_o = \kappa_3 \sum_d \tau_{od}^{-\theta} MA_d^{\frac{-(1+\theta)}{\theta}} N_d. \tag{9}$$

[34] Here, $\kappa_2 = \kappa_1 \alpha$.

[35] This result can be obtained by summing equation (5) over all destinations d and substituting $T_o(q_o^{\alpha} w_o^{\gamma})^{-\theta}$ into equation (4).

[36] This simplification would no longer be true in extended versions of the model, such as allowing for agricultural production in rural counties and manufacturing production in urban counties. These extended models generate sector-specific market access terms (e.g., FMA^A and CMA^A for the agricultural sector, or FMA^M and CMA^M for the manufacturing sector) but empirical approximations of these terms are highly correlated with each other, so the empirical analysis would anyway condense these terms into one notion of "market access."

[37] Here, $\kappa_3 = \frac{\bar{U}}{\gamma}$.

In words, a county's market access can be expressed as the sum over the cost of trading with each other county, that other county's population, and that other county's access to other markets.

Given the above simplifications, equation (6) becomes:[38]

$$\ln q_o = \kappa_4 + \left(\frac{1}{1+\alpha\theta}\right) \ln\left(\frac{T_o}{L_o}\right) + \left(\frac{1+\gamma}{1+\alpha\theta}\right) \ln(MA_o). \tag{10}$$

Equation (10) provides a useful guide for the empirical analysis. Equilibrium land rental rates (q_o) are log-linear in just one endogenous county-specific economic variable: market access. This notion of market access captures firms' desire to sell goods elsewhere for a high price and consumers' desire to buy goods from elsewhere at a low price. Immobile land in county o will be more valuable if county o has cheap access to large uncompetitive markets and/or cheap access to labor (by having cheap access to goods that workers value).

III.C Using the Model to Inform Empirical Work

Equation (10) has two key implications for estimating the aggregate economic impact of railroads. First, all economic forces that make goods markets and factor markets interdependent across counties are represented by one concept of "market access." Thus, all direct and indirect impacts of railroads are captured by analyzing changes in market access. For example, county A receiving a railroad line would affect other counties: those that can now trade with county A, those that had been trading with county A, those that had traded with county A's previous trade partners, those that had traded with county A's new trade partners, and so on. Even if access to railroads is randomly assigned, "control" counties are affected and a regression of land rents on railroad access will produce biased estimates of railroads' aggregate impact. A regression of land rents on market access will be free of this bias, in the context of our model, because all counties' market access will adjust to changes in the railroad network. In addition, the aggregate effect of counterfactual changes to the transportation network (such as the removal of railroad lines or their replacement with a proposed canal network) can be calculated easily by substituting the counterfactual values of τ_{od} into MA_o and then substituting the resulting counterfactual MA_o into equation (10).[39]

The second key implication of equation (10) is that a county's market access can increase or decrease due to changes in the railroad network far beyond that county's borders. Thus,

[38] Here, $\kappa_4 = \frac{\ln(\kappa_2) - \gamma\theta \ln(\bar{U})}{1+\theta\alpha}$.

[39] An additional effect is that of the counterfactual transportation network on $\bar{U}$. We ignore this effect (along with the direct increase in worker welfare from an increase in $\bar{U}$) because its magnitude cannot be estimated using our empirical design and depends on the integration of American labor markets with international labor markets.

the empirical estimation is not identified only from particular counties gaining railroad access, which might otherwise be correlated with land rental rates. This prediction of the model suggests some robustness checks, control variables, and instrumental variable approaches that might purge the empirical estimates of endogeneity bias arising from local railroad placement decisions.

III.D From Theory to an Empirical Specification

While equation (10) provides a useful guide for the empirical analysis, six issues complicate its direct empirical implementation.

First, the Census of Agriculture does not report land rental rates. Instead, the Census reports the value of agricultural land.[40] We use the value of agricultural land as a proxy for agricultural land rental rates.[41] While land values may reflect expected changes in market access, this should attenuate the estimated elasticity.

Second, county productivity (T_o) is not directly observed. We assume that changes in county productivity (from 1870 to 1890) are orthogonal to changes in market access. In practice, we allow for changes in county productivity to vary by state and by cubic polynomials in county latitude and longitude.[42]

Third, the construction of market access via equation (9) requires the observation of all trade costs (τ_{od}). We measure trade costs using the calculated county-to-county lowest-cost freight transportation routes described in Section II.D above.[43] The baseline results use trade costs calculated using freight rates comparable to those used by Fogel (1964), though we explore the sensitivity of our results to the particular freight rates that enter τ_{od} in MA_o.

Fourth, the market access term (MA_o) is not directly observed because some destination characteristics are unobserved.[44] Based on equation (9), however, it is possible to use data on each county's population (N_o) to express each county's market access MA_o as an implicit function of the market access of all other counties. We can solve this implicit function numerically and report empirical estimates that use counties' calculated market access in

[40] In Section II.E, we discuss modifying reported Census data to obtain a measure of the value of agricultural land (only).

[41] In particular, we assume that $V_o = q_o/r$, where V_o is the land value and r is a fixed interest rate. In practice, our results would be unaffected if the interest rate varied by county, state-year, or with any of the control variables in the empirical specification.

[42] Because county productivity (T_o) enters log-linearly in equation (10), we control for this term using county fixed effects, state-by-year fixed effects, and year-interacted cubic polynomials in county latitude and longitude. Some robustness checks include additional controls for region-specific or subregion-specific changes in productivity.

[43] We express the calculated trade costs in proportional terms using Fogel's average value of transported agricultural goods.

[44] From equation (4), the wage w_d and the destination technologies T_d are unobserved.

1870 and 1890.[45] This approach accords exactly with equation (9), but the calculation of these terms depends on running the data through the particular structure of the model. A simpler approach, which is also less model dependent, uses the following expression that provides a first-order approximation to counties' market access:[46]

$$MA_o \approx \sum_d \tau_{od}^{-\theta} N_d. \tag{11}$$

Our estimation results are insensitive to our use of the MA approximation in equation (11), as we document below, because this approximated term is highly correlated with the theoretically exact MA term derived from solving equation (9).

Fifth, the population N_d in each county d is endogenously co-determined with the land rental rate q_o in county o, which would generate endogeneity bias in a regression based on equation (10). A particular instance of this concern arises because N_o is included in the definition of MA_o in equation (11). For this reason, we exclude each county's own population from its measure of market access,[47] though our results are insensitive to this decision because the contribution of N_o to MA_o is small for most counties. An additional related concern is that a county's land value is affected by local shocks that affect nearby counties' population. In robustness checks, we calculate each county's market access when omitting other counties within particular distance buffers around that county. In further robustness checks, we calculate each county's market access in 1870 and 1890 when holding all counties' population fixed at 1870 levels.

Sixth, and finally, the expression for market access in equation (11) requires an estimate of θ. The parameter θ is known as the "trade elasticity."[48] In the absence of county-to-county trade data from our time period, we cannot estimate θ via traditional means. Our baseline estimates assume a value of θ equal to 3.8, as in Donaldson (forthcoming), though we

[45] With C counties, equation (9) becomes a system of C equations in C unknowns. An important limitation of this procedure is that it allows MA_o to be identified only up to a multiplicative scalar; intuitively, the endogenous distribution of population across counties speaks to relative market access but not the absolute level of market access. This is not problematic for the regression analysis, in which only relative market access is relevant, but it precludes us from applying this numerical estimation of MA_o in our counterfactual calculations. It is reassuring, though, that this numerically estimated MA_o term is highly correlated with our simplified MA_o term. While we have been unable to prove analytically that equation (9) has a unique solution, our numerical solutions converge to the same solution from all of the hundreds of dispersed, randomly chosen starting points that we have tried.

[46] Formally, this approximation is taken around a point at which $\tau_{od}^{-\theta} = 0$, which corresponds to the case of prohibitive trade costs (but with $\theta = 3.8$, as in our baseline estimates, even realistic trade costs bring $\tau_{od}^{-\theta}$ close to zero).

