BOSTON UNIVERSITY

GRADUATE SCHOOL OF ARTS AND SCIENCES

Dissertation

CONNECTING THE PERIPHERY: THREE PAPERS ON THE DEVELOPMENTS CAUSED BY SPREADING TRANSPORTATION AND INFORMATION NETWORKS IN THE NINETEENTH CENTURY UNITED STATES

by

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Submitted in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

2016

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Acknowledgments

First and foremost, I'd like to thank my advisor, Bob Margo, for his advice, guidance, and external projection of confidence in me. I recognize that I am a difficult student, recalcitrant and stubborn; he has nonetheless been incredibly supportive of and patient with me through this long process. He has been an excellent advisor, for which I feel very lucky and grateful.

I'd also like to thank my other committee members: Carola Frydman and Daniele Passerman. They have both provided excellent guidance, advice, and occasional encouragement. Claudia Olivetti was not officially on my committee, but gave me a great deal of her time and attention. Many other professors at BU have been very supportive along this process, but Marc Rysman, Martin Fiszbein, and Michael Manove have been particularly kind with their time.

I am very grateful to the professors and students in the economic history group at Harvard who accepted me into it and supported my work. I am appreciative that Claudia Goldin allowed me to take her class and has been endlessly welcoming, and that James Feigenbaum (perhaps unwittingly) gave me the idea for the last chapter. I'd also like to thank the group of transportation economic historians, including Dan Bogart and Florian Ploeckl, who have provided me with many outlets for my work and feed back at conferences.

I am extremely grateful to have been able to work with my coauthor on the last chapter, Steven Sprick Schuster. He has provided more than half of the drive on that, and has been a joy to work with.

Much of the work on this project involved learning unfamiliar tools, GIS and automated textual analysis. Many people have been very kind with their time, and helped me with that process: Suresh Naidu, Arthur Spirling, Dustin Tingley, and Christopher Lucas.

Many people have allowed me to build on their hard work, giving me access to data: Tom Nicholas, Jeremy Atack, Michael Haines, and Michael Meurer. Chloe Hite provided excellent research assistance.

My classmates at BU have been wonderful peers, that I've been very grateful to have to go through this process with. In particular I'd like to mention Debbie Goldschmidt, Nate Young, Shuheng Lin, and Russell Weinstein.

Finally, I'd like to thank those people who have supported me in life (and more than occasional proof reading): My parents, David Perlman and Catherine Hopper; my close friends Matthew Peverill, Claire Rojstaczer, and Allie Kleber; my close friends and occasional romantic partners April Xin and Peter Sims; and those people who've shared a home with me and provided me with family—Henry Gross; Becca Perry; Ross Corliss (who has contributed many ideas to the second chapter). Lastly, I'd like to thank Matt Berntsen, my life partner of some 16 years, who has provided steadfast support and love.

All errors are my own.

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ABSTRACT

This dissertation focuses on how transportation and information networks change the geographic distribution of economic activity. The first and second chapters examine the geographic distribution of patenting in the nineteenth century United States. The third explores the impact of the rollout of Rural Free Delivery (RFD) in the early twentieth century on voting behavior.

In Chapter One, I examine the relationship between patenting activity and transportation access, using a newly collected panel dataset at the county level spanning the nineteenth century United State. I find a robust, statistically significant, positive effect of increases in local transportation access on patents per capita. The effect is large — patents per capita double over the twenty years following introduction of the railroad. I ask if this increase is due to inventors responding to larger markets afforded by transportation improvements. I find modest evidence that market access explains the increase in patent activity, but most of the relationship seems to be explained by other variables correlated with transportation access.

The second chapter proposes a novel way to study technology diffusion, investigating how transportation changes information absorption. Using digitized patent texts, I measure whether any given patent mentions previous, novel technologies within a particular window of time. The arrival speed of these new ideas is only weakly related transportation improvements; expansions of the transportation network disproportionately benefit the most develop places. Together, these two chapters suggest that the positive effect of transportation access on patenting is due to transportation forming a nexus that encourages local agglomerations, but leave the question of the overall impact of lager transportation networks on innovation unclear.

Chapter Three focuses on the how mail delivery spread new information, studying the rollout of Rural Free Delivery (RFD) in the early twentieth century. Using a newly constructed panel data set, the analysis shows that voters in communities receiving more RFD routes distributed their votes to more parties; however, there is no evidence of an effect on turnout. RFD shifted positions taken by Representatives in line with their rural constituents, including increased support for pro-temperance and anti-immigration policies. The results only occur in counties with local newspapers, suggesting that the main channel is a lowered cost to voters of acquiring information relevant to political choices.

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List of Abbreviations

GIS	Geographic Information System
IV	Instrumental Variables
LOWESS	Local Regression
NHGIS	National Historical Geographic Information System
OCR	Optical Character Recognition
OLS	Ordinary Least Squares
PTO	United States Patent and Trademark Office
R&D	Research and Development
RFD	Rural Free Delivery

Chapter 1

Dense Enough To Be Brilliant: Patents, Urbanization, and Transportation in Nineteenth Century America

Part 1: Patents per Capita and Spreading Transportation Networks

1.1 Introduction

Ever since Marshall (1890), economists have believed that location matters for innovative activity, as co-location facilitates the transfer of innovative ideas (Jaffe et al., 1993). The spread of communication and transportation has a democratizing effect, encouraging people who would not have previously participated in innovative activity to do so (Friedman, 2006). At the beginning of the nineteenth century the world was very poorly connected, but by the end of that century the movement of people, goods, and information among places had increased dramatically.

Before railroads, waterways were by far the most efficient way to transport goods. Moving goods over land, even on the best roads, was extremely costly.[1] By the 1860s, the telegraph had become the fastest way of sending a message, and physical packages moved overland by train or over water via steamship. These changes made

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[1] It has become a commonplace to note that it cost about the same amount to ship goods between London and Boston as to travel 30 miles over land in the United States, or about the distance from downtown Boston to Concord, MA (Howe, 2007).

transportation faster, cheaper and safer, effectively reducing the distance between locations. This reduction in distance was even more dramatic on the periphery of the transportation and communication network. By the end of the nineteenth century railroad tracks densely intersected much of rural America. This promoted economic growth by linking far-flung factor and product markets, encouraging the exploitation of regional comparative advantage (Fogel, 1964; Atack et al., 2011; Donaldson and Hornbeck, 2013). Railroads also changed the character of the areas around them. They provided loci for new towns—increasing urbanization (Atack et al., 2010), attracting banks (Atack et al., 2014), and encouraging speculators to plat towns (Hudson, 1985).

I investigate how the nineteenth century “transportation revolution,” in which the most dramatic change came from the railroad, changed the location of innovative activity in the United States. I first document that the expansion of improved transportation in a county led to an increase in innovation, as measured by patenting activity. I then test the hypothesis, formulated by Sokoloff (1988), that improving transportation networks created incentives for innovation by facilitating access to larger markets.

I measure innovative activity by the number of patents per capita at the county level from 1790 to 1900. I obtain information on patents from Tom Nicholas (Akcigit et al., 2013) for the 1836-1900 period, and I construct a similar measure for 1790-1836 by collecting and geocodding data from a list of known patents from this period. I link this with new data on the spread of transportation networks from Atack (2013) to construct a measure of local transportation access, the proportion of a county’s land area that is within a specified distance of improved transportation.

I find a robust, statistically significant and positive effect of local access on patenting, that suggests that 8% of the increase in patenting over the nineteenth century was due to the spread of transportation. Because the massive increase in patenting that happened mid-century was led by the most developed places, that already had significant transportation access, increased transportation access cannot be the sole explanation. However, transportation had a significant effect for those counties that were not previously well connected; when I restrict my attention to only those counties that were not saturated by transportation in 1850, this estimate doubles. In addition to a positive main effect, increased transportation is associated with decreased concentration of patenting, particularity for more rural places. To address concerns that the documented relationship between transportation access and patenting may be driven by endogeneity in the construction of new transportation, I use straight lines drawn between the prosperous places in 1830 as an instrument for transportation access. This IV specification gives much larger point estimates (they imply that more than 20% of the increase in patenting was due to transportation), but the standard error is such that I cannot reject the hypothesis that the IV estimates and OLS estimates are the same.

Increased market access may lead to patentable innovation as the expected return to research and development is positively related to the size of the relevant market. Numerous studies using modern plant- or firm-level data have noted that exporting firms become more productive after trade liberalization.[2] Extensions to the the influential paper by Melitz (2003) by Bustos (2011) and Lileeva and Trefler (2010), give a clear motivation as to why larger markets might encourage a firm to invest in innovation; larger markets allow more units to be sold, thus providing for greater returns as firms reduce their costs.

Economic historians have also argued that increased market access contributed to

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[2] See, among others, Pavcnik (2002); Amiti and Konings (2004); van Biesebroeck (2005); Becker and Egger (2013); Deloecker (2007); Fernandes (2007); Foster et al. (2008); Topalova and Khandelwal (2011).

the increase in patenting activity in the early nineteenth century. Sokoloff (1988) finds that counties in New York and Pennsylvania along the newly-built canals (particularly the Erie Canal) saw a sharp increase in patenting activity between 1790 and 1846, and attributed this change to the increased market access in these areas.

In order to more directly test the effect of increases in the ability of an area to access larger markets, I calculate a measure of market access inspired by the methodology developed in Donaldson and Hornbeck (2013), which itself builds on earlier studies on this topic (Harris, 1954; Gutberlet, 2014). This estimate is the sum of the population of all counties in the United States; each counties' contribution to this sum is weighted by the cost of moving a ton of goods from the observation county to it.[3] In Appendix A.1 I investigate the direct impact of population density. The correlation of my estimate of market access with patenting per capita is not robust to the inclusion of controls. In particular, the inclusion of the lagged percent of county's farmland that is improved absorbs the relevant variation. Also, when both market access and local transportation access are included in the specification, local transportation access retains a positive, precisely estimated coefficient, but market access does not. It is also notable that when the percent of a county's area that within some distance from transportation is used as a local access measure, the measures that are calculated using shorter distances are more closely related to increases in patenting. This suggests that the impact of access to local transportation comes through localized changes within a county.

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[3] If counties are nodes of a network, and transportation provides connections between them, this measure of market access is a closeness centrality measure (Rochat, 2009).

1.2 Intuition from Trade Theory

1.2.1 The Gravity Model and Market Access

There are many ways to think about the concept of market access. One of the simplest ways is to understand it as the sum of all markets that a place sells to, including itself. The gravity framework gives a very simple way of estimating the trade flows between places. The empirical predictions made by this framework are some of the most robust in the literature, and many classes of trade models predict a gravity relationship. This framework uses a few simple variables to predict bilateral trade flows, while remaining agnostic on the reason why this relationship fits the data. The basic gravity relationship describes bilateral trade flows as between two places i and j:

$$trade_{ij} = \frac{y_i y_j}{y_w} (\frac{\tau_{ij}}{P_i P_j})^{1-\sigma} \tag{1.1}$$

where y_i , y_j and y_w are the incomes of i, j, and the world (total market), τ_{ij} is a bilateral resistance term, P_i and P_j are location specific resistance terms. Note that changing τ_{ij} has the same effect on trade as changing P_i or P_j, so lowering transportation cost is qualitatively similar to opening a county to trade. This is often simplified by noting that y_w is a constant for all pairs of counties and thus not needed in the estimation and taking$\frac{\tau_{ij}}{P_i P_j}$ to be the physical distance between the locations, because of the robustness of the empirical evidence relating distance to trade flows.

The size of a market i is the sum of all goods sold in it, the market in i captured by a trading partner j is the sum of its imports to i. Thus one can think of the market available to firms in location j as:

$$MA_j \approx \sum_i trade_{ij}. \tag{1.2}$$

If one labels the goods sold by j in j as $trade_{jj}$ this is a full description. Thus, market access refers to the areas with which a given region can effectively trade as adjusted for transportation costs.

The resistance term between areas incorporates anything that makes trade less likely including language barriers and cultural differences. By using closing of the Suez Canal as a natural experiment, Feyrer (2009) shows that about half of the resistance term between countries in the 1970s was due to transportation costs. In the nineteenth century United States, where there were no formal trade barriers (except during the Civil War) and no language barriers, one would expect transportation cost to be the largest factor in this term.

For the purpose of the gravity model, however any reduction in τ_{ij} will have the same effect on total trade. Thus, the steep reduction in transport costs over the 19th century should have had an effect on trade analogous to a similar reduction in trade barriers.

1.2.2 Melitz Model and Investment

Recent work in trade has examined linkages between innovation and market openness. One of the facts motivating the Melitz (2003) model was that more productive firms export, while less productive firms only serve the domestic market. In the Melitz (2003) model the difference in productivity between these two classes of firms is due to selection. For the nineteenth century, it is appropriate to think of patents not as the byproduct of a firm's Research and Development (R&D), but as a product in-and-of itself. Inventors were not employed by firms but rather were free agents who licensed and sold their improvements to others or who acted as entrepreneurs themselves.[4]

An isolated county may not engage in patenting due to the high effective cost of obtaining that patent[5] or because a patent is of limited value if its use is restricted to its own county.[6] In any one county, the pool of potential entrepreneurs looking to build on that patent is limited. Furthermore, if these entrepreneurs are effectively restricted to selling the goods they produce locally due to high transportation costs, Bustos (2011) and Lileeva and Trefler (2010) show that the incentive for these entrepreneurs to invest in productivity upgrading is low.

When local transportation arrives in a county, this may increase patenting by decreasing the fixed cost of receiving a patent. The new urban center formed near the rail stop may attract drafts-persons, lawyers, patent agents, or greater credit access in the form of a local bank. This local access may also encourage a greater scope of patenting topics. Increased urbanization might allow for greater familiarity with middle class consumptions goods.[7] The railroad itself might even become a topic of innovation. Alternately, when a county is effectively opened to trade by falling

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[4] A number of studies (Pavcnik, 2002; Amiti and Konings, 2004; van Biesebroeck, 2005; Becker and Egger, 2013; Deloecker, 2007; Fernandes, 2007; Foster et al., 2008; Topalova and Khandelwal, 2011), using modern plant- or firm-level data, note that exporting firms often do become more productive after trade liberalization, suggesting that the increased market access motivates firms to invest in innovations that lower their marginal cost of production. Also, Bustos (2011) and Lileeva and Trefler (2010) both consider models that examine the decision of a firm in an open economy to invest in process innovation, while Dhingra (2013) examines the choices firms make with regard to the introduction of a new brand (a new product). In this model, trade liberalization decreases the number of brands a firm offers; the model does not consider the question of new product entry via new firm entry. However, these settings do not reflect the nineteenth century innovation process.

[5] Which includes the cost of understanding what technology is novel.

[6] When the federal patent system came into existence in the US there was a provision for inventors to convert their state patents to federal ones, provided they gave up their state patent. Most inventors did so, and very few inventors subsequently applied for a state patent rather than a federal one. Before the federal system was existent it was common for inventors to apply for multipliable state patents, as they recognized the value of a monopoly in only one state was limited (Hrdy, 2013).

[7] The mail order business, Montgomery Ward, which primarily operated out of Chicago, was founded in 1872. It shipped, generally using freight that delivered packages to a train station (large packages were not allowed to be shipped via US Post until 1913), rural residents a large range of manufactured goods (e.g., bolts of cloth, trunks, and pens).

transportation costs, inventors have a greater incentive to patent, either because of increasing opportunities to sell or license the patent elsewhere, or because local entrepreneurs might be more interested in using these innovations. Thus, this model motivates the search for increased patenting activity following the introduction of improved transportation infrastructure.

1.3 Background

1.3.1 The Patent System

The present system of state-created and -enforced monopolies in intellectual property, patents, developed from of an older tradition of state monopoly grants (Bracha, 2004). In late eighteenth century Britain and its colonies, the process for requesting grants promoting the development of new industries and technologies in a location had been routinized. Still, the 1790 United States Patent Act,[8] which outlined uniform standards for what was patentable and a uniform process for obtaining a patent at a low fee (about $5), was the first of its kind (Khan, 2005). The United State's system became a model for other countries as they introduced or reformed their patent systems during the nineteenth century.

It is striking that, as a new country on the periphery, the 1790 Act specified that a patentee must be "the first and true inventor" anywhere in the world. Most nineteenth century patent systems allowed grants to go to those who were the first to introduce the technology into the country, as colony and then state patents had done (Hrdy, 2013). The United States system fluctuated in its enforcement of this mandate, most notably dropping any attempt to examine patents for novelty in 1793 (but increasing

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[8] The United States Constitution gives Congress the power "[t]o promote the progress of science and useful arts, by securing for limited times to authors and inventors the exclusive rights to their writings and discoveries." The 1790 Patent Act was following this mandate.

the fee to $30) and then reinstating examinations in 1836 (see appendix A.2 for more details on changes in patent law). Patents can only be issued to individuals (not to corporations), but these intellectual properties can be, and are often, sold. If the rights a patent confers have been sold prior to its being granted, it is "assigned at issue;" this assignment is recorded on the patent specification in the nineteenth century.

The creation of a monopoly over the patented invention is generally justified in two ways: by the increased incentive to engage in innovation that the monopoly creates and by the value of the information that inventors are forced to disclose as part of the application process. This public disclosure sets patenting apart from other methods that inventors might use to capture gains from innovation, most notably trade secrets (Moser, 2004). The effectiveness of the disclosure requirement varied, though inventors were required to describe their invention so that "a person having ordinary skill in the art" would understand. Until 1871,[9] anyone looking to copy the information contained in the patent would have needed to travel to Washington, DC or pay a substantial reproduction fee in order to read a patent specification. The patent office did not publish summaries of issued patents until 1872. Therefore, investors interested in newly issued patents relied on the summaries provided by private periodicals; the "Journal of the Franklin Institute" published its first issue in 1826, and the magazine "Scientific American" started publication in 1845. Both publications devoted substantial space to new inventions of British origin. The creation of a new, patentable innovation requires learning where the technological frontier is: what problems are interesting, what the existing best solutions are, and what lines of research have been or are being explored. Thus, the role of institutions that disseminate this knowledge

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[9] After which 22 depository libraries were created around the county, and the patent office distributed copies of issued patents for a reasonable fee.

is potentially important.

As was the general character of firms in the early nineteenth century, invention was primarily done by individuals. As the century progressed, large firms began to invest in research and development (R&D). It was not until the 1910s, outside of the period of this study, that in-house R&D became the dominant mode of financing innovation (Lamoreaux and Sokoloff, 2005).

1.3.2 Transportation Improvements

Before the twentieth century, transport costs were of utmost importance. Moving goods over land without mechanical power, even on the best roads was extremely costly. In the eighteenth century United States, coastal cities were more closely integrated with Europe than with their hinterlands, not only due to colonial links, but also because of the large cost differentials between sea and overland transport. The placement of cities along the St. Lawrence route to the Atlantic in Eastern Canada is a reflection of the importance of water transportation when they were first settled.

The lack of access to the interior of the country drove investments in transportation infrastructure. In the era before the steam engine, this meant the building of postal roads and efforts to increase ease of travel on rivers.[10] The early part of the nineteenth century saw a large investment in canals. The most notable of these was the Erie Canal in upstate New York, which opened in 1825, but there was also significant construction in both Pennsylvania and Ohio.