[47] Throughout the empirical analysis, we work with the variable $MA_o \approx \sum_{d \neq o} \tau_{od}^{-\theta} N_d$.

[48] As per equation (5), trade costs affect trade flows with this elasticity (in partial equilibrium, holding fixed: exporter factor prices, importer income, and the importer's total price index).

explore the results' robustness to alternative θ parameters.[49] We note that our final empirical measure of "market access" is similar to an older concept of "market potential," based on the number and size of markets available at low trade costs (Harris 1954). Harris's market potential term effectively equals $\sum_{d \neq o} (\tau_{od})^{-1} N_d$, so the difference is that we allow trade costs to diminish market sizes with a power of $-\theta$ rather than minus one. Typical estimates of θ are substantially greater than one, though we also report robustness to assuming a value of θ equal to one.

Summarizing the above discussion, we regress agricultural land values in county o and year t on log market access (MA_{ot}), a county fixed effect (δ_o), state-by-year fixed effects (δ_{st}), and a cubic polynomial in county latitude and longitude interacted with year effects ($f(x_o, y_o)\delta_t$):

$$\ln V_{ot} = \beta \ln(MA_{ot}) + \delta_o + \delta_{st} + f(x_o, y_o)\delta_t + \varepsilon_{ot}. \tag{12}$$

Based on the strict assumptions of the model outlined above, the regression coefficient β is predicted to equal a particular combination of the model parameters: $(1+\gamma)/(1+\theta\alpha)$. We compare our estimates of β to this calibrated value, but we prefer to leverage the model for its qualitative insights that railroads affect land values through market access.

The sample is a balanced panel of 2,327 counties with land value data in 1870 and 1890.[50] The regression is weighted by counties' land value in 1870, both to minimize the influence of outliers and to estimate the appropriate average effect for the counterfactual analysis.[51] Standard errors are clustered at the state level to adjust for heteroskedasticity and within-state correlation over time.[52] In practice, equivalently, we estimate equation (12) in differences and generally find it convenient to discuss relating changes in log land value to changes in log market access.

Figure 3 shows the sample counties, which are shaded to reflect their change in market

[49] Donaldson's estimate of θ was obtained in an agricultural context (in India) for a similar time period as this paper. Other estimates of θ, of which we are aware, are based on modern trade of manufactured goods.

[50] Note that our measure of county market access includes the cost of trading with each other county that has population data, even if that county is not in the regression sample.

[51] We use the estimated β to calculate the percent decline in each county's land value associated with the counterfactual decline in each county's market access, and multiply this percent decline in land value by each county's land value in 1890. The aggregate counterfactual loss gives greater weight to counties with greater land value so, if the impact of market access varies across sample counties, it is natural to estimate β weighting by county land value.

[52] The estimated standard errors are similar when allowing for spatial correlation among sample counties (Conley, 1999), assuming that spatial correlation declines linearly up to a distance of 300 miles and is zero thereafter (e.g., approximately the distance across Iowa). Compared to unweighted standard errors clustered by state, the spatial standard error on the baseline estimate is lower by 8% or 25% with distance cutoffs of 200 miles or 100 miles. The spatial standard error is higher by 10% or 18% with distance cutoffs of 400 or 500 miles, and higher by 25–31% for distance cutoffs between 600 and 1000 miles.

access from 1870 to 1890.[53] Darker shades correspond to larger increases in market access and, naturally, these areas often receive new low-cost transportation routes between 1870 and 1890 (Figure 2, panels C and D). There is a good deal of variation within broad geographic regions, though Figure 3 is unable to illustrate the full degree of within-region variation. The baseline specification (in differences) controls for state fixed effects and flexible polynomials in a county's latitude and longitude, while subsequent robustness checks also control for 20 region fixed effects or 145 subregion fixed effects.

IV Estimation Results

We now turn to a presentation of the estimation results. In the first subsection, we report the baseline estimated impact of county market access on county land value. We present some robustness checks to help motivate the baseline specification choices, but reserve most of the robustness checks to a later section in which we also present robustness of the main counterfactual estimates. In the second subsection, we explore some empirical approaches to addressing the potential endogeneity of new railroad construction.

IV.A Estimated Impact of Market Access on Land Values

Table 1 reports our baseline result from estimating equation (12). Market access is estimated to have a large and statistically significant impact on land values: a 1% increase in market access increases land values by approximately 1.1% (column 1). Column 2 reports a similar elasticity for our calibrated measure of market access, discussed above, which reflects a close correlation between log changes in the two measures of market access. Interestingly, these empirical estimates would not reject the coefficient predicted by the model (0.93).[54]

In our baseline specification, county market access increases due to expansion of the railroad network and growth in other counties' population. The baseline estimate is robust, however, to calculating counties' market access in 1870 and 1890 while holding all counties' population levels fixed at 1870 levels (column 3). This suggests that the estimated impact of market access is not driven by population growth among trade partners, which could be correlated with other shocks to a county's land value.

In a related robustness check, we calculate county o's market access based only on those counties d that are located beyond some distance buffer from county o.[55] For a distance buffer of 100 miles, column 4 reports a similar impact of market access on land values. A

[53] Counties are separated into seven equal-sized groups.

[54] The model predicts a coefficient on the market access term equal to $(1+\gamma)/(1+\alpha\theta)$, where θ represents the trade elasticity (3.8 in Donaldson (forthcoming)) and γ and α represent the labor share and land share in agricultural production (0.60 and 0.19 in Caselli and Coleman (2001)). A slightly larger labor share and smaller land share would make the coefficients very similar.

[55] We measure which counties' borders fall within a distance buffer of each county, and calculate that county's market access when setting nearby counties' market size to zero.

county's market access mainly reflects trade with more distant counties, which reduces the potential for bias from local shocks increasing both land values and access to local markets.

Column 5 reports an unweighted estimate, which is of the same magnitude but lower statistical precision than the baseline estimate. Weighting by 1870 land value reduces the influence of outlier values.[56] In a later section, we explore the results' robustness to alternative empirical specifications and transportation cost assumptions.

IV.B Endogeneity of Railroad Construction

Perhaps the main empirical concern is that expansion of the railroad network is endogenous, which may create spurious correlation between increases in county market access and agricultural land value. In particular, railroad construction may occur in counties that would otherwise have experienced relative increases in agricultural land values.[57] Some variation in local railroad construction may be exogenous, perhaps affected by politics or companies' desire to connect particular large cities, but it is difficult to isolate this variation amidst the high-density railroad network of 1890.

An important feature of our theoretical definition of market access is that much variation in a county's market access is not determined solely by that county's own railroad track. Thus, we can examine changes in counties' market access that are orthogonal to changes in counties' own railroads.

Column 1 of Table 2 reports estimates from a modified version of equation (12), which now controls for whether a county has any railroad track. Column 2 controls for whether a county has any railroad track and the county's mileage of railroad track. The estimated impact of market access declines somewhat, but remains substantial and statistically significant. The estimated impact of market access is also similar when controlling for quadratic or cubic functions of county railroad track: 0.94 (0.16) or 0.93 (0.18), respectively.[58] While local railroads increase county market access, the estimated impact of market access is robust to exploiting variation in market access that is independent of that county's own railroad construction.[59]

[56] In particular, weighting by 1870 land value removes the arbitrary distinction between omitting counties with missing (or zero) land value in 1870 and including counties with nearly zero land value in 1870.

[57] In practice, this concern may remain after controlling for changes by state and counties' longitude and latitude.

[58] The estimated impact of market access declines, but remains substantial, when controlling flexibly for railroad presence and railroad track in distance buffers around a county: the coefficient on market access declines to 0.76 (0.12), then 0.68 (0.13), then 0.65 (0.13), and settles at 0.62 (0.14) when progressively controlling for both the presence of any railroad and the mileage of railroad track within 5 miles of the county, and within 10 miles of the county, and within 15 miles of the county, ..., and within 40 miles of the county.

[59] The coefficients in columns 1 and 2 imply that market access and railroads are positively correlated; indeed, regressing log market access on the presence of railroad track and mileage of railroad track generates

It is tempting to interpret the estimated coefficients on railroad measures, holding market access fixed, as indicating the magnitude of selection bias in railroad construction. In theory, railroads should have no causal impact on land values after conditioning on market access. In practice, however, there may be measurement error in market access such that railroad measures pick up variation in counties' true market access. Measurement error in market access may also be exacerbated when controlling for county railroads, contributing to attenuation in the estimated impact.

When omitting the market access term, column 3 of Table 2 reports that county land value increases by 0.290 log points or 34% when a county receives any railroad track. Column 4 reports that county land values increase by 0.268 log points when receiving any railroad track and by an additional 0.143 log points for every 100 miles of railroad track. These estimates may reflect a causal impact of railroads on county land values, but may also reflect selection bias in which areas receive railroads. Comparing the estimates in columns 1 and 2 to those in columns 3 and 4 indicates that much of the impact of railroad track is absorbed by controlling for county market access. These estimates are consistent with our definition of market access being a particular functional form through which the railroad network affects counties.

As an alternative identification strategy, we exploit the historical substitutability between railroads and waterways. In particular, expansion of the national railroad network should have a larger impact on counties with worse market access through waterways only. Regardless of how the railroad network actually changes from 1870 to 1890, counties with better market access through waterways in 1870 are likely to have a smaller increase in market access from 1870 to 1890. Using a restricted GIS network database with no railroads, we calculate county-to-county lowest-cost freight routes and measure counties' access to markets in 1870 through waterways only.

In the first-stage specification, Table 3 reports that counties with better "water market access" in 1870 experience a relative decline in market access from 1870 to 1890 (column 1).[60] In the reduced-form specification, counties with better "water market access" in 1870 also experience a relative decline in agricultural land values (column 2). Instrumenting for the change in market access with counties' initial "water market access," market access is estimated to increase land values with an elasticity of 2.46 (0.64). This 2SLS estimate is robust to controlling for changes in county railroad track (column 4), where county railroads no longer increase land values when holding fixed county market access. Using this instru-

positive coefficients: 0.18 (0.02) and 0.065 (0.010), respectively.

[60]We discuss these results in changes, which is equivalent to estimating a two-period model with county fixed effects.

mental variables approach, the estimated impact of market access is substantially larger (and marginally statistically larger) than the baseline OLS estimates in column 1 of Table 1. The increase in the estimated coefficient is consistent with measurement error in market access, though these estimates may also reflect a violation of this alternative identification assumption (i.e., that areas with good market access through waterways would have changed similarly to areas with worse market access through waterways).

V Counterfactual Estimates

The estimated impact of market access is interesting in its own right, and as an exercise in empirical general equilibrium economics, but our main aim is to use this estimate to explore the aggregate economic impact of railroads in 1890. First, we estimate the economic impact of removing all railroads in 1890 and the robustness of these estimates to various choices in the empirical analysis (from network construction to estimation). Second, we consider the economic impact of alternative counterfactual scenarios that might have occurred in the absence of railroads.

V.A Economic Impact of Removing Railroads in 1890

Using our transportation network database, we calculate county-to-county lowest-cost freight routes in the absence of any railroads. Counties' market access in 1890 declines by 61%, on average, when all railroads are eliminated. The standard deviation of this decline is 18.5%, while the 5th and 95th percentiles are 36% and 94% declines. Projecting the impact of large counterfactual changes in market access is more credible when two conditions hold: (1) the original regressions are estimated using large changes in market access, and (2) the impact of market access is (log-)linear.

In support of the first condition, the measured changes in market access between 1870 and 1890 have a similar range as that in our counterfactual scenarios. The average percent decline in market access from 1890 to 1870 is 51%, with a standard deviation of 12.1%, a 5th percentile decline of 41%, and a 95th percentile decline of 80%. Log changes in market access from 1870 to 1890 remain large when controlling for state fixed effects and counties' longitude and latitude: the residual standard deviation is 0.09 log points (weighted) and 0.25 log points (unweighted), whereas the unconditional standard deviation is 0.13 log points (weighted) and 0.42 log points (unweighted).

In support of the second condition, the estimated impact of market access on land value does appear to be (log-)linear. We calculate residual changes in log land value and log market access, after conditioning on the control variables in equation (12). Limiting the sample to residual changes in market access within one standard deviation (plus or minus),

Figure 4 shows a kernel-weighted local polynomial and its 95% confidence interval.[61] There does appear to be a roughly linear functional relationship between changes in log land value and changes in log market access. The theoretical model also predicts that this relationship is log-linear, which gives some additional confidence in predicting counterfactual impacts based on this functional form.

Removing all railroads in 1890 is predicted to decrease the total value of US agricultural land by 63.5% or $5.15 billion, based on the calculated decline in market access and the estimated impact of market access on agricultural land value.[62] Using Fogel's preferred mortgage rate of interest, the implied annual economic loss (and standard error) is $408 million ($27 million) or 3.40% (0.23%) of GNP in 1890. The largest possible annual economic impact of railroads is only 5.35% of GNP, which would reflect the complete loss of all agricultural land value in the sample region.[63]

Decreases in agricultural land value are largest in the Midwest, but are substantial in all regions of the United States. As a fraction of national GNP, the implied annual economic impact by region is: 1.74% in the midwest, 0.59% in the plains, 0.40% in the northeast, 0.34% in the south, and 0.33% in the far west. When allowing the impact of market access to vary by region, the impact of railroads declines somewhat in the northeast.[64] The estimated impact of market access is lowest in the northeast and the far west, where we expect congestion and market power to create greater measurement error in counties' market access.[65]

The baseline counterfactual estimates hold population fixed by county in 1890, though population might be expected to relocate in response to the absence of railroads. It is challenging to estimate this relocation directly, though we consider counterfactual scenarios that shift the geographic distribution of population to that in earlier decades (1870, 1850, 1830).[66] For these three cases, the counterfactual loss from removing the railroad network

[61] The local polynomial represents the (default) Epanechnikov kernel with (default) bandwidth 0.04.

[62] County agricultural land value is predicted to fall by 1.11 log points for every log point decline in market access (Table 1, column 1), and the implied percent decline in each county's land value is multiplied by each county's land value in 1890. We include all counties from 1890 in these counterfactual estimates, though 455 counties are omitted from the regression sample due to missing data in 1870 (e.g., the counties did not exist in 1870). Losses in these non-sample counties make up 7.6% of the total counterfactual loss. In the absence of railroads, these non-sample counties experience larger average declines in market access than the regression sample counties (79% vs. 57%), but their average land value is much lower ($1 million vs. $3.3 million).

[63] Fogel also reports state-level mortgage interest rates: using these rates, the implied annual economic loss is 3.17% of GNP and the largest possible loss is 4.92% of GNP.

[64] Allowing for differential impacts of market access by region, the implied annual economic impact by region is: 1.76% in the midwest, 0.62% in the plains, 0.27% in the northeast, 0.35% in the south, and 0.32% in the far west.

[65] When allowing the impact of market access to vary by region, the estimated impacts of market access (and standard error) are: 1.25 (0.52) in the plains, 1.13 (0.16) in the midwest, 1.19 (0.27) in the south, 1.00 (0.36) in the far west, and 0.67 (0.14) in the northeast.

[66] In particular, we assign each county a population in 1890 based on the total population in 1890 and

declines in magnitude by only 3.5% to 4.5%. The counterfactual loss would increase if national population declined in the absence of the railroads.