Railroad construction in the United States began in 1820. Initial lines were short, linking nearby settlement to mines or waterways. During the 1850s the United States experienced its first great wave of rail expansion when approximately 22,000 miles

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[10] Concurrently there were large investments in turnpikes in Britain (Bogart, 2005).

of track were laid. By 1860, in addition to dense coverage in the Northeast, the railroad network had reached Illinois, Indiana, and Ohio, with significant penetration into Wisconsin and Iowa. The South saw less construction, but it too experienced substantial growth in rail access in the 1850s (Atack et al., 2010). By 1870, the transcontinental railroad had been completed, though the western market it served was mostly limited to the San Francisco Bay area. By 1890, the areas around Portland, Seattle, San Fransisco, and Los Angeles all were connected to the same national rail network that had covered the country east of the Dakotas.

1.4 Data

I use patents as a measure of innovative activity. Thought patents are imperfect indicators of technological improvement (Trajtenberg, 1990; Moser, 2004) they are the most accessible and detailed written records of innovation. As such, economists and economic historians have long studied them to probe the economics of technological development.

In order to to connect patenting to changes in transportation, the location of these patents needs to be recorded and geo-located. This requires ether going through 700,000 original patents, or using the yearly lists published by the patent office to link the recorded location with a modern geocode. I construct a Geographic Information System (GIS) database of patents issued from 1790-1836. In 1836 there was a fire in the patent office that burned all the patents that had been issued to that date. In an attempt to recover from the damage this caused, the patent office put out a call for existent information on patents; in 1874 Congress used the information the patent office had received to compile a list of patents issued from 1790-1836 (a 1847 print volume presumably provided much of this information). This 1874 Congressional list has been updated by volunteers, such as Jim Shaw and the maintainers of the Directory of American Tool and Machinery Patents, who have found patents that the 1874 list did not include. I geo-located the patents by merging the town and county information with a database of historical town names from the AniMap 3.0.2 County Boundary Historical Atlas and the United States Board on Geographic Names (part of the Department of the Interior). The rest of the data on patent location comes from Tom Nicholas' dataset of patents issued from 1836-1900 (Akcigit et al., 2013), which has latitude and longitude coordinates of the listed places on these patents.[11]

These geo-located patents are then merged with the National Historical Geographic Information System (NHGIS) shape-files of United States county boundaries. This allows patent counts by county to be created. The text of patents was scraped from Westlaw and Google Patents; these respective organizations generated these text files in an automated way (OCR) from the images of the original typeset documents.[12]

This paper uses both contemporaneous county boundaries and a sample of consistent land area counties, harmonized to 1840 boundaries as suggested in Hornbeck (2010).[13] United States Census data are from Haines (2010). Transportation data are from Atack (2013), which are linked with shape-files of United States county boundaries to explore the spread of railroads and canals.

Tables 1.1 and 1.2 show the summary statistics for each year.[14] Figure 1·1 shows the total patents in each year, the US population from the census, and the percent

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[11] Based on the consecutive numbering of patents post-1936, the Akcigit et al. (2013) data cover the vast majority of patents granted between 1836-1900, with limited geo-coding errors.

[12] Typeset documents only exist for patents post-1836. Due to the fire of 1836 few of the pre-1836 patents, which are written in long-hand, are existent.

[13] More details on this computation see the boundary shifting files available on my website or upon request.

[14] In these tables and in most of the analysis done in this paper, the number of patents refers to those issued in a three year period: the complete named year and the complete year before and after the named year.

of land area in the US that is within 5 miles of the railroad or some form of water transport. The number of patents per person is not at all smooth over time, and there is a large increase in patenting activity that starts in the 1850s, shortly following the sharp increase in rail access.

Figure 1·2 shows the spread of patenting across the country. It presents the number of patents issued per ten thousand people in three year bins around the named year[15] as well as the spread of the canal and railroad network by county for four benchmark years. Note the increasing area that is involved in patenting, as well as the increase in patenting per person.

Figure 1·3 shows how the concentration of patenting and population has changed over time. The Herfindahl index of patent concentration falls substantially over the nineteenth century, reaching a low in 1870. This is in contrast to population which rises steadily after 1840. However, it is not so dissimilar from the concentration of urban population. Breaking the country into regions, as is done in the second panel of Figure 1·3, shows significant heterogeneity among them. The Northeast levels out after 1830, where as the Midwest does so in 1860, and the South has an upward trend between 1860 and 1880. Thus both the Northeast and Midwest show declines in the concentration of location of patents during their transportation booms.

1.5 Patents per Capita and Local Transportation Access

Starting the analysis of the relationship between transportation access and patenting, I examine the point estimates on the dummy variables for the number of years

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[15] Idem.

to the arrival of the canal or railroad in a county from a regression of:

$$PatentMeasure_{it} = \alpha + \beta \mathbf{YearstoArrivalDummies_{it}} + \gamma_i + \delta_t + \varepsilon \tag{1.3}$$

where $PatentMeasure_{it}$ is the measure of patenting at the county level, $\mathbf{YearstoArrivalDummies_{it}}$ are dummy variables for the number of year until a county, i, receives a railroad (as above), γ_i are county fixed effects, and δ_t are year fixed effects; standard errors are clustered at the county level.

Figure 1·4 plots these point estimates. I split the sample into two groups: counties in which I observed at least one patent before arrival of the railroad to that area, and counties that did not. The latter group mechanically has fewer patents than the former before the arrival of transportation. Notice that both plots show that there is an increase in patenting after the arrival of the mode of transportation, but the increase is gradual rather than being abrupt. The plot examining the railroad in Figure 1·4 is less noisy than the one examining the canal, but in both the number of patents per capita in counties that patent before transportation remains relatively steady until the arrival of transportation, at which point it starts to increase. Counties that do not patent before transportation arrives also show this change in slope.

Turning to my main specification, a fixed effect specification with year and county fixed effects and pre-trends in transportation access:

$$\begin{aligned} PatentMeasure_{it} = \alpha + \beta TransportMeasure_{it} + \varphi \mathbf{X_{i(t-1)}} + \gamma_i + \delta_t \\ + Region \times \delta_t + T.M._{i(t-N)} \times \delta_t + \varepsilon \end{aligned} \tag{1.4}$$

where $PatentMeasure_{it}$ is the measure of patenting at the county level, $TransportMeasure_{it}$ (abbreviated $T.M._{it}$) is the specified measure of transportation access, $\mathbf{X_{it}}$ are county level controls,[16] γ_i are county fixed effects, δ_t are year fixed effects, and $Region$ are fixed effects at the nine-region level; $t - N$ denotes the use of all previously observed values.[17]

Local transportation access is measured as the percent of a county's land area that is within a specified distance of some form of improved transportation (railroads, canals, steam navigable rivers, or ports). Table 1.3 shows estimates using the percent of a county's land area that is within 1.5, 5, or 15 miles of transportation and the number of patents per 10,000 people with the fixed effects and pre-trends of transportation access included as controls. Table 1.4 adds lagged county-level controls one category at time. The largest impacts on the coefficient on local transportation access come from the inclusion of the percent of a county's population engaged in manufacturing, and from the percent of a county's farm land that is improved. This effect is particularly magnified when these two groups of variables are included, causing the size of the estimate to fall to slightly less than half. When all controls are added the effect of a change in the percent of a county's land area that is within 15 miles of transportation is no longer precisely estimated, but the percent of the county's land area that is within five miles (people living in this band would have been able to make a trip to the mode of transportation and back to their homes in a day) and the percent that is within 1.5 miles remain precisely estimated. These estimates imply that

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[16] Controls that maybe included (when noted) are the percent of the county that is: employed in manufacturing, urban (2,500+), metropolitan (25,000+), literate, in school, born out of state, and foreign born, as well as the percent of farm land that is improved. Each variable is included at lagged values, and interacted with time dummies. More precisely, a variable that is observed in year t takes on the value zero before year $t+1$, and takes on its value in year t for all years following year $t+1$. This variable is interacted with year dummies. This is a more complete way of controlling for observables since many of these variables are only observed for some census years, and often those years are non-consecutive.

[17] A variable that is observed in year t is interacted with year dummies such that several new variables are included. One that takes on the value of zero in all years before year t, and takes on its value in year t and then zero thereafter, another one that takes on the value of zero in all years before year $t+1$, and takes on the value from year t in year $t+1$ and then zero thereafter, etc. for all remaining years to $t + N = 1900$.

a one standard deviation change in local transportation access in 1860 (about 13% more of the county within 1.5 miles of transportation) is associated with 0.1 more patents per ten thousand people, or 5% of 1860's mean; in 1850 this would imply an increase of about 20% of the mean or 0.1 standard deviation in patenting rates.

There are many ways to investigate potential heterogeneous effects of increased transportation access; Table 1.5 follows the specification that Forman et al. (2014) use to examine the impact of increased internet access on patenting rates. I have adapted this equation for a multi-period model using first differences:

$$\begin{aligned} \Delta PatentMeasure_{it} &= \alpha + \beta PatentMeasure_{i(t-1)} + \varphi \Delta TransportMeasure_{it} \\ &+ \zeta \Delta T.M._{it} \times P.M._{i(t-1)} + \eta \mathbf{X_{i(t-1)}} + \delta_t + Region_i \times \delta_t + T.M._{i(t-N)} \times \delta_t + \varepsilon \end{aligned} \tag{1.5}$$

where the variables are as defined above in Equation 2.4, one period represents ten years. The first column of Table 1.5 shows the relationship between the number of patents per capita last period and the increase between the last and this period. The negative coefficient suggests there is a process by which there is regression to the mean—places with more patenting see patenting grow more slowly. The second column presents the impact of increased transportation on changes in patenting, this coefficient is in line with the ones shown in Table 1.4. The last two columns add the interaction between lagged levels of patents and increased transportation. The main effect of lagged levels of patenting remains negative, while that of increased transportation remains positive. The interaction between these two is negative, suggesting that transportation helps spread out the location of patenting—places with more patenting that receive increased transportation see less of an increase in their patenting rates than other places. The second panel of Table 1.5 uses the growth rate of patents per capita instead of first differences, with consistent results.[18]

1.5.1 Instrumental Variables

Given how much smaller the estimates become with the inclusion of county level controls, there is significant reason to worry about reverse causality. Counties that receive the railroad may be positively selected such that counties that received the railroad earlier will patent more.[19] Because these counties are positively selected there is also reason to worry that after this positive section there may be regression to the mean—the estimates of a county's pre-transportation patenting levels may be inflated—and thus the estimates presented above may have downward bias. In addition, though the location of the transportation lines is measured quite precisely, the locations of the places where people might interact with a train or boat (i.e., stops) are not measured. Thus, there may be attenuation bias. To address this, I propose a "straight line" instrument for the spread of the railroad across the country.[20]

Figure 1·5 shows the lines that are used in the instrument. These originate from the 14 port cities with a customs house or public warehouse that had been built by the US government by 1826 (Congress, 1826), which were the largest ports, and run to the largest city or county in every state in the Midwest or western part of the South in 1830—five years before the first railroad was built in the United States. Lines are restricted so that, with the exception of those originating from New Orleans, only cities with approximately the same latitude are connected. Note the way these lines correspond with where population had settled by the 1860s, heavily in upstate New

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[18] Growth rate is computed as $1 - \frac{P_t}{P_{t-1}}^{\frac{1}{10}}$, one period represents ten years.

[19] Atack et al. (2010) address the question of if the railroad was built "ahead of demand." They find that it followed economic growth but increased urbanization.

[20] This instrument owes its inspiration to Gutberlet (2014), which uses lines between pre-existing cities in Germany to predict the spread of the railroad, and Michaels (2008), which uses the orientation of a line between the nearest city and a county centroid to predict the presence of an interstate highway.

York, but not proceeding onward to Michigan, across the southern mid-west (Ohio, Indian, and Illinois). This means that most of the variation in the instrument is coming from the industrialized North, and the local treatment effect may be larger than in the more agrarian South. The few lines running north from New Orleans capture those that settled along the Mississippi. The variable is defined at the county level: a county takes on the value of one always if in 1810 more than 1% of the county is within 1.5 miles of water transportation, one in 1850 on if three or more of these lines intersects it, one in 1860 on if two or more of these lines intersect it, a value of one in 1870 if more than one line intersects it, and zeros otherwise.[21]

Table 1.6 shows fixed effects regressions following equation 2.4 and the first stage and two stage least squares estimation given by:

$$TransportationMeasure_{it} = \alpha + \beta ConnectionLine_{it} + \varphi \mathbf{X_{it}} + \gamma_i + \delta_t + T.M._{i(t-N)} \times \delta_t + \varepsilon \tag{1.6}$$

and

$$PatentMeasure_{it} = \alpha + \beta \widehat{TransportMeasure}_{it} + \varphi \mathbf{X_{it}} + \gamma_i + \delta_t + T.M._{i(t-N)} \times \delta_t + \varepsilon \tag{1.7}$$

where $PatentMeasure_{it}$ is the number of patents issued per 10,000 people; $TransportationAccess_{it}$ (abbreviated $T.M._{it}$) is the measure of transportation access which will generally be the percent of the county's area within 5 miles of a railroad; $ConnectionLine_{it}$ is the indicator for whether or not one of the lines described above intersects a county and the year is as described above; $\mathbf{X_{it}}$ are county characteristics; γ_i are county fixed effects, δ_t are year fixed effects, and $t - N$ denotes the use of all

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[21] Results from a variation on this instrument where counties take on values based on lines from the port cites that run due west and north available upon request or on my website.

previously observed values.[22]

Because the variation in the instrument is in the years 1850 through 1870 Table 1.6 restricts the sample to 1840-1870.[23] When a full set of controls is used the instrument is not as strong as one might prefer, and the coefficient on local transportation access is very imprecisely estimated. The point estimate of this coefficient is similar to the one without county level controls, which is much more precisely estimated. The predicted growth in patents is consistent across the two tables. All alternate specifications examined suggest even larger coefficients. Using the estimates from Table 1.6 with controls, about 20% of the change in patenting between 1840 and 1870, can be explained by local changes in transportation access. The fixed effects estimates, by contrast, suggest 2% of the increases in patenting were due to changes in local transportation access.

1.6 Demand: Market Access

The hypothesis in Bustos (2011), Lileeva and Trefler (2010), and Sokoloff (1988) was that increased market access leads to more people being willing to pay a fixed cost for innovation. Above I explored the relationship between local transportation access and patenting, this section explores a measure of transportation access driven by expansions elsewhere in the network. The construction of this measure of market access is described below.

Data: Approximating Market Access

The question of how access to a larger market influences innovation can be more directly addressed by approximating the size of the market that is within easy reach

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[22] All IV regressions are done using xtivreg2 (Schaffer, 2010).

[23] Tables showing the full sample available upon request or on my website.

of a location. Equation 1.2 is the starting point for this approximation. It is worth noting that if counties are thought of as nodes in a network, where each node (county) is connected to the nodes (counties) physically adjacent to it, this market access approximation is a measure of closeness centrality (Rochat, 2009).

Several approximations must be made to apply Equation 1.2 to the data available for the nineteenth century United States, where there are no good estimates of counties' incomes nor of the trade flows between counties. First is the estimated transportation cost between i and j, which I will discuss below. Second, since GDP is unavailable at the county level, population is used as a crude proxy for income.[24] There are alternate county level measures that one might use instead of population, for instance the access of a county to nearby patenting is also explored in an Appendix available upon request, or on my website.

Market access for a county, MA_i, can be approximated as:

$$MA_i \approx \sum_j pop_j \cdot c_{ij}^{-\theta} \tag{1.8}$$

where pop_i is the population of location i, c_{ij} is the resistance term between i and j (i.e., the transportation cost between i and j), and $\theta = \sigma - 1$. The same formula is used in Donaldson and Hornbeck (2013). Market access can rise either when c_{ij} falls, or when pop_i increases; over the nineteenth century both the general cost of transportation and the population level will change substantially. While the population that a county contains is an important component of market access, it independently affects the patenting rate.[25] I also explore taking the cost term to be only related to

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[24] One can think of the market available to a firm as the number of people that it can reach with its product; people are out of reach if transportation costs make the product unfeasibly expensive. So a firm's reach expands with falling transportation costs. This reach can be estimated by a cost weighted sum of the people in all locations.

[25] Indeed, since I measure patenting as patents per capita, it mechanically effects this variable.

the straight line distance between county centroids. I refer to this as an "as the crow flies measure," that only varies because of population movement, as the relationship between counties is fixed.

Figure 1·6 shows approximate market access in 1830 and 1870; notice the high computed market access along the coast, the low computed market access in Appalachia, and the increasing importance of the railroad over time.

Transportation cost is computed by a procedure that assumes that each county is only linked to those counties that are physically adjacent to it (or accessible through the network of water transportation if the county contains a port). This can be thought of as a network where counties are nodes and links exist where physically adjacency exits or there is a waterway connection. This procedure will move along the network, starting from a seed county, to compute a transportation cost from every county to that seed county.

The algorithm starts from a reference county and computes approximate costs from this reference to all adjacent counties. The cost of getting from the seed county to each adjacent county is then conditionally updated with a new cost. This new cost adds the cost that was just computed from the reference county to this adjacent county to the cost that was previously computed between the seed county and the reference county. The information on transportation cost to this adjacent county is updated if the newly calculated travel cost is lower than the previous value, or if it had no previous value. If the cost is updated, this adjacent county is added to a queue. Counties are popped from the queue one at a time and each, in turn, is taken to be the reference county. This procedure repeats until the queue is empty. This procedure yields the minimum transit costs from the original seed county to all other counties.

The information on the transportation network is created by joining transportation data (Atack, 2013) with the 1840 United States county boundary shapefile from NHGIS. Each county is then denoted as having a railroad, river, canal, or port. If two adjacent counties have one of these features, they are assumed to be connected by that mode of transportation. Starting from the county centroid in question (reference county) I give approximate costs to every county adjacent to it using centroid to centroid distances (if less than 150 miles from each other) and rates taken from Donaldson and Hornbeck (2013), which takes them from Fogel (1964).[26] I restrict the cost between county pairs so that it never increases between two observations, I compare my computed cost for year t to the one from $t-1$ and I assign in year t the lower of the two costs. While the adjacency rules in this procedure are not as precise as using ArcGIS's Network Analyst, the data that are used need not have the level of precision necessary for that program to produce results. All port counties are assumed to be adjacent to all other port counties, with a distance computed by using modern waterway network data, which is compatible with ArcGIS's Network Analyst, from the National Transportation Atlas Databases. Other county adjacency is computed by modifying a tool written by Chieko Maene (Maene, 2011).

Results

Tables 1.7 and 1.8 use the specification described in Equation 2.3, using estimated market access[27] as the transportation variable. Table 1.7 tests the impact of adding different sets of controls to the estimated relationship between market access and patenting. Controlling for the lagged percent of county's farm acres seems, in partic-

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[26] Travel along a railroad costs 0.63 cents per ton-mile, a canal 0.50 cents a ton-mile, river or other waterway 0.49 cents per ton-mile, wagon or overland 23.1 cents per ton-mile, and changing mode of transportation 50 cents per ton (e.g., unloading from a rail car onto a river barge). Also following Donaldson and Hornbeck (2013) I take θ to be 3.8. I test both the conventional 1.0 and a suggested 8.22 and I find 3.8 fits my patents per capita data the best.