V.B Robustness to Alternative Specifications and Cost Parameters

Table 4 presents the sensitivity of the empirical results to modifications in the construction of the network database (panel A), the definition of market access (panel B), and the empirical specification (panel C). Column 1 reports the estimated impact of market access, column 2 reports the estimated percent decline in national agricultural land value without the railroads, and column 3 reports the implied annual economic impact as a percent of GNP.[67]

It is useful to verify the robustness of the empirical results to plausible alternative parameter choices for freight transportation costs (panel A), particularly as much academic debate has centered on Fogel's choice of these cost parameters. Water transportation is always low cost, but the estimated impact of market access is not sensitive to further lowering the cost of sea routes or all water routes (rows 1 and 2).[68] The annual impact of railroads declines somewhat with lower water costs, as a counterfactual without railroads becomes more manageable. Our empirical estimates are less sensitive than social saving estimates, however, which change proportionally with the difference in point-to-point costs by rail and water.

One advantage to railroads was in reducing transshipment charges, incurred whenever transferring goods to/from a railroad car, river boat, canal barge, or ocean liner. The estimates are not sensitive, however, to eliminating transshipment charges within the waterway network (row 3). In addition, transportation through the railroad network was not entirely seamless: congestion, fragmented track ownership, or differences in gauges may have required periodic transshipment; and scheduled freight routes would be less direct than those calculated on the GIS network. We consider a moderately higher railroad rate (0.735 cents) that reflects a need for two transshipment points within an average length railroad route, and a higher railroad rate (0.878 cents) that makes railroad routes as indirect as wagon routes.[69] The estimated impact of market access is not sensitive to higher railroad rates (rows 4 and 5), whereas the annual impact of railroads declines slightly with a decrease in the relative

that county's share of national population in the earlier decade. We then calculate counties' counterfactual market access based on the counterfactual cost of trading with each other county and the counterfactual population in each other county.

[67]The standard errors for the estimates in columns 2 and 3 are calculated using the delta method, which transform the standard errors in column 1.

[68]The lower waterway rate (0.198 cents per ton-mile) reflects Fogel's preliminary rate for waterway transportation, prior to his adjustments for supplemental costs associated with waterway transportation.

[69]In the first case, we consider an average length railroad route of 926 miles (Fogel, 1964) and assign an additional dollar over this distance (which becomes 0.108 cents per mile). In the second case, we increase the baseline railroad rate by the same factor (1.4) used to adjust for indirect wagon routes (Fogel, 1964).

advantage of railroads.

Wagon transportation costs are likely to be an important feature of the database. Fogel emphasized that the baseline wagon rate may be too high and his social saving estimates are substantially lower for decreased wagon costs of 14 cents per mile.[70] By contrast, this lower wagon rate increases the estimated impact of market access such that the annual impact of railroads is moderately higher (row 6). In further analysis below, we consider a counterfactual scenario in which improvements to country roads reduce wagon costs in the absence of railroads.

The estimated impact of market access is affected little by the inclusion of a waterway route between the Pacific Ocean and the Atlantic Ocean (rows 7-9).[71] This waterway route has little impact on the calculation of market access because the transcontinental railroad was available in 1870 and 1890. By contrast, this waterway route has more influence on the estimated annual impact of railroads because it provides the only link between Western and Eastern markets in the absence of the railroads (aside from wagons). The costs of waterway shipping may have been driven down by competition with railway shipping, however, which we explore in later analysis.

Aside from changes in the network database, we also consider the estimates' robustness to changes in the definition of market access (panel B). We only directly measure US counties' access to other US counties, but the results are similar when adjusting for the influence of international markets (row 10). As a simple adjustment, we assign additional population to counties with major international ports, based on the value of merchandise traded and nominal GDP per capita.[72]

One technical issue is that a county's market access should theoretically include access to its own population, though our baseline measure omits this term due to simultaneity

[70]To clarify, the cost of 14 cents per mile reflects Fogel's considered lower cost (10 cents per mile) and Fogel's adjustment factor for indirect wagon routes (1.4). It is more convenient for us to scale up the price of routes, rather than equivalently scale up the distance required.

[71]The network database includes a waterway route from the Pacific (near San Diego) to the Atlantic (near Florida), which reflects the potential to transport goods around Cape Horn or through Panama (by railroad). The transcontinental railroad was generally preferred after its construction, but waterway routes were used for some goods and the baseline estimates assume a Pacific-to-Atlantic waterway cost of $8 such that the overall GIS-calculated cost of transporting goods from San Francisco to New York City was similar by rail and water. Robustness checks assign this waterway cost such that the GIS-calculated costs by rail and water were similar between Seattle and New York City (a $5 connection) or between San Diego and New York City (a $11 connection).

[72]For 11 major international ports, which cover 90% to 93% of international trade in 1870 and 1890, we assign additional county population in 1870 and 1890 based on the ports' average value of exports and imports divided by nominal GDP per capita in 1870 and 1890 (Bureau of Statistics, 2003; Carter et al., 2006). This adjustment mainly increases the "effective population" in New York City, New Orleans, Boston, Baltimore, Philadelphia, and San Francisco. There are also large percent increases in Galveston, Savannah, and Charleston, and smaller percent increases in Norfolk and Portland.

concerns (as discussed in Section III.D). A county's own population forms a small share of its total market access, however, so including its own market has little impact on the results (row 11). In a similar trade-off between simultaneity concerns and the model's suggested measure, we omit counties' access to nearby counties and the results are similar (rows 12-14).

Our baseline measure of market access includes counties' access to all other counties, based on a model of trade among all US counties. Alternatively, agricultural counties may only benefit from selling/buying goods to/from cities. The estimated impact of market access is similar when only measuring counties' access to urban areas or cities (rows 15 and 16), which reflects the large influence of urban areas and cities in determining counties' overall market access.[73] The implied economic impact of railroads is somewhat smaller in these specifications, which could reflect railroads' comparative advantage in linking rural areas with each other.[74]

Calculating our measure of market access requires assuming a value of θ (the "trade elasticity"), for which our baseline measure assumes a value of 3.8 (Donaldson, forthcoming). We now consider assuming a value of 1, which reduces our measure of market access to an older notion of "market potential" (Harris, 1954). The estimated impact of market access is much larger when $\theta = 1$ (row 17), but this is mainly a mechanical re-scaling of "market access" and the implied impact of railroads is only moderately larger.[75] Rows 18 and 19 report estimates when assuming larger values of θ: 4.12 is from Simonovska and Waugh (2011), and 12.86 is the largest estimate from Eaton and Kortum (2002).[76] These alternative choices (mechanically) reduce the estimated impact of market access but have less effect on the implied impact of railroads.

The above changes in the network database or measurement of market access affect both the estimated impact of market access and the counterfactual decline in market access without railroads. Panel C considers alternative empirical specifications that affect the estimated impact of market access but do not change the counterfactual decline in market access without railroads. In this case, changes in the estimated coefficient (column 1) directly map into changes in the implied impact of railroads (column 2), though by less in percent

[73]The Census defines urban areas as places with population greater than 2,500, and defines cities as areas with population greater than 25,000.

[74]Note that the "distance buffer" (rows 12-14) and "city access" (rows 15 and 16) estimates would suffer from omitted variables bias if counties value access to non-included areas, so we emphasize these results mainly as a sensitivity check on our baseline estimates. These estimates do not strictly decompose the benefits of market access to cities, to urban areas, and to rural areas.

[75]Note that this is a non-linear re-scaling; otherwise, there would be no impact on estimating the impact of market access in logs.

[76]Our preferred estimate of θ is from an historical agricultural context (though in India), whereas larger estimates are from modern trade of manufactured goods. For modern trade of manufactured goods, estimates of θ are generally within the range of 4 to 9 (Anderson and van Wincoop, 2004).

terms due to the log functional form.

First, we control for region-specific changes in addition to the baseline controls for changes by state and latitude/longitude. In rows 20 and 21 we include year-specific controls for the fraction of each county in 20 "resource regions" or 145 "resource subregions" (Hornbeck, 2010), though these regions were mapped in 1966 and may be endogenous to the availability of railroads. Comparing counties within local regions may also exacerbate measurement error in county market access, due to simplifications in our network database and calculated county-to-county freight transportation costs. The estimated magnitudes are attenuated somewhat in these specifications, though the impacts remain substantively and statistically significant.