[27] This estimate includes the county's own population in the summation, and $\theta = 3.8$

ular to reduce the coefficient on market access, loading more weight onto a county's own population. Several variables seem to reduce the coefficient on population: the lagged percent of county that is engaged in manufacturing, the lagged percent of the county that lives in an urban area, and the lagged percent of the county that is foreign born and the lagged percent of the county that is born out of state. All of these things are higher in more populous areas, so this apparent correlation is not surprising. Nor is the relationship between market access and farming, as this has long been established (Fogel, 1964; Donaldson and Hornbeck, 2013); it is not clear if the channel of increase in patenting is an income effect, access to larger markets, or some other thing. The inclusion of the percent of the county that is enrolled in school, or the percent of the native born, over 21, white male population that is literate also cause a drop in the coefficient on market access. These have been shown to be related to increased access to transportation (Atack et al., 2012), and are also related to income from the economic growth caused by yields from farming in the Midwest. When all controls are added, nether of the coefficient on market access nor the coefficient on population is large or precisely estimated.

In Table 1.8, columns (1) and (4) use local transportation access as the variable of interest, replicating columns (3) and (4) of Table 1.4. The next set of columns, (2) and (5) use estimated market access as the transportation variable. Like local transportation access, the point estimate drops, and it is less precisely estimated when controls are included.[28]

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[28] The same instrument as used above can be used for market access that is transportation cost weighted. Consistent with the IV estimates of local transportation access, these estimates increase. Because this measure of market access is highly imprecise, attenuation bias may be significant. The point estimate in the IV specification without controls would imply that changes in market access explain 7.5% of the change in patenting between 1840 and 1870, while the point estimate (which is very imprecisely estimated) in in the IV specification with controls would imply that it explains 40% of this increase.

The largest gains in market access are from counties that had no form of improved transportation receiving their first connection to the larger network. Thus, columns (3) and (6) of Table 1.8 put the local transportation access measure and the estimation of market access in the same regression, thus examining how expansions of the network and local connections relate to patenting while controlling for the other. Transportation access and market access are weakly correlated in the beginning of the nineteenth century, becoming more strongly correlated as the century progresses. Also, as seen in Tables 1.1 and 1.2, the variance in this measure decreases with time. Thus it is somewhat unclear how to interpret the imprecisely estimated negative coefficient in column (3). When the full set of county controls are added in column (6), the only coefficient that does not appear to be different from zero is local transportation access. Overall, this suggests that it is increased transportation in the local area, and not in other locations on the network that is important for the relationship between patenting and transportation. In Appendix refsec: I explore the ways in which local transportation access and expansions of the network effect some types of places differently from other types of places, I focus on difference in initial connectivity.

Exploring the relationship between the previous patenting level in a county and the increase in patenting, Table 1.9 uses the specification described in Equation 1.5. Note that as in Table 1.5, regression to the mean in patenting levels is seen, similarly, increasing market access increases geographic dispersion—places with more patenting have less increase in patenting due to increases in market access. The overall effect of increased market access in column (2) of panel one in Table 1.9 seems to be negative, however it is positive in panel two and in columns (3) and (4). The average calculated marginal effect of an increase in market access is, in all cases, close to zero, suggesting there is little over all impact of increased market access.

These results are consistent with transportation leading to a decreased cost of patenting. They are also consistent with a model in which areas innovate on their local production using methods that are distinctive. Gaining access to transportation raises the number of patents a county produces, while the direct impact of market access is unclear.

1.7 Conclusion

I find a robust, statistically significant, and positive effect of increases in local transportation access on patenting. I sought to establish a richer empirical basis for considering market access as a driver of innovation, starting by establishing the relationship between local transportation access and patenting. Using a large dataset of geo-located patents cross-referenced with a map of the expansion of transportation infrastructure, I show that the arrival of improved transport, primary the railroad, has a positive effect on patenting behavior. Gains are realized slowly over time, suggesting that transportation access causes a trend change in the overall rate of development rather than a sudden innovative shock, and it is increases in very local (within 5 miles) improved transportation access that drive the increase in patenting. This expansion in patenting is largely due to locations registering their first patents.

Today most patenting comes from the Research and Development investments that firms make. Though the patents, by law, are still issued to individual inventors, these individuals have likely contracted to automatically assign their intellectual property to their employer. In the nineteenth century such arrangements were rare, with most inventors self-financing, and only later licensing or assigning the rights to their inventions to others.[29] Thus, these inventions represented individuals investing in a

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[29] Of the 21 important inventions as defined by books on the subject (Brown, 1994; United States Patent and Trademark Office, 1981; van Dulken, 2001) patented before 1860, 3 were assigned at

technology that was to be the basis of a business, or in the intellectual property for its value when sold or licensed to others.

Transportation helps encourage general economic development, which in turn leads to more resources available for inventive activity. Because transportation encourages urbanization, it encourages patenting in many ways. Urban areas allow for greater specialization, which might encourage patenting by giving people in those areas better access to the bureaucracy of patenting (e.g., lawyers, machinists, draftspeople), or by encouraging innovation directly. Urban areas also allow for better access to formal credit markets, lifting liquidity constraints for potential innovators. Finally, in an urban area, secrecy may not effectively protect inventions, leading to patenting.[30]

I then test the hypothesis that increased market access due to the transportation revolution was a key driver of innovation for the United States in the nineteenth century (Sokoloff, 1988), as well as the hypothesis that increasing transportation access increased information flows that drove patenting.

Increases in the estimate of market access that I create do not show this relationship. When both are included, it is local transportation access that maintains a positive, precisely estimated coefficient. However, because most connections in this period connected less developed places to more developed places, it does not follow that market access was unimportant for innovation. It may mean that in the United States during the nineteenth century, local connections were responsible for the majority of the changes in transportation costs, but it does cast doubt on the market

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issue: guncotton, the machine gun, and the safety pin. Patents on the vulcanization of rubber, rotary printing press, and automatic sewing machines were among those not assigned at issue.

[30] It is not *a priori* obvious that a transportation link will lead to more innovation in peripheral areas. It might also have increased the importance of being in the center of the network, or lead to human capital flight by providing an easier way to migrate to urban areas where high human capital is better rewarded.

access hypothesis.

It appears that local transportation access is related to increases in patenting primarily because transportation forms a nexus around which local agglomerations occur. That patent quality does not increase when local transportation access increases but quantity does is a result consistent with these agglomerations facilitating patenting by reducing the effective cost of participating in the formal intellectual property system.

1.8 Figures and Tables

1.8.1 Figures

Introduction

Figure 1·1: Number of Patents Issued Each Year and Total Population over Time

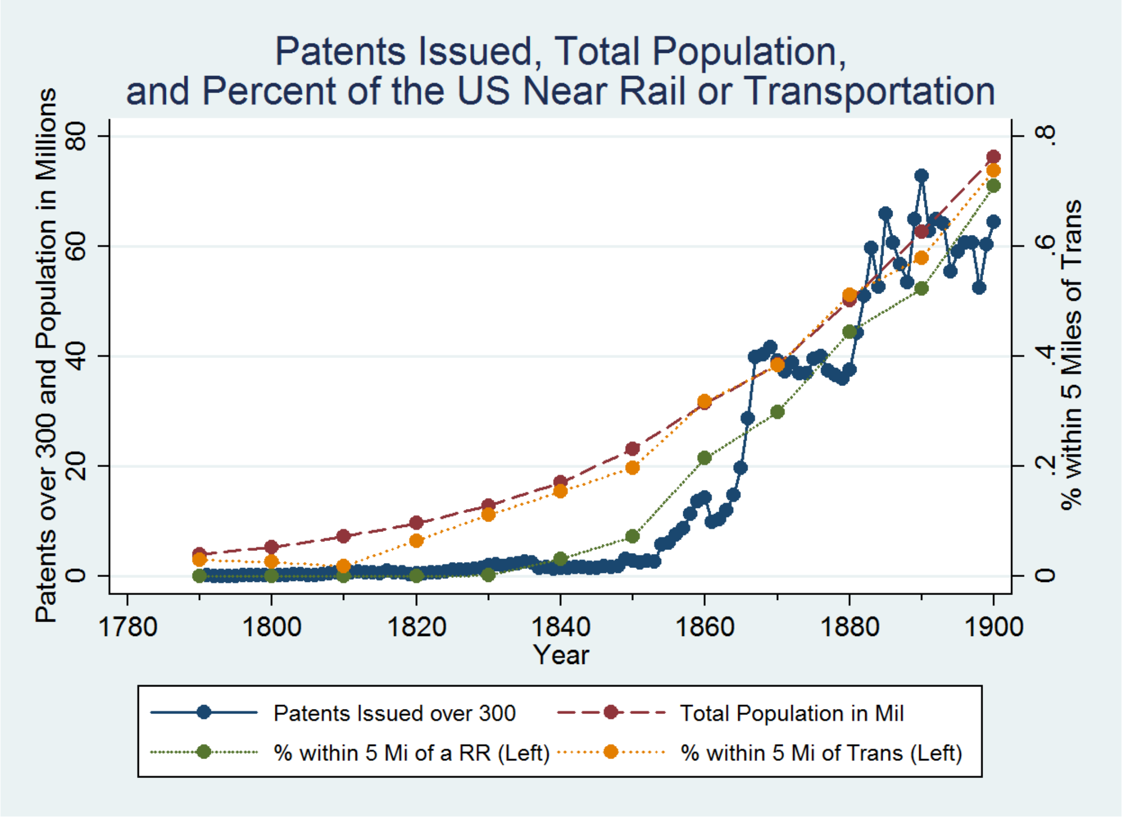

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Figure 1·2: Patents per 10,000 People with Transportation

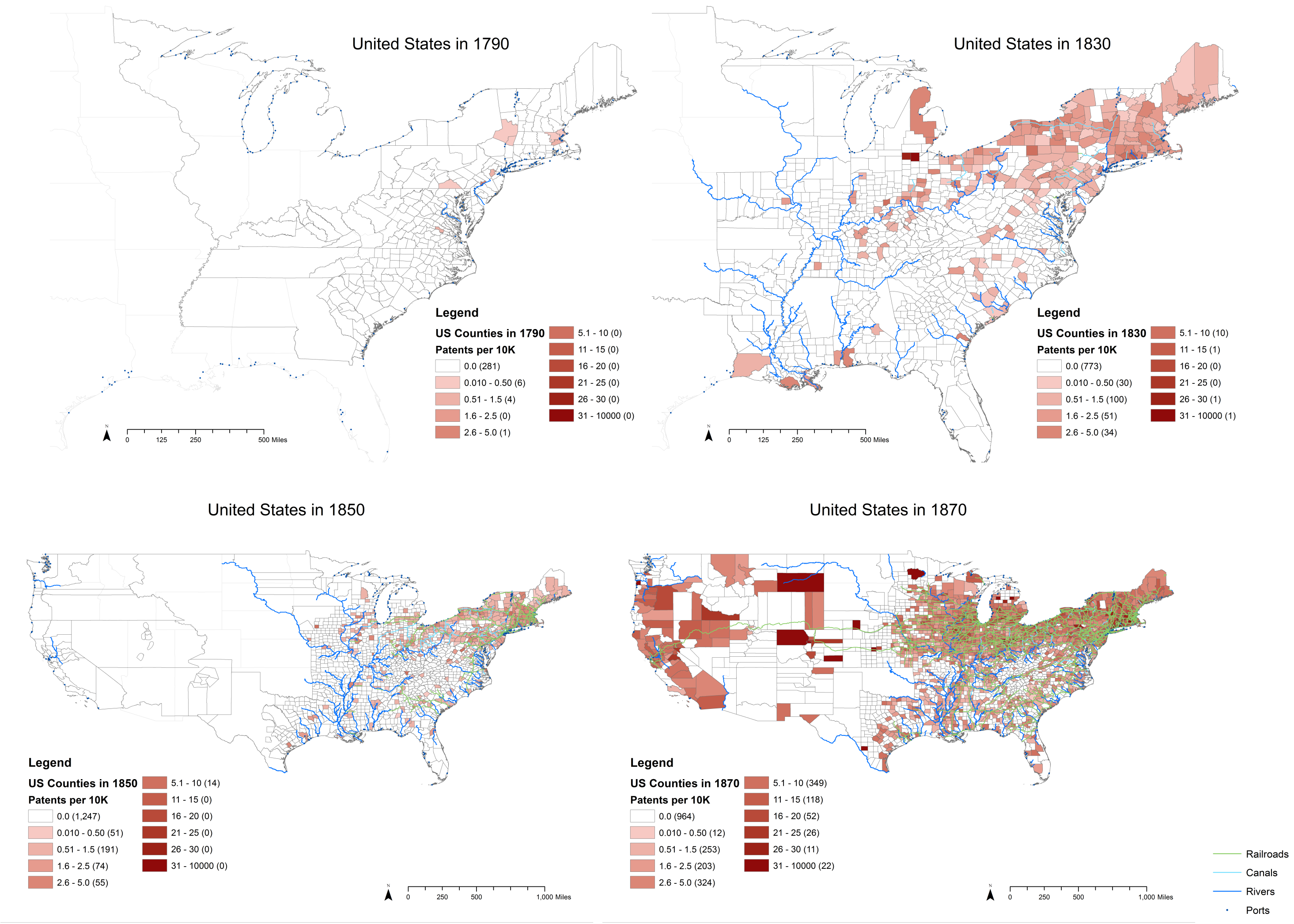

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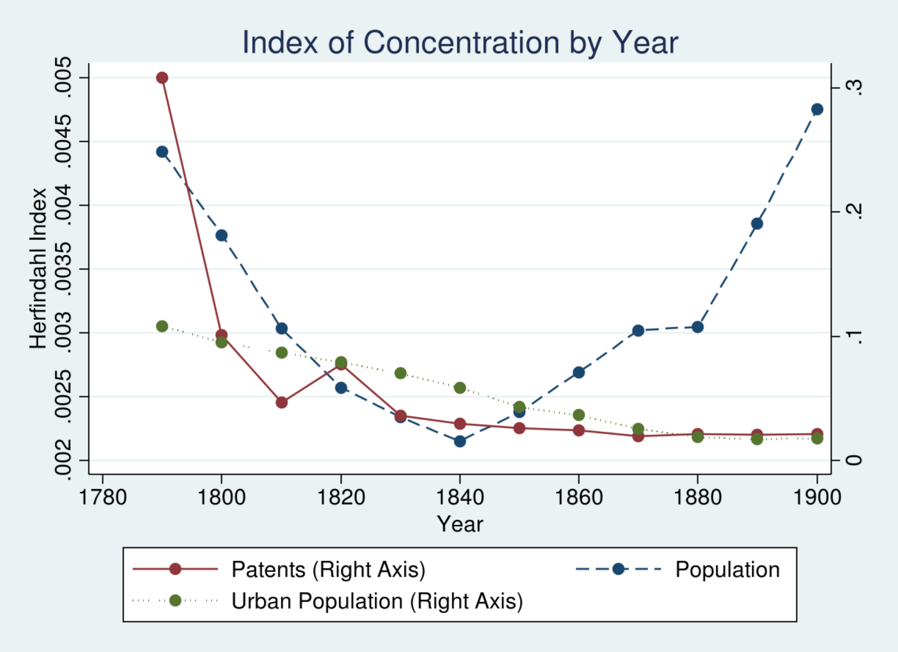
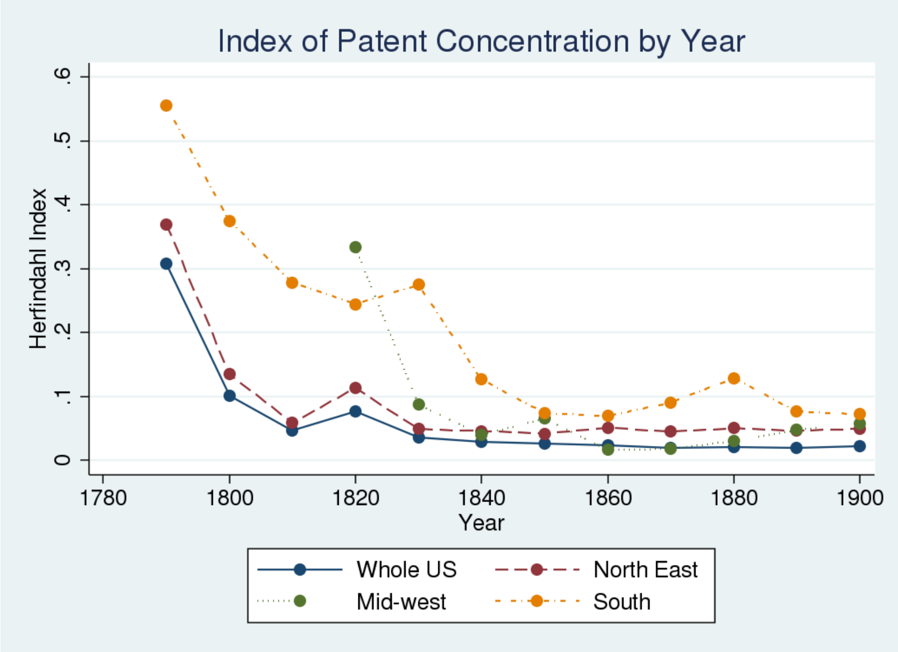
Figure 1·3: Concentration of Patents and Population in Counties by Year, Herfindahl Index



Concentration of Patents by Region in Counties by Year, Herfindahl Index



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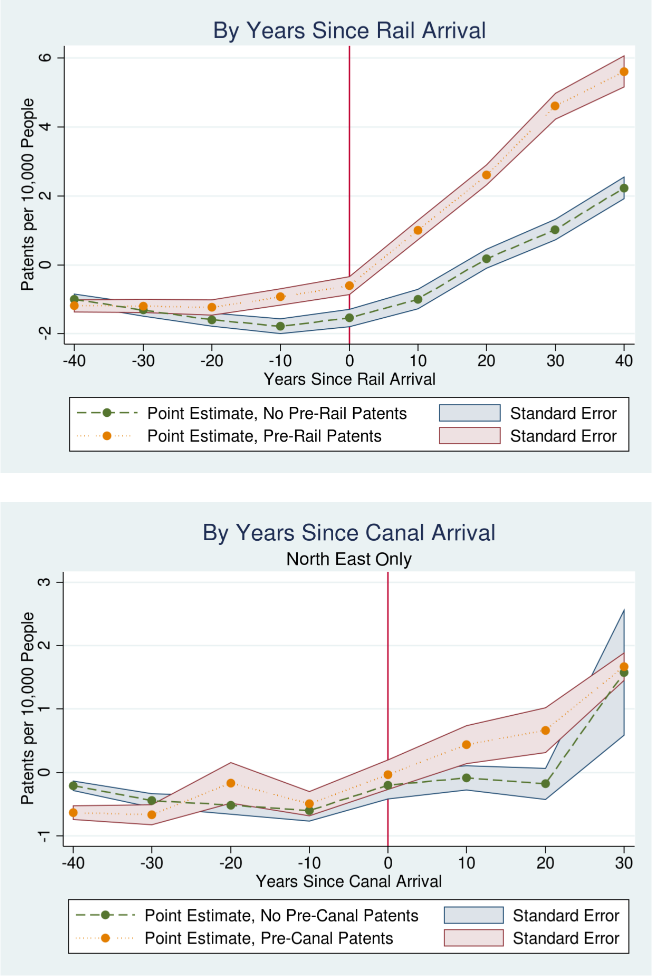
Local Transportation Access

Figure 1·4: The Mean Patents per 10,000 People by the Years to Railroad or Canal Arrival



The point estimates and standard errors come from a regression of patents per capita on the dummy variables for the number of years to the arrival of a railroad canal in a county and year and county fixed effects; standard errors are clustered at the county level.