Second, we exclude outlier values for changes in market access and changes in land value. When excluding the largest and smallest 1% or 5% of changes in market access (rows 22 and 23), the estimated impact of market access is similar or slightly larger. These coefficients mechanically imply a similar or slightly larger impact of railroads, as we include all counties when calculating the implied decline in agricultural land value. When excluding the largest and smallest 1% or 5% of changes in land value (rows 24 and 25), the estimated impact of market access (and railroads) is similar or slightly smaller. Increasingly excluding outlier values in the outcome variable is known to attenuate estimates, but it is useful to verify that the estimates are not driven by large percent changes in a small number of sample counties. Indeed, part of the rationale for weighting the regressions is to reduce the influence of sparsely settled counties experiencing large increases in land value.

V.C Additional Counterfactual Scenarios

In evaluating whether railroads were "indispensable" to the US economy, it is reasonable to consider whether other technological solutions might have been available. Prior to the railroads, many resources were devoted toward building a canal network in the Eastern United States; in the absence of the railroads, a system of canals might have been built through portions of the Midwest and Eastern Plains. As described in Section I, Fogel (1964) proposes a feasible system of canals that would have brought 70% of the "infeasible region" within 40 miles of a navigable waterway. In Fogel's estimates, and in our preliminary extension of Fogel's analysis in Section I, this system of canals mitigates 30% of the intraregional losses from removing railroads. These estimates require assuming how much land values are affected by distance to a waterway, however, and counties' distance to a waterway is an imperfect proxy for what they actually value: access to markets.

To measure the impact of Fogel's proposed canals, we calculate county-to-county lowest cost transportation routes for a counterfactual network database that replaces all railroads with Fogel's proposed extension to the canal network. Using these costs to re-calculate counties' reduction in market access in 1890 without railroads, and multiplying this decline by the estimated impact of market access, we estimate that agricultural land values would still decline by 55.3% with a standard error of 4.4%. The proposed canals are a poor substitute for the railroad network, mitigating only 13% of the losses from removing railroads. While canals reach within 40 miles of many Midwestern areas, the railroad network provides substantially better access to markets. This result is foreshadowed by the remarkably dense railroad network in 1890 seen in Figure 2.

Fogel's proposed canals would have generated annual gains of $53 million in the absence of the railroads, which does exceed their estimated annual capital cost of $34 million. Fogel's proposed canals were not actually built, presumably because they were made unnecessary by the presence of the railroads. Indeed, using a network database that includes both railroads and the canal extensions, we estimate that the proposed canals generate an annual economic benefit of just $0.23 million.

As an alternative technological solution, in the absence of railroads, there may have been substantial improvements in road-based transportation. Fogel speculates that motor trucks might have been introduced earlier, but a more immediate response could have been the improvement of country roads. For a counterfactual network database that excludes railroads and reduces the cost of wagon transportation to the cost along improved roads (10 cents per mile traveled, 14 cents for a straight route; down from 16.5 and 23.1 respectively in our baseline procedure), agricultural land values still decline by 50.9% (4.1%). Adaptation through improved country roads therefore mitigates only 20% of the loss from removing railroads. We do not find that improving country roads is particularly complementary with extending the canal network: doing both together mitigates 32.4% of the loss from removing railroads, compared to their summed impact of mitigating 32.9%.[77]

This alternative technological solution is predicated on the notion that the absence of railroads would heighten incentives to improve country roads. In a world without railroads, we estimate a $81 million annual benefit from decreased wagon costs; in a world with railroads, we estimate a $51 million annual benefit from decreased wagon costs. Railroads indeed reduce the gains from decreasing wagon transportation costs, but there remain large gains from improving country roads in a world with railroads.

It is difficult to quantify whether the absence of railroads might have encouraged the earlier introduction of motorized trucking, but we can measure how much wagon costs would need to decline to compensate for the absence of railroads. We calculate counterfactual

[77]For this exercise, we calculate market access for a counterfactual scenario that both includes proposed canals and reduces the cost of wagon transportation.

scenarios without railroads, decreasing the wagon cost to 5 cents, 2.5 cents, and 1 cent per ton mile.[78] When replacing the railroads with a lower wagon cost of 5 cents or 2.5 cents, agricultural land values fall by 33.9% (3.3%) and 18.4% (2.0%), respectively. Agricultural land values increase by 4.4% (0.71%) when replacing railroads with a lower wagon cost of 1 cent, at which point the wagon rate is nearing the railroad rate of 0.63 cents.

Other economic changes might exacerbate the absence of railroads, whereas Fogel focuses on compensatory responses that mitigate the impact on transportation costs from removing railroads. In particular, competition from railroads may have dramatically lowered the costs of shipping by waterway. Holmes and Schmitz (2001) discuss how waterway shipping rates may have roughly doubled in the absence of the railroads, due to increased holdup at transshipment points and adoption of inefficient technologies. For a counterfactual network database that excludes railroads and doubles the cost of water transportation, we estimate that agricultural land values would decline by 77.3% (4.0%). This decline would generate an annual economic loss of $496 million ($26 million) or 4.14% of GNP (0.21%), roughly 22% higher than the baseline estimated economic impact from removing railroads.

VI Concluding Remarks

This paper develops a new method for evaluating the aggregate economic impact of railroads, drawing on a new database of county-to-county transport costs and recent trade research. Our approach exploits county-level variation in the railroad network over time, while dealing with the general empirical challenge that railroads in one county may well affect other counties. Dealing with this empirical challenge has required some theoretical guidance, but the empirical analysis has been able to proceed in a fairly reduced-form manner without calibrating a general equilibrium trade model. The general equilibrium impacts of railroads are captured, in wide class of trade models, by measuring the changes induced in counties' "market access." Our approach captures a simple economic logic: the benefits to each location are capitalized into the price of an immobile factor (land); and locations benefit from increased access to markets through railroad network expansion, rather than access to railroads *per se*.

Our estimates imply that railroads were critical to the agricultural sector in 1890: the absence of railroads would have decreased agricultural land values by 63.5%, generating annual losses of $407 million or 3.40% of GNP. Further, railroads' contributions to the agricultural sector were largely irreplaceable. We estimate that feasible extensions to the canal network would have mitigated only 13% of the losses from removing railroads. Improvements to country roads would have mitigated 20% of the losses from removing railroads, though the

[78] Note that, after adjusting for straight routes, the assumed wagon costs are 7.5 cents, 3.5 cents, and 1.4 cents per ton mile.

majority of gains from improved country roads would also have accrued in the presence of railroads. It is difficult to imagine how the impact of railroads within the agricultural sector could ever be "indispensable" to the US economy, a notion disputed by Fogel, as the total loss of all agricultural land value would only generate annual losses equal to 5.35% of GNP. Our estimates do imply, however, that railroads were both critical and irreplaceable to the agricultural sector.

Our "market access" estimates indicate a moderately larger impact of railroads than Fogel's "social saving" estimates, as well as less ability for alternative transportation improvements to substitute for the loss of railroads. When comparing our results with those from Fogel's social saving approach, we note that Fogel focused deliberately on obtaining an upper bound on the railroads' impact. By contrast, our approach strives at an unbiased point estimate. Whereas social saving estimates depend in large part on assuming the impact on land values from changes in transportation distances, our empirical analysis ultimately lets the data estimate how new railroads improve market access and how market access raises land values. The data indicate that county land values are affected strongly by market access, and that railroads had a critical and irreplaceable role in increasing counties' market access. Much of the difference between our results and Fogel's results appears to reflect our modern ability to construct a GIS network database and measure more precisely the impact of transportation methods on counties' access to markets. Using these data to estimate the aggregate impact of railroads has required exploiting recent advances in general equilibrium trade theory, but the model maintains the neoclassical framework underlying the social saving approach.

Our empirical analysis follows Fogel's in focusing on gains within the agricultural sector, which neglects many other potential benefits from the railroads. For example, in the context of our model, there are gains to consumers throughout the country (and the world) from cheaper agricultural goods. Outside of our model, there would be gains to consumers in the form of decreased passenger rates (e.g., Fishlow, 1965; Boyd and Walton, 1971; Leunig, 2006). We have also neglected gains in other sectors, such as the manufacturing sector, for which railroads may increase access to inputs and to consumers. Finally, our analysis only measures static gains from specialization and exploitation of comparative advantage, but the largest gains may be dynamic due to increases in technological innovation.

We see significant potential for future research to quantify channels through which the railroads impacted the development of the American economy. This paper provides a framework to think about general equilibrium impacts of the railroads through changes in "market access," which we hope will enable future research to estimate the aggregate impacts of railroads in addition to relative impacts on particular areas or sectors.

Finally, as a broader methodological exercise, this paper demonstrates a tractable approach to estimating aggregate treatment effects in the presence of spillover effects. For general settings in which spillover effects are at a national or global scale, some amount of theoretical structure is needed to move beyond estimating relative impacts in more-affected areas. Using theory as a guide, it is possible to estimate aggregate effects in a reduced-form manner. Empirical research in all fields of economics is increasingly estimating relative magnitudes by comparing areas that are relatively more or less affected by some plausibly exogenous treatment, but we hope our efforts might encourage similar attempts to exploit relative variation in addressing questions that are more aggregate in nature.

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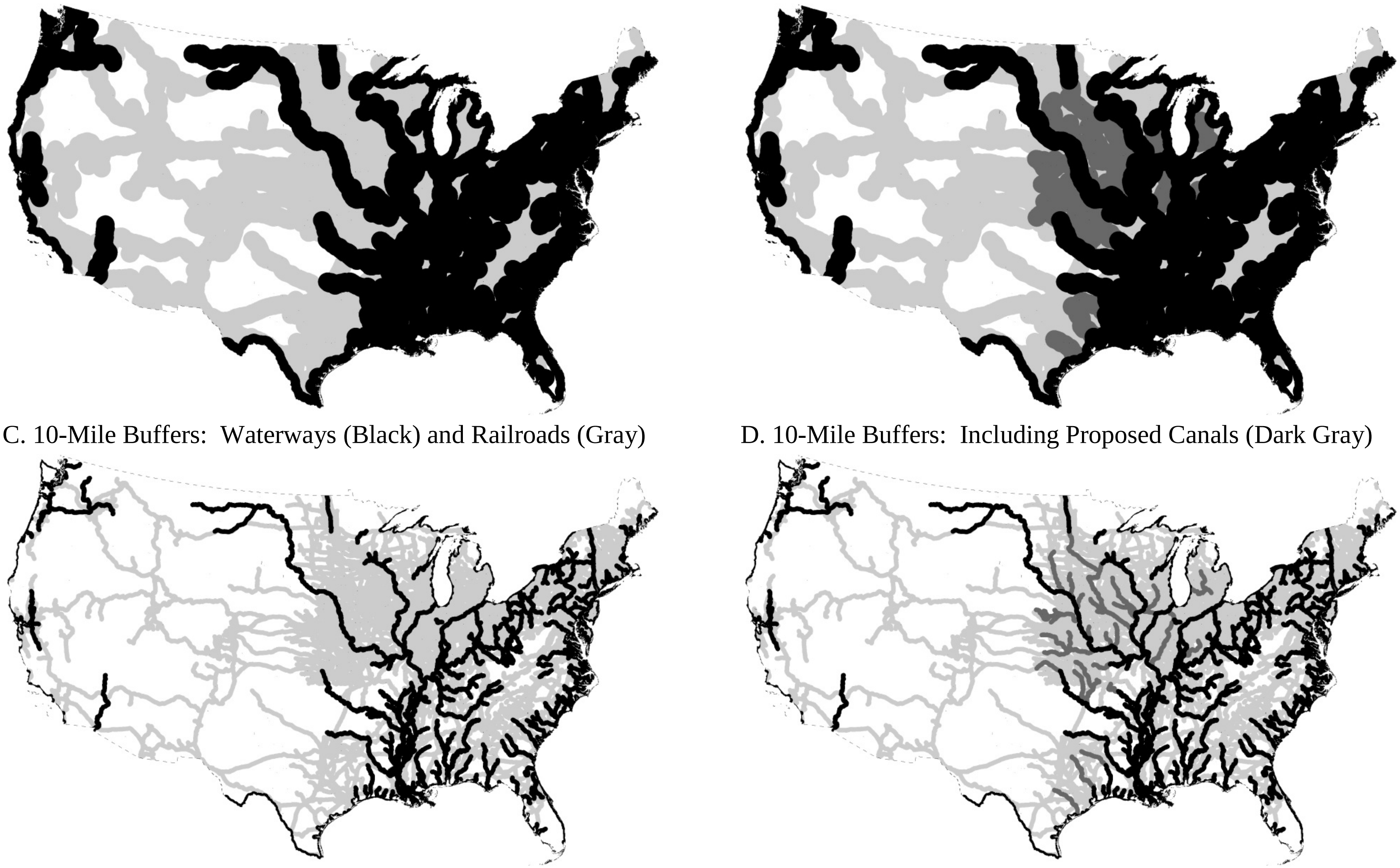
Figure 1. Distance Buffers in 1890 around Waterways, Railroads, and Proposed Canals

A. 40-Mile Buffers: Waterways (Black) and Railroads (Gray)

B. 40-Mile Buffers: Including Proposed Canals (Dark Gray)



C. 10-Mile Buffers: Waterways (Black) and Railroads (Gray)

D. 10-Mile Buffers: Including Proposed Canals (Dark Gray)

Notes: In Panel A, areas shaded light gray are within 40 miles of a railroad in 1890 but not within 40 miles of a waterway (shaded black). In Panel B, areas shaded dark gray are further than 40 miles from a waterway but within 40 miles of Fogel's proposed canals. Panels C and D are equivalent for 10-mile buffers.

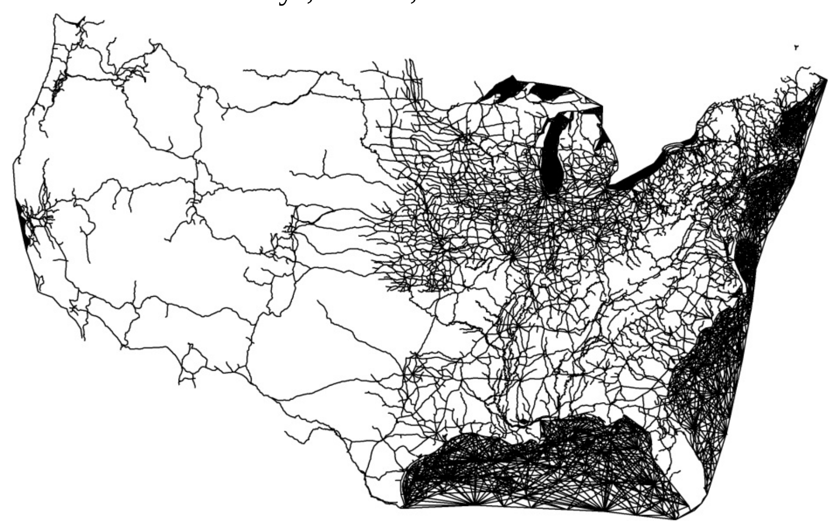
Figure 2. Constructed Network Database (Partial)