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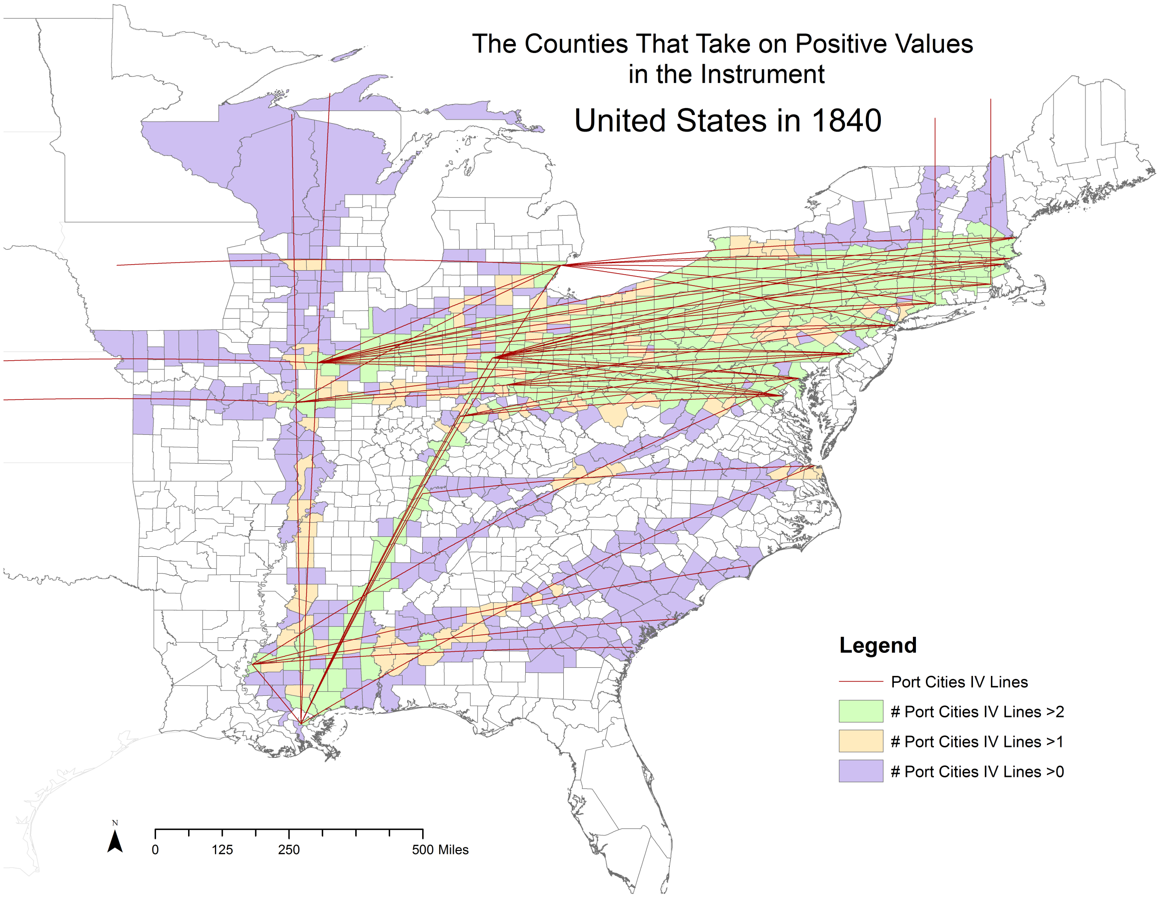
Instrument

Figure 1·5: Counties Affected by the Port City Driven Instrument



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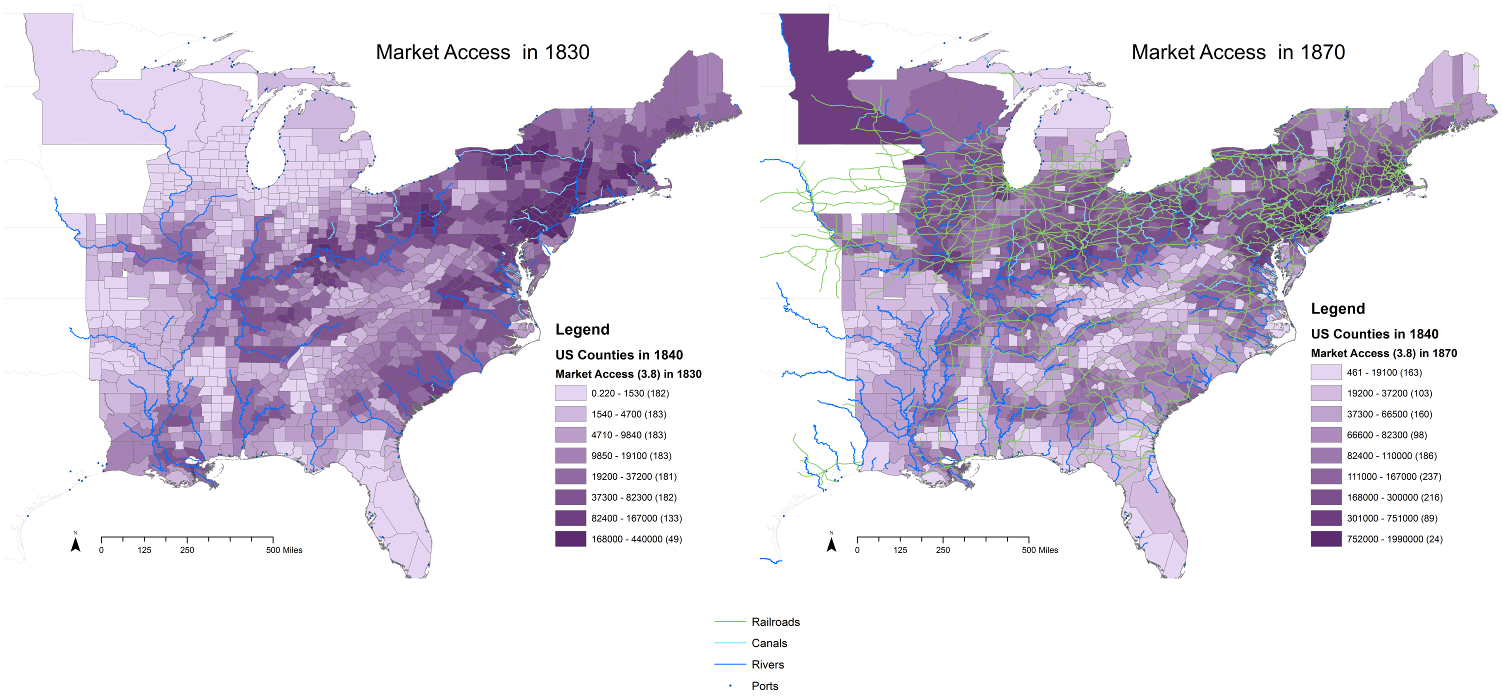
Market Access

Figure 1·6: Computed Market Access



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1.8.2 Tables

Table 1.1: Means by Year, 1790-1840

	1790	1800	1810	1820	1830	1840
Total Population	7,054	7,719	7,274	8,710	10,585	13,363
	(8,471)	(9,694)	(10,337)	(11,837)	(14,356)	(17,661)
Number of Patents	0.0250	0.0227	0.351	0.232	0.962	1.003
	(0.497)	(0.257)	(2.689)	(2.291)	(6.453)	(6.049)
Patents per 10K	0.0397	0.0346	0.144	0.0780	0.314	0.294
	(0.591)	(0.530)	(0.621)	(0.485)	(1.383)	(0.810)
# of NBER Subcategories						2.668
						(2.607)
% Urban, 2500+	0.0141	0.0150	0.0153	0.0149	0.0194	0.0264
	(0.0853)	(0.0910)	(0.0941)	(0.0873)	(0.0980)	(0.112)
% Urban, 25K+	0.00286	0.00308	0.00327	0.00416	0.00390	0.00519
	(0.0481)	(0.0473)	(0.0517)	(0.0567)	(0.0561)	(0.0643)
Pop per Square Mile	17.44	20.53	20.43	23.67	29.86	39.03
	(64.66)	(106.4)	(142.5)	(173.0)	(265.1)	(398.8)
% within 1.5 miles of transport	0.00306	0.00360	0.00524	0.0241	0.0436	0.0725
	(0.0250)	(0.0275)	(0.0373)	(0.0705)	(0.0797)	(0.101)
% within 5 miles of transport	0.0169	0.0189	0.0236	0.0788	0.139	0.214
	(0.0920)	(0.0958)	(0.105)	(0.176)	(0.216)	(0.248)
% within 15 miles of transport	0.0552	0.0626	0.0780	0.206	0.349	0.501
	(0.193)	(0.203)	(0.225)	(0.344)	(0.392)	(0.406)
log Market Access	4.356	5.727	7.468	8.333	9.183	10.02
	(4.139)	(4.102)	(3.226)	(2.869)	(2.186)	(1.427)
% Manufacturing				0.0233		0.0299
				(0.0223)		(0.0332)
% Literate						0.880
						(0.118)
% Pop in School						0.0749
						(0.0866)

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Table 1.2: Means by Year, 1850-1900

	1850	1860	1870	1880	1890	1900
Total Population	17,807	23,409	27,733	34,788	41,701	49,693
	(25,405)	(36,546)	(46,763)	(59,165)	(82,606)	(111,868)
Number of Patents	1.978	8.642	26.44	25.49	42.12	36.06
	(11.20)	(47.26)	(128.1)	(129.6)	(210.6)	(183.5)
Patent per 10K	0.440	1.851	4.455	3.420	4.640	3.602
	(1.009)	(4.254)	(6.309)	(5.052)	(6.237)	(4.329)
# NBER of Subcategories	3.255	4.389	6.834	6.220	7.271	6.265
	(3.550)	(4.308)	(5.742)	(5.595)	(6.399)	(5.934)
% Urban, 2500+	0.0428	0.0642	0.0921	0.113	0.152	0.179
	(0.136)	(0.158)	(0.178)	(0.192)	(0.215)	(0.226)
% Urban, 25K+	0.0108	0.0150	0.0216	0.0309	0.0414	0.0528
	(0.0875)	(0.101)	(0.117)	(0.139)	(0.160)	(0.179)
Pop per Square Mile	56.43	80.72	95.88	103.6	126.6	141.1
	(653.0)	(1,027)	(1,193)	(974.2)	(1,236)	(1,145)
% within 1.5 miles of transport	0.0931	0.154	0.189	0.256	0.287	0.366
	(0.111)	(0.132)	(0.143)	(0.170)	(0.171)	(0.167)
% within 5 miles of transport	0.269	0.422	0.495	0.610	0.667	0.786
	(0.265)	(0.285)	(0.284)	(0.288)	(0.268)	(0.207)
% within 15 miles of transport	0.599	0.795	0.855	0.912	0.946	0.987
	(0.392)	(0.315)	(0.260)	(0.207)	(0.151)	(0.0678)
log Market Access	10.51	11.09	11.33	11.70	11.92	12.12
	(1.278)	(1.138)	(1.117)	(0.977)	(0.886)	(0.815)
% Manufacturing	0.0193	0.0199	0.0287	0.0271	0.0370	0.0405
	(0.0303)	(0.0312)	(0.0366)	(0.0404)	(0.0477)	(0.0455)
% Acres Improved	0.399	0.443	0.474	0.528	0.572	0.582
	(0.174)	(0.197)	(0.208)	(0.217)	(0.209)	(0.200)
% Literate	0.868		0.887			
	(0.109)		(0.0907)			
% Pop in School	0.156		0.147			
	(0.0835)		(0.0842)			
% Born Out of State	0.226		0.189	0.160		
	(0.191)		(0.148)	(0.123)		
% Foreign Born	0.0522	0.0670	0.0661	0.0596	0.0599	0.0525
	(0.0869)	(0.0947)	(0.0907)	(0.0831)	(0.0859)	(0.0766)

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Local Transportation Access

Table 1.3: The Effect of Local Transportation Access on Patents per Capita, 1790-1900

VARIABLES	(1) Patents per 10K People	(2) Patents per 10K People	(3) Patents per 10K People
% within 1.5 miles of transport	3.366***		
	(0.468)		
% within 5 miles of transport		0.946***	
		(0.152)	
% within 15 miles of transport			0.179*
			(0.0984)
Years	1790-1900	1790-1900	1790-1900
Included County Controls	None	None	None
Region by Year FE	Yes	Yes	Yes
Counties	1249	1249	1249
Observations	13,237	13,237	13,237
R-squared	0.707	0.689	0.667

All specifications control for county dummies, year dummies, and pre-trends.
Robust standard errors in parentheses, standard errors clustered by county.
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Sources: Patent data as described in the text, U.S. Census Data is from Haines (2010) (county boundaries harmonized to 1840 as in Hornbeck (2010)), transportation data from Atack (2013).

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Table 1.4: The Effect of Local Transportation Access on Patents per Capita with Controls

1790-1900

VARIABLES	(1) Patents per 10K People	(2) Patents per 10K People	(3) Patents per 10K People	(4) Patents per 10K People
% within 5 miles of transport	0.946*** (0.152)	0.680*** (0.138)	0.429** (0.168)	0.393*** (0.151)
Included County Controls	None	People	Economic Activity	All
Region by Year FE	Yes	Yes	Yes	Yes
R-squared	0.689	0.772	0.732	0.786

VARIABLES	(1) Patents per 10K People	(2) Patents per 10K People	(3) Patents per 10K People	(4) Patents per 10K People	(5) Patents per 10K People	(6) Patents per 10K People
% within 5 miles of transport	0.748*** (0.149)	0.842*** (0.137)	0.648*** (0.164)	0.833*** (0.147)	0.817*** (0.164)	0.935*** (0.153)
County Controls	Manufacturing	Urban	Improved Acres	Migration	Literacy	Schooling
Region by Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Counties	1249	1249	1249	1249	1249	1249
Observations	13,237	13,237	13,237	13,237	13,237	13,237
R-squared	0.726	0.761	0.695	0.715	0.692	0.691

Robust standard errors in parentheses, standard errors clustered by county.
All specifications control for county dummies, year dummies, and pre-trends.
*** p<0.01, ** p<0.05, * p<0.1

Included controls are:

- Manufacturing (Economic Activity): the percent of the county that is employed in manufacturing
- Urban (People): the percent of the county that is urban (2,500+), metropolitan (25,000+)
- Improved Acres (Economic Activity): the percent of farm land that is improved
- Migration (People): the percent of the county that is born out of state, and foreign born
- Literacy (People): the percent of the county that is literate
- Schooling (People): the percent of the county that is in school

Each variable is include at lagged values, and interacted with time dummies. See Footnote 1

Sources: Patent data as described in the text, U.S. Census Data is from Haines (2010) (county boundaries harmonized to 1840 as in Hornbeck (2010)), transportation data from Atack (2013).

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Table 1.5: First Differences Patents per Capita and Local Transportation Access with Interactions

VARIABLES	(1) FD Pat per 10K Ppl	(2) FD Pat per 10K Ppl	(3) FD Pat per 10K Ppl	(4) FD Pat per 10K Ppl
Lag Pat per 10K Ppl	-0.344***		-0.337***	-0.484***
	(0.0551)		(0.0607)	(0.0381)
FD % within 5 miles of transport		0.611***	0.917***	0.591***
		(0.127)	(0.216)	(0.130)
Lag Pat per 10K Ppl × FD % within 5 miles			-0.216	-0.196*
			(0.179)	(0.108)
Marginal Effect of FD % 5 mi			0.562	0.269
			(0.176)	(0.162)
z-stat.			3.184	1.655
Included Controls	None	None	None	All
Counties	1249	1249	1249	1249
Observations	11,954	11,954	11,954	11,954
R-squared	0.383	0.280	0.385	0.543

VARIABLES	(1) Pat per 10K Ppl Growth Rate	(2) Pat per 10K Ppl Growth Rate	(3) Pat per 10K Ppl Growth Rate	(4) Pat per p10K Ppl Growth Rate
Lag Pat per 10K Ppl	-0.0185***		-0.0154***	-0.0263***
	(0.00341)		(0.00306)	(0.00453)
FD % within 5 miles of transport		0.110***	0.202***	0.176***
		(0.0318)	(0.0342)	(0.0347)
Lag Pat per 10K Ppl × FD % within 5 miles			-0.0892***	-0.0811***
			(0.0112)	(0.0128)
Marginal Effect of FD % 5 mi			0.0550	0.0427
			(0.0308)	(0.0312)
z-stat.			1.783	1.368
Included Controls	None	None	None	All
Counties	1249	1249	1249	1249
Observations	11,954	11,954	11,954	11,954
R-squared	0.118	0.103	0.124	0.160

Robust standard errors in parentheses, standard errors clustered by county.
*** p<0.01, ** p<0.05, * p<0.1

Included in specifications with controls are, the percent of the county that is: employed in manufacturing, urban (2,500+), metropolitan (25,000+), literate, in school, born out of state, and foreign born, as well as the percent of farm land that is improved. Each variable is include at lagged values, and interacted with time dummies.

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Table 1.6: Instrumental Variables: The Effect of Local Transportation Access on Patents per Capita, 1840-1870

VARIABLES	(1) OLS Patents per 10K People	(2) First Stage Percent Trans 5.0 Miles	(3) IV Patents per 10K People	(4) OLS Patents per 10K People	(5) First Stage Percent Trans 5.0 Miles	(6) IV Patents per 10K People
Line Instrument		0.0471***			0.0259***	
		(0.00882)			(0.00875)	
% within 5 miles of transport	2.655***		7.391**	0.374		7.183
	(0.446)		(3.138)	(0.450)		(5.085)
log Total Pop				-0.585	0.00378	-0.599
				(0.779)	(0.00784)	(0.674)
Wald Stat.			38.12			11.77
Years	1840-1870	1840-1870	1840-1870	1840-1870	1840-1870	1840-1870
Included County Controls	None	None	None	All	All	All
Region by Year FE	No	No	No	No	No	No
Counties	1229	1229	1229	1229	1229	1229
Observations	4,912	4,912	4,912	4,912	4,912	4,912
R-squared	0.627	0.860	0.372	0.742	0.877	-0.101

All specifications control for county dummies, year dummies, and pre-trends.
Robust standard errors in parentheses, standard errors clustered by county.
*** p<0.01, ** p<0.05, * p<0.1

Included in specifications with controls are, the percent of the county that is: employed in manufacturing, urban (2,500+), metropolitan (25,000+), literate, in school, born out of state, and foreign born, as well as the percent of farm land that is improved. Each variable is include at lagged values, and interacted with time dummies. See Footnote 1

Sources: Patent data as described in the text, U.S. Census Data is from Haines (2010) (county boundaries harmonized to 1840 as in Hornbeck (2010)), transportation data from Atack (2013).