A. Natural Waterways

B. Natural Waterways and Canals

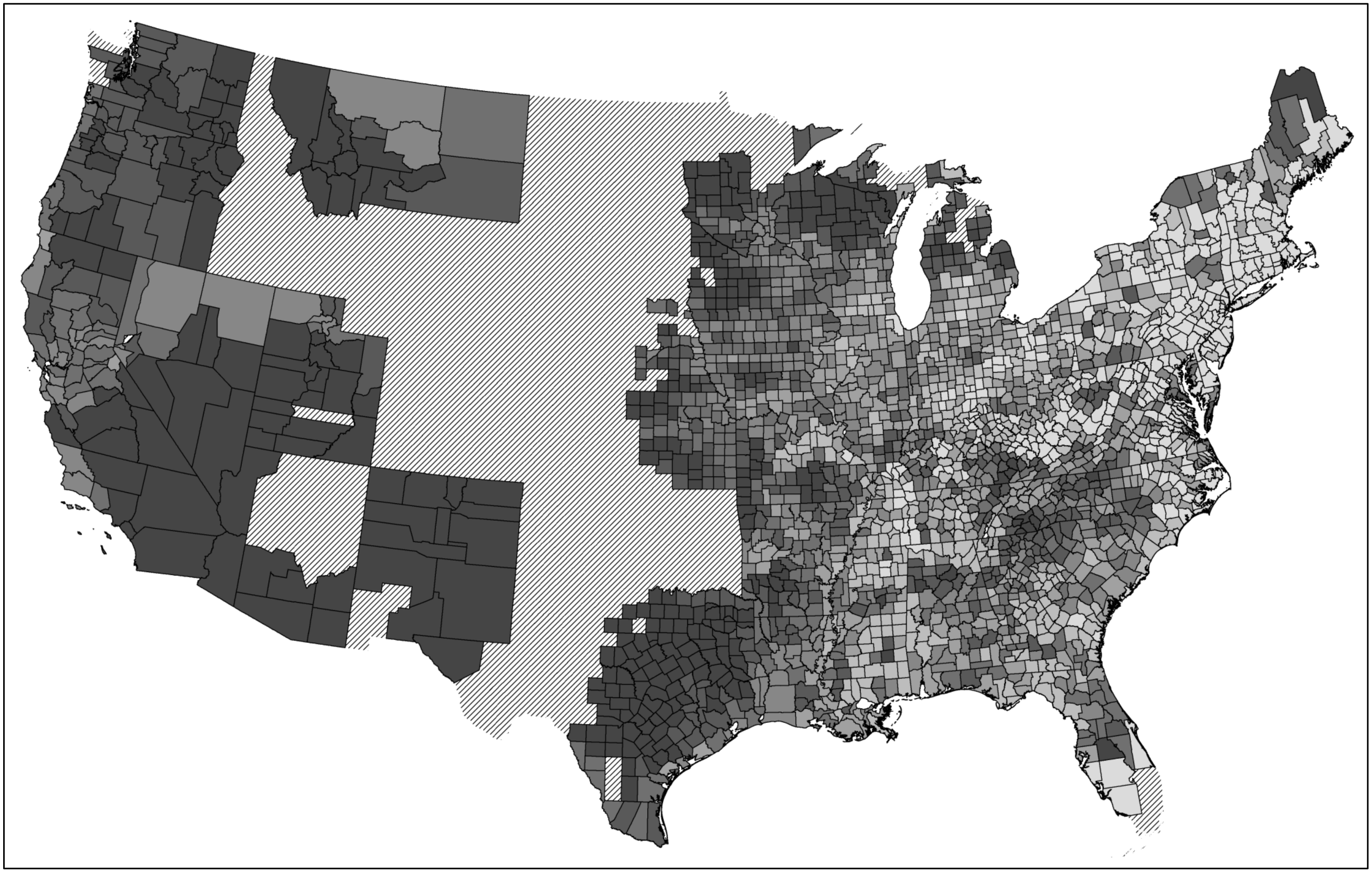
C. Natural Waterways, Canals, and 1870 Railroads

D. Natural Waterways, Canals, and 1890 Railroads



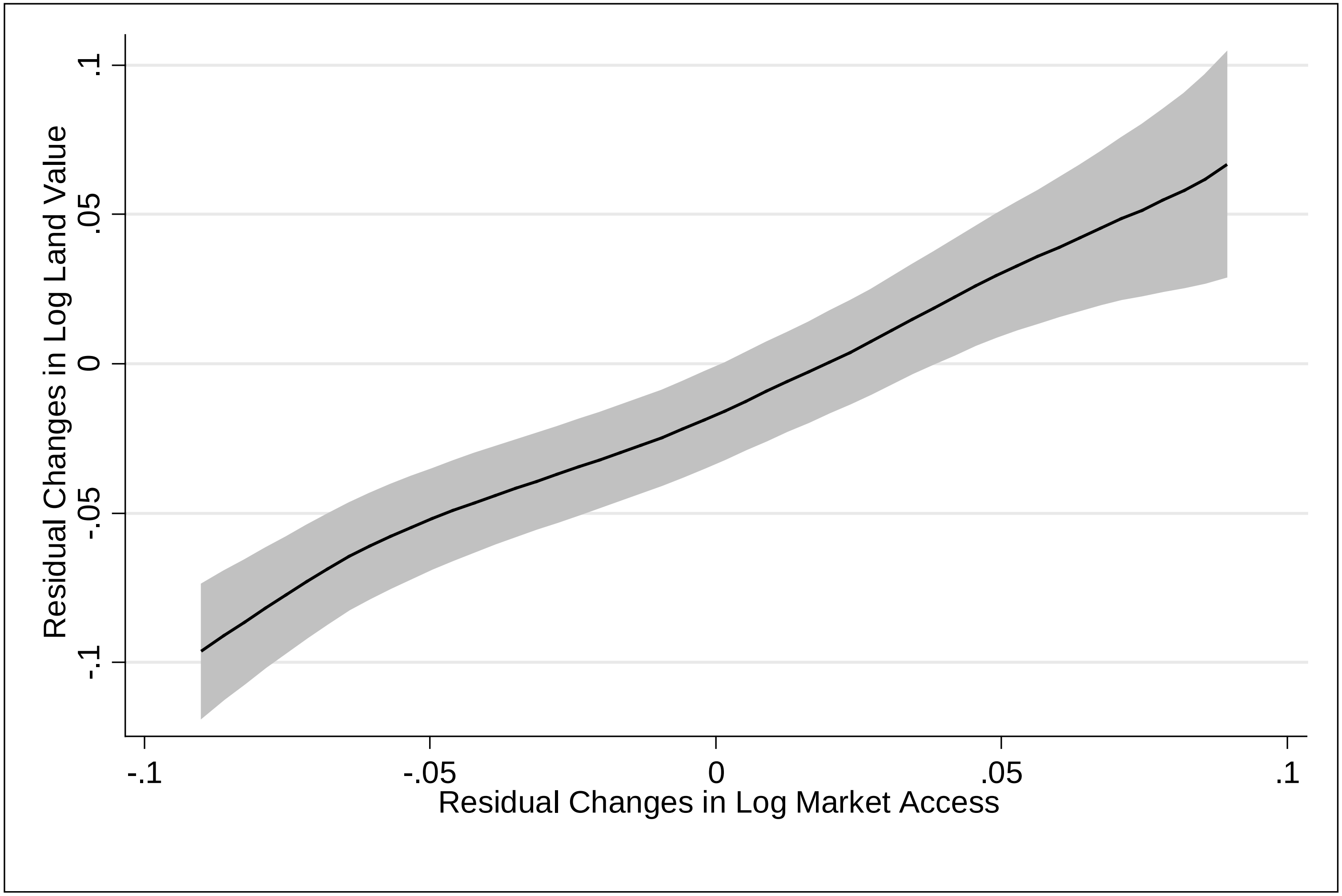
Notes: Panel A shows all natural waterways, including navigable rivers and routes across lakes and oceans. Panel B adds the canal network (as actually constructed in 1890). Panel C adds railroads constructed in 1870, and then Panel D adds railroads constructed between 1870 and 1890.

Figure 3. Calculated Changes in Market Access from 1870 to 1890, by County



Notes: This map shows the 2,327 sample counties, shaded according to their calculated change in market access from 1870 to 1890. Counties are divided into seven groups (with an equal number of counties per group) and darker shades denote larger changes in market access.