Because the variation in the instrument is in the years 1850 through 1870 this table restricts the sample to 1840-1870. Tables showing the full sample are available upon request or on my website.

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Market Access

Table 1.7: The Effect of Market Access on Patents per Capita with Controls, 1790-1900

VARIABLES	(1) Patents per 10K People	(2) Patents per 10K People	(3) Patents per 10K People	(4) Patents per 10K People
log Market Access	0.137	0.210***	-0.0590	0.0264
	(0.101)	(0.0652)	(0.0797)	(0.0695)
log Total Pop	0.303***	-0.246**	0.305***	-0.0272
	(0.114)	(0.123)	(0.0989)	(0.0895)
Included Controls	None	People	Economic Activity	All
Region by Year FE	Yes	Yes	Yes	Yes
R-squared	0.673	0.773	0.732	0.787

VARIABLES	(1) Patents per 10K People	(2) Patents per 10K People	(3) Patents per 10K People	(4) Patents per 10K People	(5) Patents per 10K People	(6) Patents per 10K People
log Market Access	0.139*	0.226***	-0.115	0.299***	0.0915	0.133
	(0.0799)	(0.0663)	(0.0928)	(0.105)	(0.108)	(0.110)
log Total Pop	0.0807	-0.137	0.598***	-0.229	0.343***	0.326***
	(0.106)	(0.0896)	(0.110)	(0.142)	(0.116)	(0.115)
County Controls	Manufacturing	Urban	Improved Acres	Migration	Literacy	Schooling
Region by Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Counties	1249	1249	1249	1249	1249	1249
Observations	13,237	13,237	13,237	13,237	13,237	13,237
R-squared	0.722	0.761	0.685	0.705	0.676	0.675

Robust standard errors in parentheses, standard errors clustered by county.
All specifications control for county dummies, year dummies, and pre-trends.
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Included controls are:

- Manufacturing (Economic Activity): the percent of the county that is employed in manufacturing
- Urban (People): the percent of the county that is urban (2,500+), metropolitan (25,000+)
- Improved Acres (Economic Activity): the percent of farm land that is improved
- Migration (People): the percent of the county that is born out of state, and foreign born
- Literacy (People): the percent of the county that is literate
- Schooling (People): the percent of the county that is in school

Each variable is include at lagged values, and interacted with time dummies. See Footnote 1

Sources: Patent data as described in the text, U.S. Census Data is from Haines (2010) (county boundaries harmonized to 1840 as in Hornbeck (2010)), transportation data from Atack (2013).

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Table 1.8: The Effect of Market Access and Local Transportation Access on Patents per Capita, 1790-1900

VARIABLES	(1) Patents per 10K People	(2) Patents per 10K People	(3) Patents per 10K People	(4) Patents per 10K People	(5) Patents per 10K People	(6) Patents per 10K People
log Market Access		0.137	-0.0391		0.0264	-0.0118
		(0.101)	(0.0804)		(0.0695)	(0.0636)
% within 5 miles of transportation	0.865***		0.746***	0.391***		0.389**
	(0.149)		(0.164)	(0.143)		(0.151)
log Total Pop	0.354***	0.303***	0.349***	0.00957	-0.0272	-0.00174
	(0.0751)	(0.114)	(0.118)	(0.0800)	(0.0895)	(0.0917)
Years	1790-1900	1790-1900	1790-1900	1790-1900	1790-1900	1790-1900
Included County Controls	None	None	None	All	All	All
Region by Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Counties	1249	1249	1249	1249	1249	1249
Observations	13,237	13,237	13,237	13,237	13,237	13,237
R-squared	0.692	0.673	0.699	0.786	0.787	0.789

All specifications control for county dummies, year dummies, and pre-trends.
Robust standard errors in parentheses, standard errors clustered by county.
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Included in specifications with controls are, the percent of the county that is: employed in manufacturing, urban (2,500+), metropolitan (25,000+), literate, in school, born out of state, and foreign born, as well as the percent of farm land that is improved. Each variable is include at lagged values, and interacted with time dummies. See Footnote 1

Sources: Patent data as described in the text, U.S. Census Data is from Haines (2010) (county boundaries harmonized to 1840 as in Hornbeck (2010)), transportation data from Atack (2013).

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Instrumented market access available upon request or on my website.

Table 1.9: First Differences Patents per Capita and Market Access with Interactions

VARIABLES	(1) FD Pat per 10K Ppl	(2) FD Pat per 10K Ppl	(3) FD Pat per 10K Ppl	(4) FD Pat per 10K Ppl
Lag Pat per 10K Ppl	-0.314***		-0.291***	-0.460***
	(0.0562)		(0.0658)	(0.0382)
FD log Market Access		-0.0191	0.136	0.0375
		(0.0805)	(0.0880)	(0.0613)
Lag Pat per 10K Ppl × FD log Market Access			-0.0810 (0.0702)	-0.0968*** (0.0276)
Marginal Effect of FD			0.00292	-0.122
			(0.0834)	(0.0629)
z-stat.			0.0350	-1.934
Included Controls	None	None	None	All
Counties	1249	1249	1249	1249
Observations	11,954	11,954	11,954	11,954
R-squared	0.367	0.274	0.369	0.544

VARIABLES	(1) Pat per 10K Ppl Growth Rate	(2) Pat per 10K Ppl Growth Rate	(3) Pat per 10K Ppl Growth Rate	(4) Pat per p10K Ppl Growth Rate
Lag Pat per 10K Ppl	-0.0170***		-0.0141***	-0.0265***
	(0.00328)		(0.00328)	(0.00472)
FD log Market Access		0.0287***	0.0418***	0.0297***
		(0.00789)	(0.00802)	(0.00858)
Lag Pat per 10K Ppl × FD log Market Access			-0.0113*** (0.00415)	-0.0106* (0.00602)
Marginal Effect of FD			0.0233	0.0122
			(0.00877)	(0.0108)
z-stat			2.654	1.133
Included Controls	None	None	None	All
Counties	1249	1249	1249	1249
Observations	11,954	11,954	11,954	11,954
R-squared	0.124	0.110	0.127	0.161

Robust standard errors in parentheses, standard errors clustered by county.
*** p<0.01, ** p<0.05, * p<0.1

Included in specifications with controls are, the percent of the county that is: employed in manufacturing, urban (2,500+), metropolitan (25,000+), literate, in school, born out of state, and foreign born, as well as the percent of farm land that is improved. Each variable is include at lagged values, and interacted with time dummies.

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Chapter 2

Dense Enough To Be Brilliant: Patents, Urbanization, and Transportation in Nineteenth Century America
Part 2: Investigating Changes in Information Absorption and Distribution using Automated Text Analysis

"Research in the Patent Office records is often frustrating because one comes in expecting invention and finds property, because one seeks evidences of intellectual breakthroughs and usually finds the bric-a-brac of our industrial society."

~ Reingold (1960)

2.1 Introduction

The previous chapter demonstrated the link between the spread of transportation and decreasing concentration of patenting. However, this analysis explicitly ignored the content of these patents. Not every patent represents the same contribution to the movement of the technology frontier, and some patents represent a more important innovative contribution than others.[1] Using a pure count variable (as the previous chapter did) implicitly assumes that each patent is equivalent. This chapter focuses on the text of patent grants as its basic object of study, again asking how the spatial

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[1] While people have addressed this in a number of ways when working with modern patents, the most popular way is to use patent citations. However, patents did not start citing each other until the twentieth century.

distribution of innovation changed in response to the growing transportation network, but using the content of the patent grant provides for a more nuanced study of the innovations patents represent.

In addition to moving goods, transportation facilitates greater communication between areas. All forms of transportation studied here also moved passengers, allowing for easier, faster, and shorter trips between locations.[2] This greater exchange of ideas may change where innovation occurs by helping more areas learn about new technologies.[3] Several studies have examined access to a different communication medium, the internet, on the location of innovation, finding that "diffusion of the internet worked against the trend toward increasing geographic concentration of inventive activity" (Forman et al., 2014), and that an increase in communication seemed to allow for greater task specialization (Agrawal and Goldfarb, 2008). Investigating transportation technologies with the movement of people in mind, Agrawal et al. (2014) examines the effect of highways on patenting. Agrawal et al. (2014) find that not only does increased highway access increase patenting in an area, but it also increases those patents' propensity to cite patents whose inventors are located further away in the same region. These studies suggest that changes in information movement can change the location of innovation.

As automated text analysis tools have become available, economists have followed the examples set by political scientists and started to make use of these tools.[4] For

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[2] Any landing along a canal or a railroad stop was also a place where mail was exchanged.The United States had a very developed mail system early in its history; providing for the mail is one of the responsibilities laid out for the federal government in the Constitution. Mail service was very adaptive, taking early advantage of new modes of transportation.

[3] There is abundant evidence that location matters for innovative activity; see Feldman and Kogler (2010) for a recent survey. One explanation for this importance is that proximity facilitates the exchange of ideas and tacit knowledge (Jaffe et al., 1993; Audretsch and Feldman, 2004). However, there are many other reasons why location might matter for innovation, including credit access, access to skilled labor, or access to knowledge that resists easy diffusion.

[4] It is no longer feasible to cite every paper in economics that is using automated text analysis, as it was just a few years ago when I started this project.

instance, a recent paper searched for the phrases like “a method for” in order to classify patents as process rather than product patents (Bena and Simintzi, 2016). Other papers have made the text itself the object of study. Wang et al. (2012) looks for language shifts in slavery-related court cases in the United States before 1866, which allows them see shifts in precedent. Using modern patents, Goldschlag (2015) looks for evidence that patents help promote diffusion by searching future patents and scientific articles for text that is substantially similar to the language used in the patent. This technique is tested with scientific articles that are known to be influential. No evidence of technology transmission is found. In a case of simultaneous invention, Packalen and Bhattacharya (2012, 2015b,a) examine the correlates of new n-grams (words) in patents.

Outside the field of economics, automated analysis of patents has also been a popular subject of study, often with the objective of identifying current important inventions or prior art (Abbas et al., 2014; Balsmeier et al., 2015; Gerken and Moehrle, 2012; Tseng et al., 2007). Other previous work with patent text has focused on very limited samples, as these are what it is feasible to read. For example, Farrell-Beck (1992) looks at inventions relating to garment manufacture, Israel and Rosenberg (1991) at the inventions of Thomas Edison, and Risch (2012) employs a team of assistants to read every existent patent issued before the examination system was implemented in 1836 as well as a few years after the examination system is in place.

To investigate the importance of information about new technologies, I use the text of patents as documentation of the movement of idea-use over time and space. I construct a measure of how many new words, from a list of words relating to new technologies, appear in the patent record of any given county. If in a particular county one of these words is observed one year after it is first used in a patent anywhere, then this county is measured as receiving new words at the rate of one new word a year. This measures the use of new technologies in patents originating from a county, telling us how quickly novel technologies become present in inventors' work. In contrast to the strong relationship between local transportation access and patents per capita, increases in local transportation access seem to have no effect on the novelty of innovation (a measure of quality).

To understand this pattern in more detail, I examine a sample of patents in newly-connected counties. This examination suggests that newly connected places patented objects related to local industry, such as machines to help with the production of cotton or grain. Then, patents related to the railroad itself—couplers and, in the north, ways to clear snow from the tracks started to appear. Following urbanization, newly connected places began patenting middle class consumption goods, such as medicine and furniture. This suggests that patenting is driven by concerns that are locally salient, rather than more general problems on the technological frontier.

Because of this local aspect of patenting, I also examine the diversity of ideas in a location. I compute the number of unique words used in the patents in a county. If all patents in a county are on the same topic, the patents from this county are likely to use a smaller number of words than a county with a diversity of topics. As Fiszbein (2016) shows, diversity of technological know-how is likely to improve the future growth prospects of a location.

Counterfactual distributions of patents were computed by fixing the number of patents per county and from the pool of patents issued in the year under consideration randomly drawing that number of patents. This group of patents is then considered a synthetic county. The actual distribution of patents contains counties that, for every size, use fewer unique words and have a slower speed of word arrival. This is increasingly so over time. The diversity of words used in country increases overtime, but the within county diversity does not increase as quickly.

The spread of transportation does not have a uniform effect on counties' speed of mentioning new technologies. There is no net overall effect of increased local transportation access, while increasing market access increases the speed of mentioning new technologies more for more developed places. The net effect of the expansion of the transportation network is this increase of advantage of more developed places. However, the level of participation in the patent system increases in every location impacted by the spread of the transportation network.

2.2 Data

The text of each patent contains a great deal of information about the contribution the patent represents. Automated text analysis allows access to this information (in the approximately 700,000 patents issued 1836-1900), and in this chapter I assign counties a score based on how soon their patents mention new technologies. In addition, I explore the heterogeneity in a county's patents through the number of unique words used in that county.

As described in the previous chapter, I geolocated pre-1836 patents, while the location of patents after 1836 was taken from the data constructed by Akcigit et al. (2013). Transportation data are from Atack (2013). Contemporaneous county boundaries, harmonized to 1840 boundaries as suggested in Hornbeck (2010), are used.[5] United States Census data are from Haines (2010).

The text of patents is taken from two sources, Westlaw and Google, both of which used optical character recognition (OCR) on images of typeset patents (post-1836 patents) to create machine readable text. I then associate this text with the patent's location. Further analysis is done in Python with NLTK and scikit-learn.

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[5] More details on this computation available upon request or in the boundary shifting files on my website.

My primary object of study is the speed at which new words (1-grams) or two-word phrases (2-grams), here collectively referred to as n-grams, move through the patent record. If in a particular county a single n-gram appears one year after it is first used in a patent anywhere, then this county is measured as receiving new words at the rate of one new word a year.

2.2.1 Computing of the Speed of Word Arrival

To compute the speed at which words arrive in a county, I start at the beginning of the existent record (1836), and find the first appearance of an n-gram anywhere in the record as well as its first appearance in every county. The number of years between the first appearance of an n-gram anywhere and the n-gram's first appearance in a county, referred to as the time lag, is a measure of how long it takes a new concept to be used in an innovation in any one place. For example, Figure 2·1 shows the counties in which the word "vulcanized"[6] appeared by 1850, 1860, and 1880. The word spreads from locations that are recognizable centers of innovation to counties that are dispersed across the country.

To save on computation and have my measure more accurately reflect technological innovation, I do not use every word that has appeared in the patent record, but rather a list of about 4,000 n-grams that was generated by a) looking for n-grams that did not appear early on but were common later, b) selecting n-grams that are key to important patents of the nineteenth century as found in Brown (1994); United States Patent and Trademark Office (1981); van Dulken (2001) both by hand and algorithmically, and c) finding synonyms of the concepts from the important patents

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[6] The vulcanization of rubber was patented in the US–though not in Britain, where it was patented by someone else in what appears to be case of simultaneous invention–by Charles Goodyear in 1844 (US Patent No. 3,633) from New York, NY. This patent did not use the term vulcanized, however an 1848 patent by Charles Goodyear (moved to New Haven, CT) did, as did two other patents, from New York, NY and Worcester, MA, in that year.

in the Oxford English Dictionary's Historical Thesaurus. The word list is available upon request or can be found on my website.[7]

In a given year, for each county I find the number of n-grams that made their first appearance in that county in that year. I then compute a speed of word arrival for that county-year as:

$$Speed_{it} = \sum_{T=0}^{N} \frac{\text{Number of New Words}_{itT}}{(T+1)} \tag{2.1}$$

where N is the number of years of time lag used in the computation (e.g., 10 years), Number of New Words$_{itT}$ is the number of n-grams observed in county i in year t with time lag T[8] (e.g., 3 n-grams first appear in New York, NY, in 1850 with a time lag of 6 years).[9]

Figure 2·2 shows a map of each county in 1850 and 1870 computed with $N = 10$, the zeros seen in these figures are places that had only patents that did not use any n-grams that were new to the patent record in the last ten years. Because both patents and new word appearances are rare, I have used three year bins for the analysis in this chapter.[10] Further, to compensate for the general downward trend of this statistic over time I have expressed speeds as a ratio. Speeds are always values between zero and one: the computed speed for the county over the largest speed computed for that year. Of particular note is the large increase in patenting between 1850 and 1870, and that the vast majority of those counties are not ones that use words that were new in the past ten years. The highest speed counties seem to be more concentrated

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[7] Address: *http://people.bu.edu/perlmane/code/wordsForCountySpeed.csv.*

[8] I use $T + 1$ as the denominator of the above sum so that I never divide by zero.

[9] They are: gasometer, plastic, and printing plate.

[10] Thus, $Speed_{i1850}$ is taken to mean $Speed_{i1849} + Speed_{i1850} + Speed_{i1851}$.

in 1870, clustered near areas of high population, with fewer high speed counties along corridors such as the Erie Canal.

This paper uses the ratio of three year bins as described above with both $N = 10$ and all years. The latter means that there is no fixed number of years after which a word is no longer considered new,[11] however I count all words that appear before 1842 as "old" words. The mean of these speeds for each year can be found in Tables 2.1 and 2.2

2.2.2 Constructing Synthetic Counties

To test the importance the content of the patents in a county, rather than the sheer number of patents, I construct counterfactual distributions of patents where the number of patents in a county is held fixed, but the patents a randomly chosen. To construct a counterfactual distribution I count the number of patents issued by a county, and then randomly draw that number of patents from the pool of patents issued in the three year period under consideration. I refer to this group of randomly drawn patents as the patents in a synthetic county. This process of creating a simulated distribution was repeated forty times, so that there are at least forty observations for every existent county size, year combination.

The degree to which the speed of word arrival is driven by the number of patents produced by a count are explored in Figures 2·3 and 2·4. Figure 2·3 presents histograms of the speed (with N=100) computed in these randomly drawn counties and observed counties in a year, by the number of patents in these counties. The first

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[11] This means the maximum time lag possible depends on the year the statistic is computed for, as the data start in 1836 and I consider words that appeared before 1842 as "old", the maximum time lag the data allow for words appearing in a county in 1850 is 8 years, and in 1860 is 18 years.

column shows counties with only one patent; in 1850 it appears that these two distributions are the same, but in 1880 the real data are completely missing observations in the right tail. Similarly, the 1880 distributions for the speed of word arrival in counties with between 9 and 11 patents or between 99 and 104 patents seem to be missing faster observations. One cannot reject the null, using the Kolmogorov-Smirnov test, that the distribution of speeds of randomly drawn counties with one patent is the same for 1850. However, for 1880 the Kolmogorov-Smirnov test rejects the null at the level 3%, suggesting that patents from real counties contain fewer new words than randomly drawn patents from that year. For next two columns, the pattern is the same: the null cannot be rejected in 1850, but is rejected at the 1% level in 1880.

The full relationship between the number of patents and the speed of word arrival in a county is examined in Figure 2·4. The blue area represents to 25th to 75th percentile range of speeds for counties with a given number of patents; the red area repents the same for randomly drawn counties. In 1850 the distribution of speeds for real and constructed counties appears the same, whereas in 1880 the distribution of real counties appears slower than the distribution of randomly drawn counties. Again, using the Kolmogorov-Smirnov test, one cannot reject the null in 1850, but can reject it at above the 1% level in 1880. Table 2.3 shows the P-Values for every year, the real distribution and the simulated one become more disparate as the nineteenth century progresses.

2.3 The Number of Unique Words

A more general way of examining the content of the patents in a county is to look for diversity in content, as measured by the number of unique words used in that county. Figure 2·5 plots the number of unique words used in all patents issued as well as the number of patents issued each year. The first panel shows this at a yearly frequency, while the second shows three year bins once every ten years. While these series of patent counts and word counts are highly correlated, they are not perfectly so. At the onset of the Civil War, the number of patents declines faster than the number of unique words, and the volatility in the 1880s is not reflected in the word count.

The plots in Figure 2·6 show the median, 25th percentile, and 75th percentile number of unique words in 10, 50, and 100 patents drawn 100 times. This explores the diversity in words used in patents, holding the number of patents fixed. Notice that the number of unique words in any fixed quantity of patents increases during the civil war, and seems to rise steadily after 1866. This steady rise is in strong contrast to the variability in the number of patents issued over this period.

As the lines in Figure 2·6 appear to be strongly associated, I investigate the relationship between the number of patents and the number of unique words. Table 2.4 shows

$$\log \text{Number of Unique Words}_i = \alpha + \beta \log \text{Number of Patents}_i + \varepsilon_i \tag{2.2}$$

for three year bins, every ten years.[12] This regression uses the data underlining the third panel of Figure 2·6, the second panel of Figure 2·5, as well as draws of 10, 500, and 1,000 patents. In later years each patent is estimated to add a greater number of unique words, but the first patent is estimated to contain slightly fewer words.

---

[12] The natural logarithm is used.

Figure 2·7 maps the number of unique words in the patents issued by a county. The left two panels show pure word counts, while the right two normalize for the number of patents issued in the county. This normalization is done by subtracting the predicted mean and dividing by the counterfeiter standard deviation. The number of words for a given number of patents is predicted from Table 2.4, and the standard deviation is taken from the number of unique words observed when drawing that number of patents many times.[13] Note that negative numbers dominate this map, indeed the mean and median are negative in every year, and decrease over time.[14] In particular, as shown in Figure 2·8, the relationship between the normalized number of words in a county and the number of patents in that county starts off fairly flat in 1840 but becomes more negative as time goes on. This suggests that individual counties are more homogeneous than the country as a whole, and the more patents a county contains the more scope there is for this deliverance to been identified.

The words used in patents become more diverse over time, however, individual counties do not by and large increase their word-diversity as quickly.

2.4 Speed of Word Arrival and Transportation

2.4.1 Local Transportation Access

Improved transportation did not only have the effect of decreasing freight rates, but decreased the cost and increased the speed of individual travel and the movement of the mail. A local connection to transportation may, therefore, increase a county's access to innovative ideas. The increase in patenting observed above may be because

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[13] As discussed in Section 2.2.2, for any given year I draw a selection of patents equal to the number of patents in that county. Since there are many counties with two patents, a group of two patents is drawn many more times than a group of 44 patents. This process was repeated 40 times.

[14] Even when using a more flexible specification in which I calculate the mean number of words for every number of patents observed.

people are learning about things near the technology frontier more quickly (see Appendix A.4 for a simple framework to motivate this). As noted previously, I cannot observe the movement of ideas directly, but the text of patent grants contain a great deal of information about the innovation in question, and I can observe the words inventors use to discuss their technologies.

The second use of a new word (or two word n-gram) in the patent records suggests that the inventor authoring the patent that contains this word is part of an information network that transmitted knowledge of this new concept. I can glean some understanding of how ideas move by looking at where and when words appear in the patent record. I have constructed a measure how many new words are appear in the patent record of any given county; if in a particular county one new word appears in one year after it is first used, than this county is measured to receive new words at the rate of one new word a year. This measure of the speed of word arrival is discussed in more detail in Section 2.2.1.

Starting the analysis of the relationship between transportation access and the speed of word arrival, I examine the point estimates on the dummy variables for the number of years to the arrival of the canal or railroad in a county from a regression of:

$$Speed_{it} = \alpha + \beta \mathbf{YearstoArrivalDummies_{it}} + \gamma_i + \delta_t + \varepsilon \tag{2.3}$$

where $Speed_{it}$ is the speed of word arrival measure used, $\mathbf{YearstoArrivalDummies_{it}}$ are dummy variables for the number of years until a county, i, receives a railroad (as above), γ_i are county fixed effects, and δ_t are year fixed effects; standard errors are clustered at the county level. When examining railroad, I denote the year I first observe a railroad year zero, ten years before that year -10 and ten years after I first observe a railroad year 10 and so on.

Figure 2·9 plots the coefficients from the regression described in Equation 2.3, with two measures of speed used as the dependent variable. One measure only considers words new if they appeared in the last ten years ($N = 10$),[15] while the other considers words new if they appeared any time after 1842 (the record of patent text starts in 1836). Note that including the counties that do not patent as counties observed with a speed of zero changes the precision of the estimate, but does not meaningfully change the point estimate. There appears to be no relationship between the speed of word arrival when $N = 10$, but there seems to be a positive change in the slope when there is no cut off for when a word is considered new. However, as will be discussed below, this positive slope reflects the increasing number of patents in the county due to the railroad, rather than the content of these patents.

My main specification is:

$$\begin{aligned} PatentMeasure_{it} = \alpha + \beta TransportMeasure_{it} + \varphi \mathbf{X_{i(t-1)}} + \gamma_i + \delta_t \\ + Region_i \times \delta_t + T.M._{i(t-N)} \times \delta_t + \varepsilon \end{aligned} \tag{2.4}$$

where $PatentMeasure_{it}$ is the measure of patenting at the county level (here the speed of word arrival), $TransportMeasure_{it}$ (abbreviated $T.M._{it}$) is the specified measure of transportation access, $\mathbf{X_{it}}$ are county level controls,[16] γ_i are county fixed effects, δ_t are year fixed effects, and $Region_i$ are fixed effects at the nine-region level;

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[15] This means there is no overlap in the words used between consecutive observations.

[16] Controls that may be included (when noted) are the percent of the county that is: employed in manufacturing, urban (2,500+), metropolitan (25,000+), literate, in school, born out of state, and foreign born, as well as the percent of farm land that is improved. Each variable is include at lagged values, and interacted with time dummies. More precisely, a variable that is observed in year t takes on the value zero before year $t+1$, and takes on its value in year t for all years following year $t+1$. This variable is interacted with year dummies. This is a more complete way of controlling for observables since many of these variables are only observed for some census years, and often those years are non-consecutive.

$t - N$ denotes the use of all previously observed values. Local transportation access is measured as the percent of a county's land area that is within five miles of some form of improved transportation (railroads, canals, steam navigable rivers, or ports). This is a a fixed effect specification with pre-trends in transportation access, region by year fixed effects, and year and county fixed effects.

Table 2.5 shows estimates from this specification, using speed of word arrival computed with only words that were new in the previous ten years and also with speed computed with all years after 1842. The second panel examines the relationship between the number of patents and the observed speed by controlling for the mean speed of a collection of randomly drawn patents from that year equal size to the observed county. There does not appear to be a statistically significant relationship between local transportation access and the speed at which words arrive in a county. Note that population is strongly related to the speed of word arrival in the first panel, but the inclusion of mean synthetic speed (or number of patents, not reported here)[17] absorbs this relationship.

Speed of word arrival is influenced by the content of patents, however, each additional patent represents gives counties a greater chance of mentioning a new technologies. If the data generating process is purely random draws of words from a pool of words, there is a positive probability of drawing a word that is new on every draw. Thus, having more draws will lead to more new words. With this data generating process patent counts would be a sufficient statistic for the speed with which new words arrive. I try to disentangle what aspect of the computed speed of word arrival is the number of patents (draws), rather than the content of theses patents by

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[17] Population and number of patents are very strongly correlated.

computing counterfactual relationships produced through random selection.

Figure 2·10 plots histograms of coefficients computed for counterfactual data. Each of the forty observations is derived from a set of synthetic counties, counties with the observed number of patents, but with each of these patents being a random draw from the year in question (see section 2.2.2). The first panel uses speed of word arrival computed with words new in the last ten years, plots the coefficients from the regression from the first column of Table 2.5, the panel directly below it corresponds to column (5) of Table 2.5. The two adjacent panels correspond to columns (2) and (6) respectively. While none of the coefficients from the actual distribution of patents are strongly outside the distribution of counterfactual coefficients, they are all clearly on the bottom end of the distribution. This suggests, as do Figures 2·3 and 2·4, that the patents in the counties with increasing levels of transportation (which will, in general, be on the periphery) refer to technology that is older than the technology discussed in randomly selected patents.

To examine the relationship between spreading transportation and the concentration of ideas, Table 2.6 replicates the specifications used to examine the effect of the spread of the internet in Forman et al. (2014). This is a first differences specification with pre-trends in transportation access, region by year fixed effects, and year fixed effects:

$$\begin{aligned} \Delta PatentMeasure_{it} = \alpha + \beta PatentMeasure_{i(t-1)} + \varphi \Delta TransportMeasure_{it} \\ + \zeta \Delta T.M._{it} \times P.M._{i(t-1)} + \eta \mathbf{X_{i(t-1)}} + \delta_t + Region_i \times \delta_t + T.M._{i(t-N)} \times \delta_t + \varepsilon \end{aligned} \tag{2.5}$$

where, as above, $PatentMeasure_{it}$ is the measure of patenting at the county level, $TransportMeasure_{it}$ (abbreviated $T.M._{it}$) is the specified measure of transportation access, $\mathbf{X_{it}}$ are county level controls, δ_t are year fixed effects, and $Region_i$ are fixed effects at the nine-region level; $t-N$ denotes the use of all previously observed values.

The first column of Table 2.6 explores the relationship between the speed of word arrival observed in a county in year $t-1$ on the change in speed between year $t-1$ and year t. In general, the faster a county is in $t-1$, the less the speed will increase–given that speeds are always between zero and one, and tend to be near the low end of that range, a coefficient of -0.29 is substantial. If a county increases its speed by 0.01 (the mean speed in 1850) it will move from the 50th percentile of change in speed to the 5th percentile. Column (2) shows the first difference of the percent of a county within five miles of improved transportation, as one would expect from Table 2.5, there is no strong relationship for speed computed with 10 years. Speed computed with all years does have a positive relationship.

The last two columns add the interaction between the lagged level of the speed of word arrival and the first difference of local transportation access. The negative relationship between lagged level of the speed of word arrival and the increase in speed remains, but the relationship between the first difference of local transportation access and the increase in speed changes. The main effect of increased transportation access is positive, and remains even after adding all county level controls. This is countered by a negative coefficient on the interaction term, so that when the marginal effect of the first difference of local transportation is computed there seems to be no relationship between the change in speed and the change in transportation access. Furthermore, the negative coefficient on this interaction suggests that transportation is helping to dampen the relationship between being fast in $t-1$ and being fast in t. Thus, increasing transportation works against increased clustering of fast places.[18]

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[18] The most developed places are unlikely to increase their transportation access as I have defined it–they start the 1850s with the majority of their counties near transportation. The group of counties with no change in transportation between 1850 and 1860 is less urban than the overall sample, but with a larger standard deviation.

To check the degree these relationships are driven by the number of patents in a county, Table 2.7 adds the mean speed of synthetic counties with the same number of patents as the factual counties. The negative relationship between speed in $t-1$ and change in speed increases, suggesting that when counties are faster than their number of patents would predict they revert to the mean. This term decreases the main effect of the change in local transportation access in the top panel, but otherwise the results from the above remain. There is no overall effect of increasing transportation on the speed of word arrival, but the counties that are the slowest at mentioning new technologies gain the most from increasing their transportation access.

2.4.2 Market Access

The hypothesis that inspired the first chapter (and Sokoloff (1988)) was that increased market access leads to more people being willing to invest in innovation. Local transportation access is correlated with market access, but it is by no means the only factor in determining market access. Thus, Table 2.8 uses estimated market access as the transportation variable of interest in Equation 2.4.[19] Market access is associated with faster counties, this association is stronger when speed is computed using only ten years worth of words. Adding in the mean on synthetic counties increases the estimate of the relationship between market access and speed for speed using all years, but decreases it for speed using only words that are new in the last ten years. Overall, there seems to be a small positive relationship between increased market access and the speed of word arrival in a county. In other analysis I find that this appears only in more developed counties, suggesting that increase market access primarily improves the speed of new technologies being mentioned for these more developed counties.

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[19] See the previous chapter for details of the market access estimation.

Tables 2.9 and 2.10 reinforce this result. The main effect of the speed of word arrival in $t-1$ on the change in speed is, again, found to be negative. The overall effect of change in market access, in contrast to change in local transportation, is now positive, as are the main effect and the interaction. That the interaction is positive suggests that increased market access helps concentrate previous advantages. Table 2.10 shows that these results remain after controlling for mean synthetic speed.

To explore the heterogeneous effects on different counties, Figure 2·11 plots the difference between two sets of predicted values of the speed of word arrival. Both are created using the specification described in Equation 2.5, however, both local transportation and market access and their interactions with previous speed are included. The first set of predicted values uses the observed 1870 values of all covariates; the second replaces the local transportation and market access values with their 1850 values. Figure 2·11 allows for the comparison of the predicted impact of the negative coefficient on the interaction between previous speed and the change in local transportation and the positive coefficient on the interaction between previous speed and the change in market access. On net, the specification from Equation 2.5 predicts that less populous places have fewer new words arrive once they are connected to transportation, but that more populous places benefit from the increase in their market access due to expansions of the transportation network.

While increasing local transportation access helps make the locations that mention new technologies quickly more diffuse, increasing access to markets increases the speed of word arrival to those at the center of the network.

2.5 The Number of Unique Words and Transportation

There is a positive relationship between the number of unique words in a county and the speed of word arrival in that county. This remains (and is statistically significant) even after controlling for the mean number of words and the mean speed predicted for that number of patents in that year. However, diversity of technologies may also be an advantage apart from the speed at which new innovations have been incorporated today; it may help a place adapt to new technologies. This section explores the relationship between the number of unique words used in a county and transportation access.

Tables 2.11 and 2.12 show results using the fixed effect specification detailed in Equation 2.4. Table 2.11 uses the percent of a county's land area that is within five miles of improved transportation as the transportation measure of interest. There is a positive relationship between local transportation access and the number of unique words used, even after including all the controls. However, the mean number of words predicted by the number of patents in that county and the year is so strongly correlated with the observed values, it leaves very little room for other variation. Table 2.12 also shows this pattern: market access is predicts more unique words, even after adding controls, but the mean number of words predicted dominates all other variation.

The next two tables, Tables 2.13 and 2.14, present the results of the first differences specification described in Equation 2.5. When not controlling for the mean predicted number of word, the overall tendency is for places with more words in $t-1$ to have smaller increases. Increasing local transportation access increases the change in word diversity, and also decreases centralization. When controlling for the mean predicted number of words only the positive relationship between transportation and increase in number of words remains. Unlike its relationship with the speed of word arrival, market access has a qualitatively similar relationship with number or unique words as local transportation access. The main effect of increasing market access is positive, and the interaction between it and the number of words is weakly negative. Both increasing local access and increasing the size of the network increases word diversity.

2.6 Conclusion

This chapter explores the textual content of patents issued between 1836 and 1892 using automated text analysis. These automated tools allow corpora that are prohibitively large for a research to read to be used in econometric analysis. This chapter presented two measures: the speed at which words referring to new technologies arrive in the county, and the number of unique words used in a county's patents. Both measures capture different aspects of the content of patents issued in a county.

As part of the exploration of these measures, counterfactual distributions of patents were computed by creating synthetic counties through fixing the number of patents per county and randomly drawing that number of patents from the pool of patents issued in the year under consideration. The actual distribution of patents contains counties that, for every size, use fewer unique words and have a slower speed of word arrival. This is increasingly so over time. The diversity of words used in country increases overtime, but the within county diversity does not increase as quickly.

The spread of transportation does not have a uniform effect on counties' speed of mentioning new technologies. Overall, there appears to be no relationship between increases in local transportation access and changes in word arrival speed. However, when an interaction between the speed and transportation improvement is added, transportation is found to decrease the advantage of fast counties, while having a positive main effect. In contrast, changes in market access increase the advantage of faster counties. These opposite effects are such that the dominant one is not immediately clear, even when both measures are included in the regress both retain their precisely estimated non-zero coefficients. In 1860 and 1880 for the average county with less than 20 percent of the population living in an urban area, and for the average county with more than 80 percent of its population living in an urban area, the predicted positive contribution of change in market access is greater than the predicted negative contribution of change in local transportation access. However, the predicted positive contribution of change in market access is proportionally greater for the more urban counties—these counties predicted change in speed increased by 30 percent after both marginal effects are taken into account. In the less urban counties the predicted change in speed increased by 20 percent from a very small, negative, baseline.

The net effect of the expansion of the transportation network is to increase the advantage of more developed places in terms of the content of their innovations, but to increase the general level of participation in the patent system in every impacted location.