Figure 4. Local Polynomial Relationship Between Changes in Log Land Value and Log Market Access, 1870 to 1890



Notes: Residual changes in sample counties are calculated by regressing changes in the indicated variable on state fixed effects and county longitude and latitude, as in equation (12). This figure then plots the local polynomial relationship between changes in log land value and changes in log market access, based on an Epanechnikov kernel function with bandwidth 0.04. The shaded region reflects the 95% confidence interval.

Table 1. Estimated Elasticity of Land Value to Market Access

	Log Value of Agricultural Land				
	Baseline Specification	Calibrated Market Access	Fixed 1870 Population	100-mile Buffer Market Access	Unweighted
	(1)	(2)	(3)	(4)	(5)
Log Market Access	1.11	1.17	1.11	1.04	1.07
	(0.14)	(0.15)	(0.14)	(0.14)	(0.27)
Number of Counties	2,327	2,327	2,327	2,327	2,327
R-squared	0.62	0.63	0.62	0.62	0.61

Notes: Column 1 reports estimates from equation (12) in the text: for a balanced panel 2,327 counties in 1870 and 1890, the Log Value of Agricultural Land is regressed on Log Market Access (as defined in equation 11), county fixed effects, state-by-year fixed effects, and year-specific cubic polynomials in county latitude and longitude. The regression is weighted by counties' 1870 value of agricultural land. Columns 2 through 5 report robustness checks, as discussed in the text: column 2 uses a calibrated measure of market access (equation 9 in the text); column 3 uses a measure of market access for 1890 that holds counties' population levels fixed at 1870 levels; column 4 uses a measure of market access only to counties beyond 100 miles of a county; and column 5 reports estimates from the baseline specification when not weighting by counties' 1870 land value. Robust standard errors clustered by state are reported in parentheses.

Table 2. Market Access Elasticity: Robustness to Controls for Local Railroads

	Log Value of Agricultural Land			
	(1)	(2)	(3)	(4)
Log Market Access	0.93	0.83		
	(0.14)	(0.13)		
Any Railroad	0.112	0.117	0.290	0.268
	(0.052)	(0.051)	(0.046)	(0.042)
Railroad Length		0.089		0.143
(Units = 100 mi)		(0.042)		(0.040)
Number of Counties	2,327	2,327	2,327	2,327
R-squared	0.63	0.63	0.61	0.62

Notes: Column 1 reports the baseline specification from Table 1 (column 1), but controlling for a dummy variable for whether the county contains any railroad track. Column 2 also controls for county railroad track mileage (in units of 100 miles). Columns 3 and 4 omit Log Market Access from the specifications reported in columns 1 and 2. All regressions include county fixed effects, state-by-year fixed effects, and year-specific cubic polynomials in county latitude and longitude. All regressions are weighted by counties' 1870 value of agricultural land. Robust standard errors clustered by state are reported in parentheses.

Table 3. Market Access Elasticity: Instrumenting with Water Market Access in 1870

	Δ Log Market Access	Δ Log Value of Agricultural Land		
	First-stage	Reduced-Form	2SLS	2SLS
	(1)	(2)	(3)	(4)
Δ Log Market Access			2.46	2.58
			(0.64)	(0.70)
Log Water Market Access in 1870	- 0.091	- 0.224		
	(0.030)	(0.052)		
Δ Any Railroad				- 0.200
				(0.134)
Δ Railroad Length				- 0.025
(Units = 100 mi)				(0.050)
Number of Counties	2,327	2,327	2,327	2,327
R-squared	0.57	0.60	0.57	0.57

Notes: Columns 1 and 2 report the impact of Log Water Market Access in 1870 on changes in the indicated outcome variable between 1870 and 1890. Column 3 reports the estimated impact of a change in Log Market Access on the change in Log Value of Agricultural Land, instrumenting for the change in Log Market Access with Log Water Market Access in 1870. Column 4 presents the same estimate as in column 3, but also controls for changes in the presence of any railroad in the county and changes in the county's railroad track mileage. All regressions include state fixed effects and cubic polynomials in county latitude and longitude, and are weighted by counties' 1870 value of agricultural land. Robust standard errors clustered by state are reported in parentheses.

Table 4. Robustness of Estimated Elasticity and Counterfactual Without Railroads

	Impact of Market Access	Percent Loss Without Railroads	
		In Land Value:	In GNP:
	(1)	(2)	(3)
Baseline Specification	1.11 (0.14)	63.5 (4.2)	3.40 (0.23)
Panel A. Alternative Transportation Cost Parameters			
1 .Reduce sea routes to 0.198 cents	1.10 (0.14)	60.2 (4.2)	3.22 (0.23)
2. Reduce water costs to 0.198 cents	1.09 (0.15)	54.1 (4.2)	2.90 (0.23)
3. Remove transshipment within waterways	1.11 (0.14)	62.3 (4.2)	3.33 (0.23)
4. Raise railroad cost to 0.735 cents	1.14 (0.15)	61.7 (4.2)	3.30 (0.22)
5. Raise railroad cost to 0.878 cents	1.16 (0.15)	59.3 (4.2)	3.17 (0.22)
6. Reduce wagon cost to 14 cents	1.70 (0.22)	68.6 (4.2)	3.67 (0.23)
7. Reduce Pacific-to-Atlantic cost to $5	1.10 (0.14)	62.9 (4.2)	3.37 (0.23)
8. Increase Pacific-to-Atlantic cost to $11	1.11 (0.14)	64.2 (4.3)	3.44 (0.23)
9. Exclude Pacific-to-Atlantic connection	1.12 (0.14)	67.4 (4.0)	3.61 (0.21)
Panel B. Changes in Definition of Market Access			
10. Include access to international markets	1.12 (0.14)	63.2 (4.3)	3.38 (0.23)
11. Include access to own market	1.12 (0.14)	63.8 (4.3)	3.41 (0.23)
12. Limit access to counties beyond 5 miles	1.09 (0.14)	63.3 (4.3)	3.39 (0.23)
13. Limit access to counties beyond 50 miles	1.06 (0.14)	62.5 (4.3)	3.34 (0.23)
14. Limit access to counties beyond 200 miles	1.05 (0.14)	62.8 (4.6)	3.36 (0.24)
15. Limit access to only urban areas	1.10 (0.14)	59.4 (4.2)	3.18 (0.22)
16. Limit access to only cities	1.10 (0.14)	56.7 (4.1)	3.03 (0.22)
17. Set parameter "theta" equal to 1	4.19 (0.54)	66.5 (4.3)	3.56 (0.23)
18. Set parameter "theta" equal to 4.12	1.02 (0.13)	63.2 (4.2)	3.38 (0.23)
19. Set parameter "theta" equal to 12.86	0.33 (0.04)	57.3 (4.0)	3.07 (0.22)
Panel C. Regional Controls and Excluding Outliers			
20. Fixed Effects for 20 "resource regions," by year	0.96 (0.14)	58.9 (4.8)	3.15 (0.25)
21. Fixed Effects for 145 "resource subregions," by year	0.88 (0.13)	55.8 (4.9)	2.99 (0.26)
22. Drop top/bottom centile of changes in market access	1.12 (0.15)	64.0 (4.3)	3.43 (0.23)
23. Drop top/bottom 5 centiles of changes in market access	1.19 (0.16)	66.0 (4.4)	3.53 (0.24)
24. Drop top/bottom centile of changes in land value	1.12 (0.15)	64.0 (4.3)	3.42 (0.23)
25. Drop top/bottom 5 centiles of changes in land value	1.02 (0.13)	60.9 (4.3)	3.26 (0.23)

Notes: Each row reports estimates from the indicated specification, as discussed in the text (section V.B). Column 1 reports the estimated impact of Log Market Access on Log Value of Agricultural Land; column 2 reports the estimated percent decline in agricultural land value for an 1890 counterfactual scenario with no railroads; and column 3 reports the implied annual percent loss in GNP for an 1890 counterfactual scenario with no railroads. Robust standard errors clustered by state are reported in parentheses.