2.7 Figures and Tables

2.7.1 Figures

Speed of Word Arrival

Figure 2·1: Counties in Which the Word Vulcanized Appeared

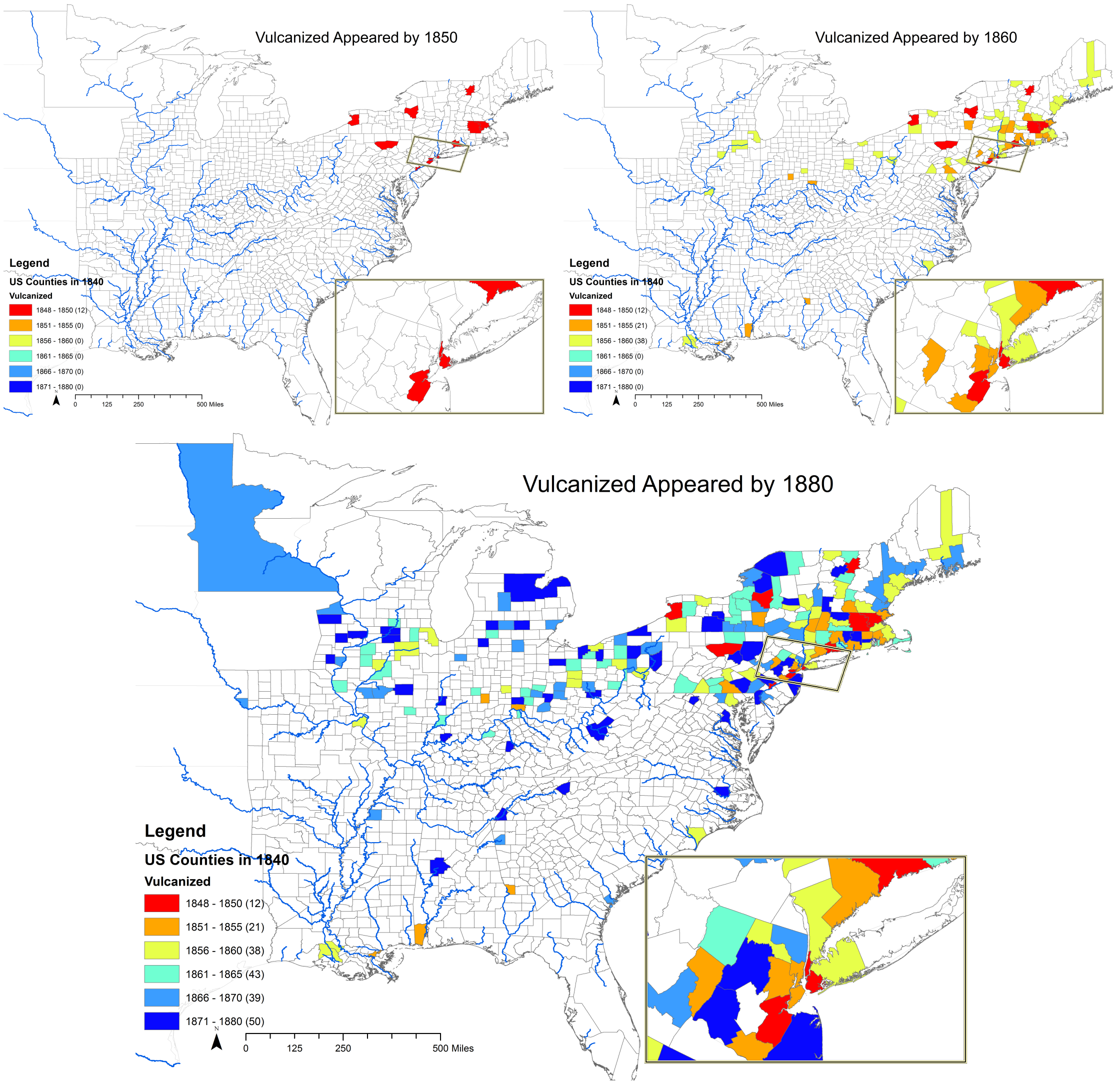

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Figure 2·2: The Speed of New Word Arrival in a County's Patents

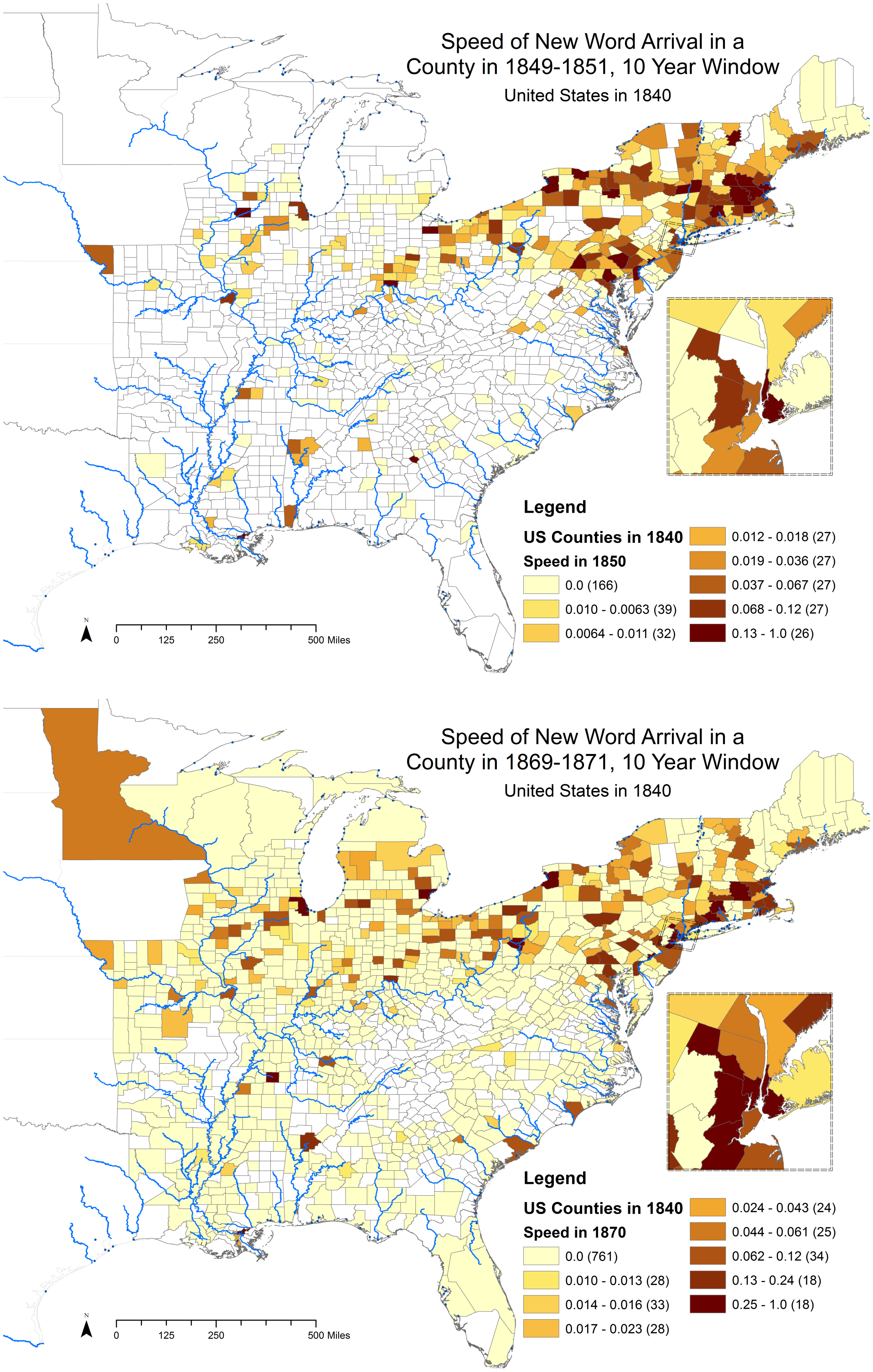

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Figure 2·3: Histogram

There are 126 counties with one patent, and 5038 randomly drawn patents.

There are 15 counties with between 9 and 11 patents, and 600 such randomly drawn counties.

There is one county with 83 patents, and 40 such randomly drawn counties.

There are 167 counties with one patent, and 6673 randomly drawn patents.

There are 62 counties with between 9 and 11 patents, and 2480 such randomly drawn counties.

There are 4 counties wbetween 99 and 104 patents, and 160 such randomly drawn counties.

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Figure 2·4: Real vs. Random Draws

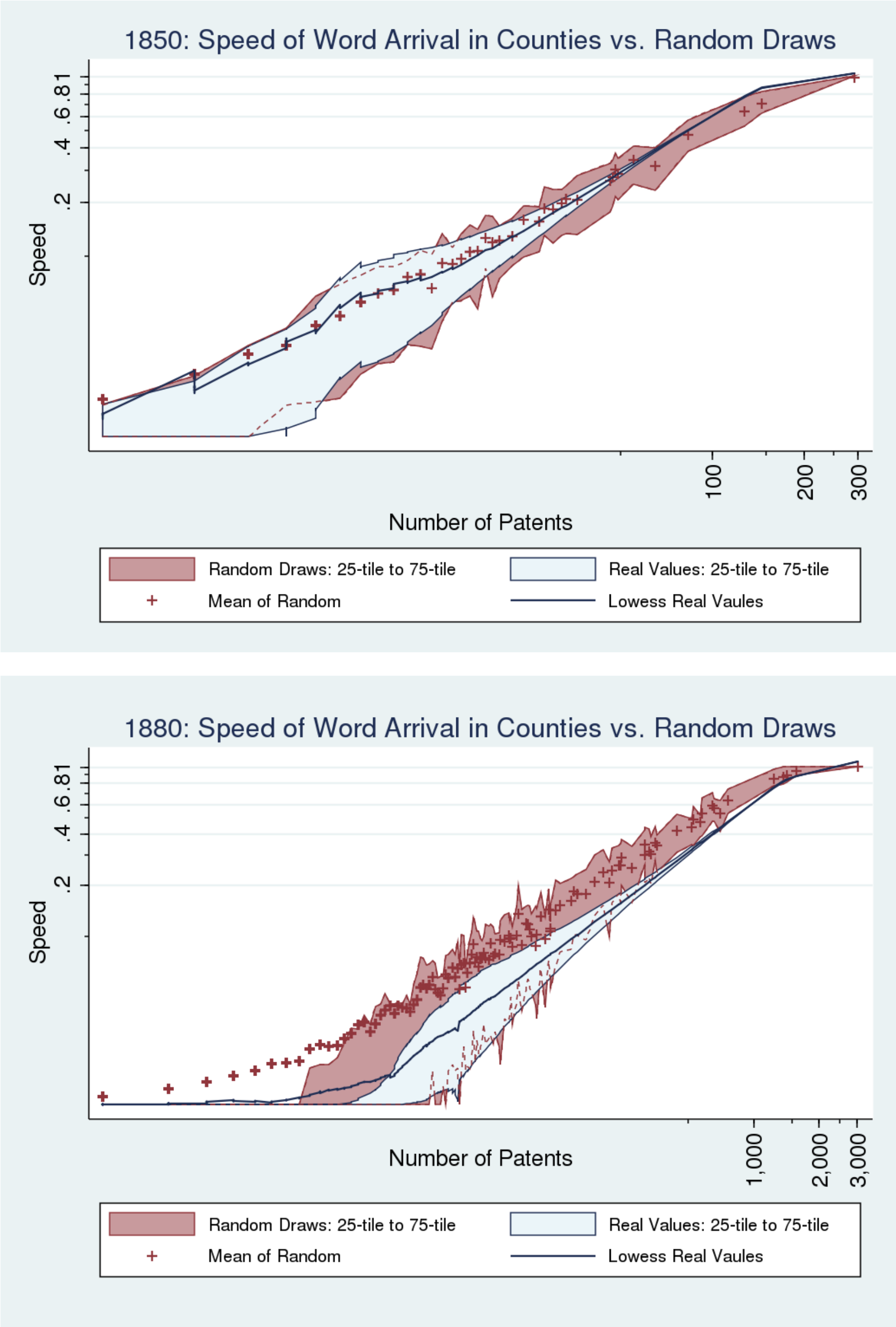

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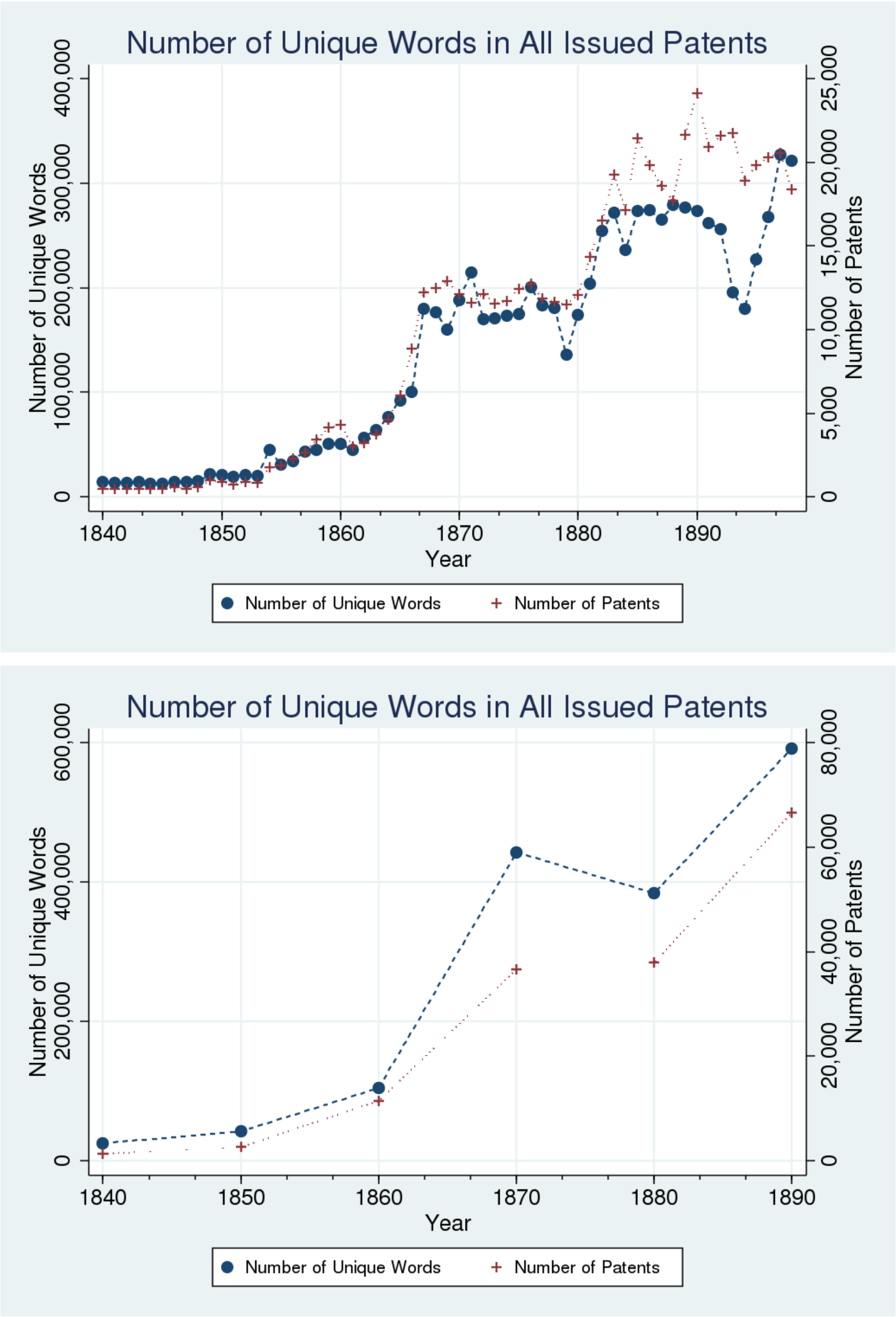
Figure 2·5: The Number of Unique Words Used in All Issued Patents and Issued Patents



Sources: See section 2.2.

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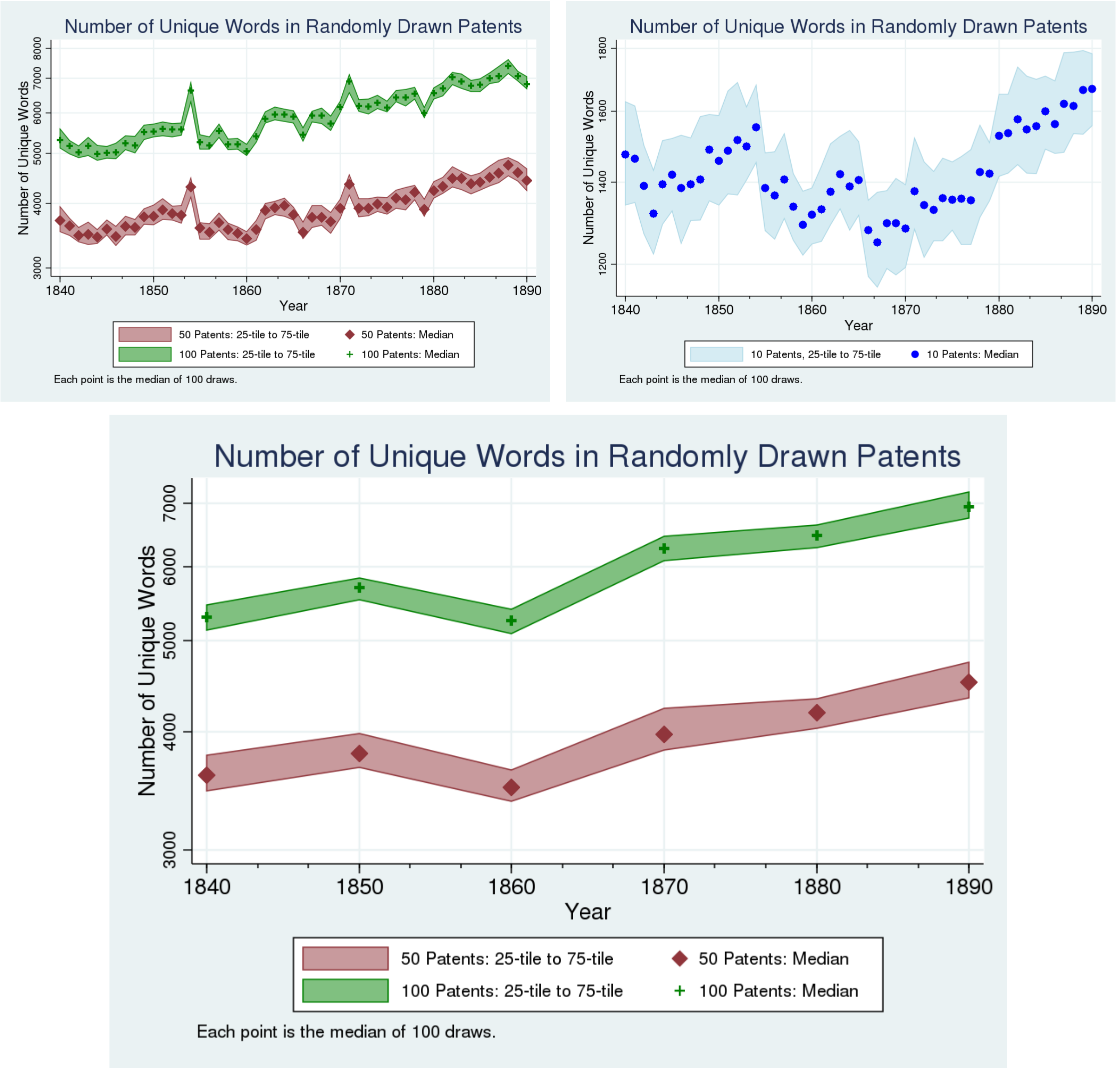
Figure 2·6: The Number of Unique Word in 100, 50, and 10 Random Patents from a Year


Number of Unique Words in Randomly Drawn Patents

Each point is the median of 100 draws.

Number of Unique Words in Randomly Drawn Patents

Each point is the median of 100 draws.

Number of Unique Words in Randomly Drawn Patents

Each point is the median of 100 draws.

Sources: See section 2.2.

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Figure 2·7: The Number of Unique Words in Patents Issued in a County and the Amount this Differs from a Prediction Based on the Number of Patents Issued in that County

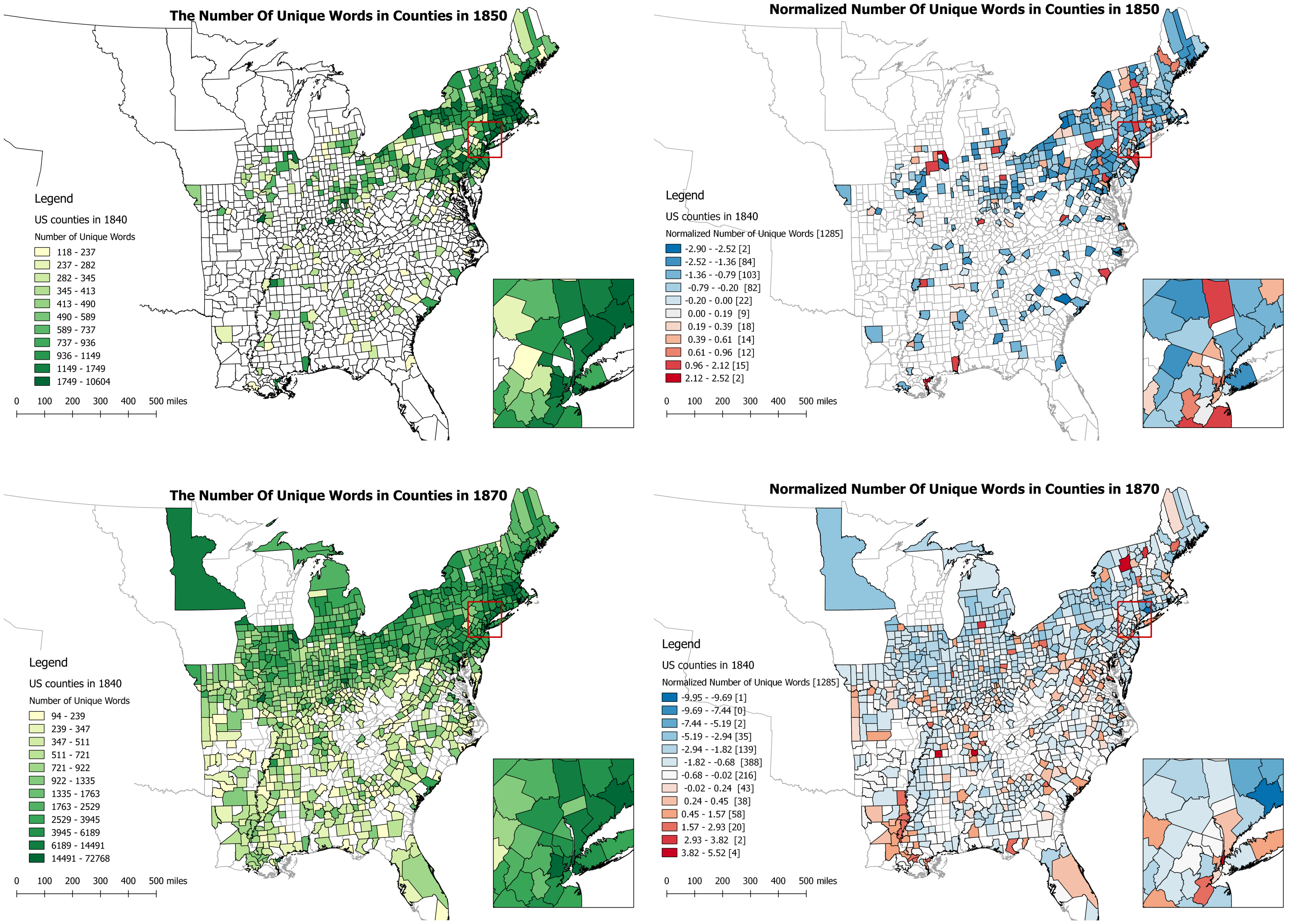

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Figure 2·8: The Normalized Number of Unique Words in a County vs. the Number of Patents Issued

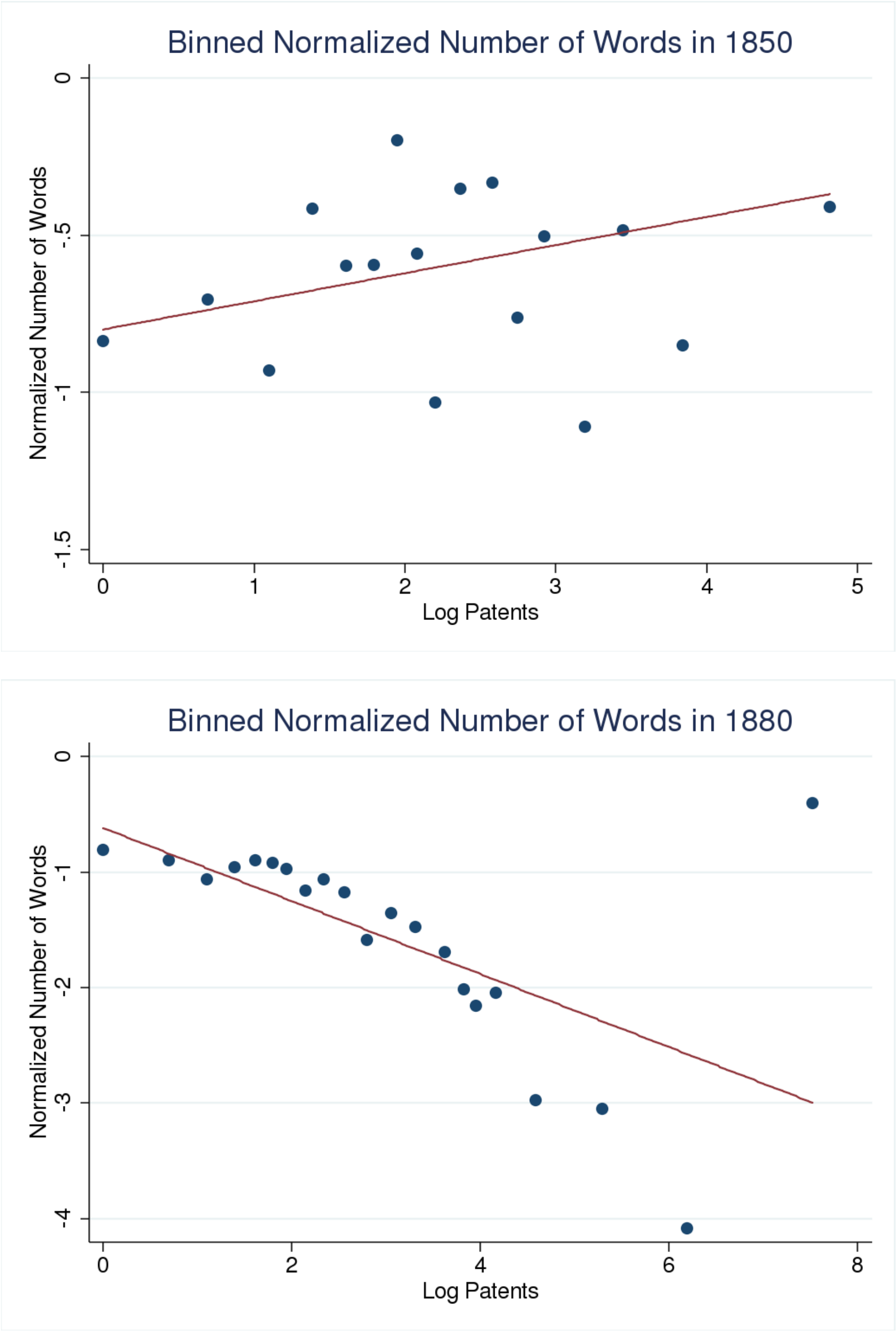

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Figure 2·9: The Mean Speed Measured Using Words New in the Last Ten Years or in All Years by the Years to Railroad Arrival

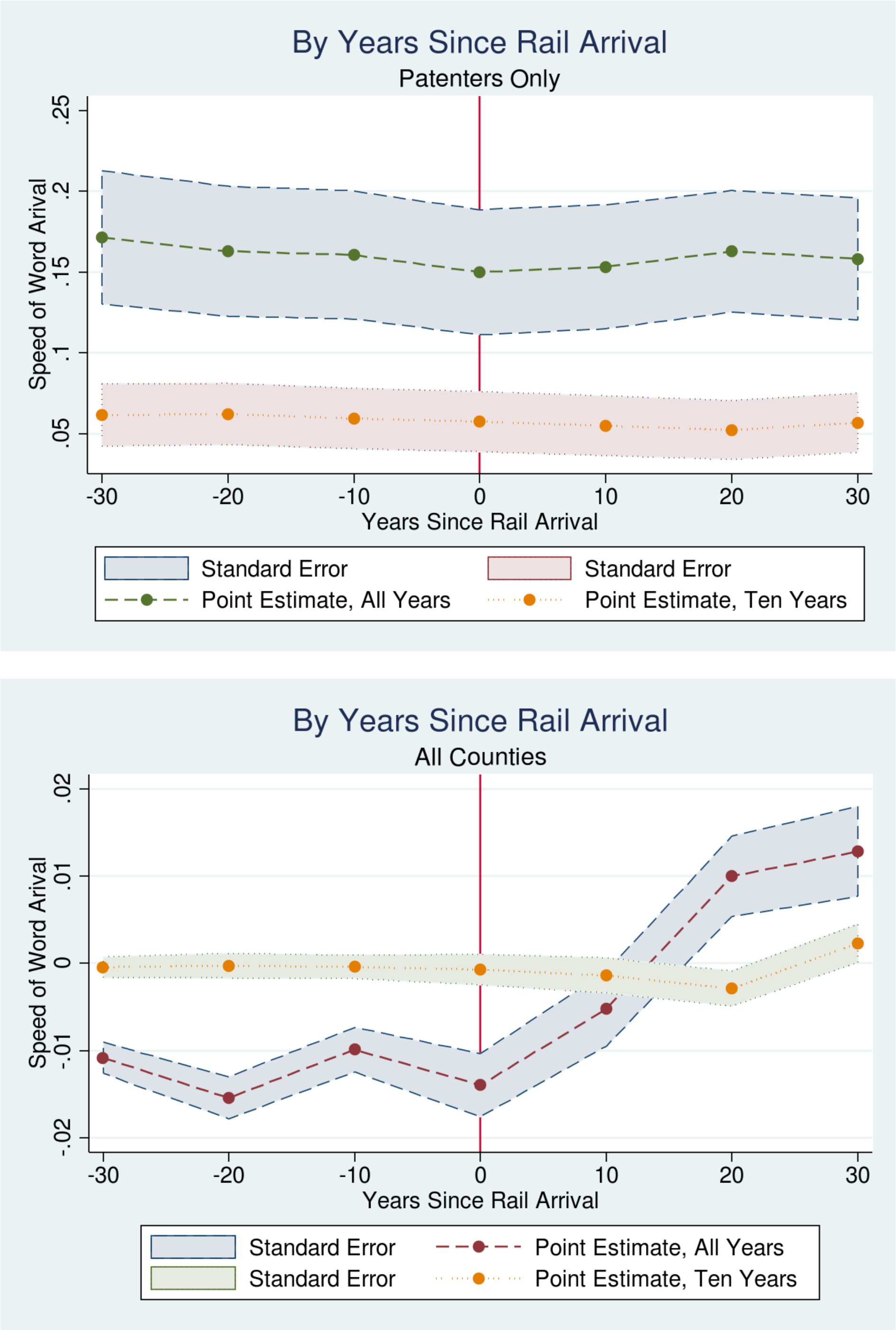

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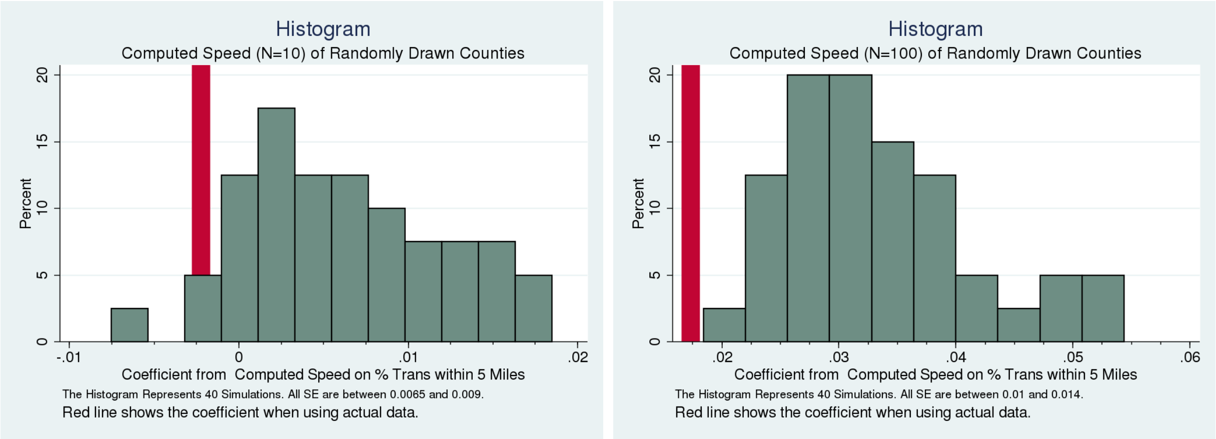
Figure 2·10: Coefficients from the Speed of Word Arrival Computed with Counterfactual Data

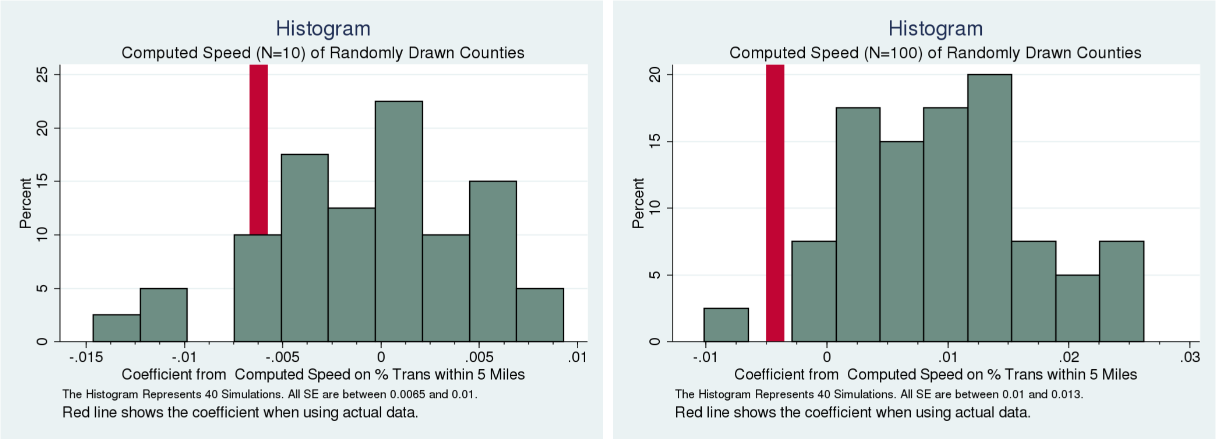
No County Level Controls



The Histogram Represents 40 Simulations. All SE are between 0.0065 and 0.009.
Red line shows the coefficient when using actual data.

The Histogram Represents 40 Simulations. All SE are between 0.01 and 0.014.
Red line shows the coefficient when using actual data.

All County Level Controls



The Histogram Represents 40 Simulations. All SE are between 0.0065 and 0.01.
Red line shows the coefficient when using actual data.

The Histogram Represents 40 Simulations. All SE are between 0.01 and 0.013.
Red line shows the coefficient when using actual data.

See Table 2.5 for more detail on the estimation of the real coefficients.

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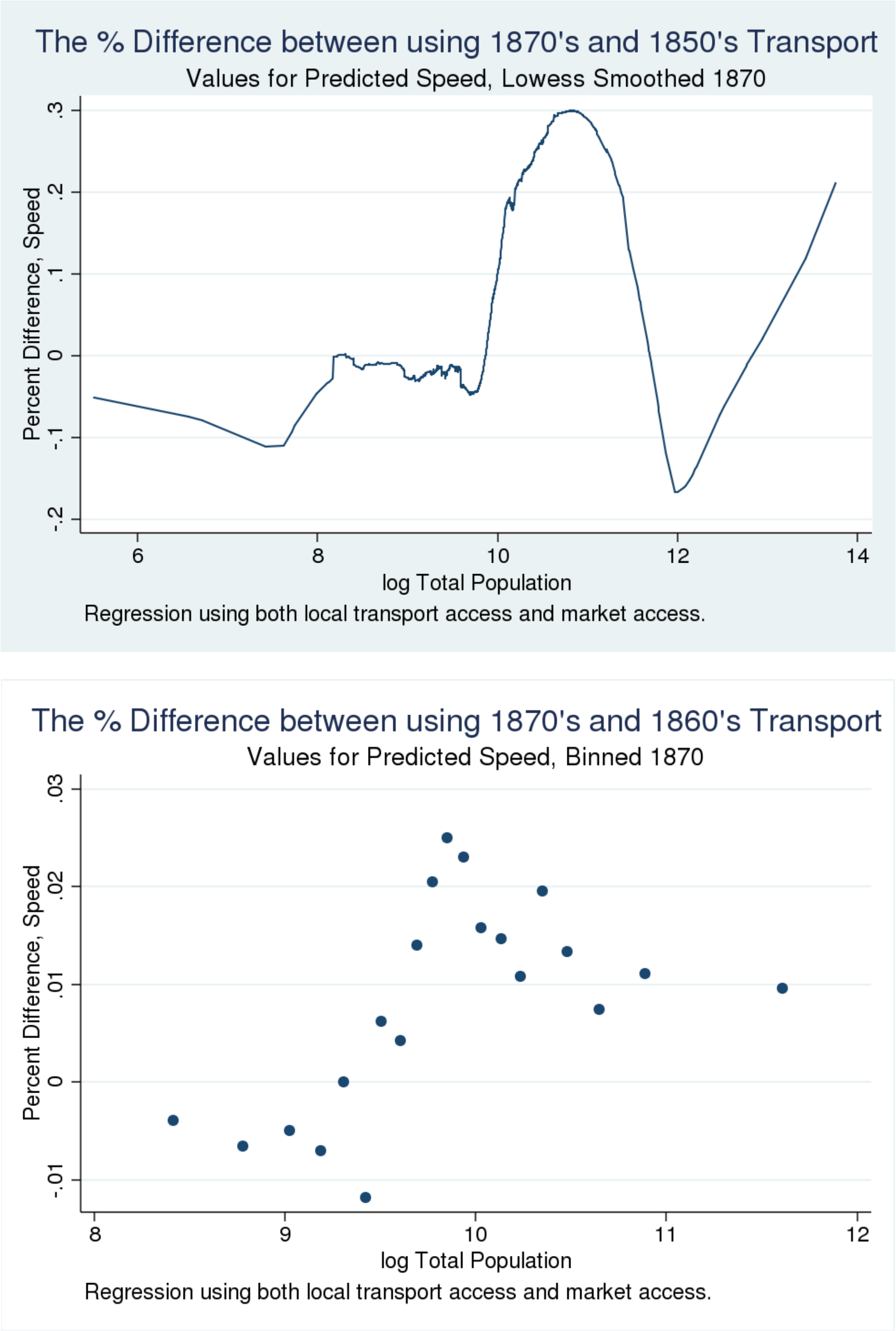
Figure 2·11: The Difference between the Predicted Speeds of Word Arrival if 1870 or 1850 Values of Local Transportation and Market Access are Used



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2.7.2 Tables

Table 2.1: Means by Year, 1790-1900

	1790	1800	1810	1820	1830	1840
Total Population	7,054	7,719	7,274	8,710	10,585	13,363
	(8,471)	(9,694)	(10,337)	(11,837)	(14,356)	(17,661)
Number of Patents	0.0250	0.0227	0.351	0.232	0.962	1.003
	(0.497)	(0.257)	(2.689)	(2.291)	(6.453)	(6.049)
# of NBER Subcategories						2.668
						(2.607)
# Words						647.0
						(682.8)
# Words Norm						-0.222
						(0.933)
% within 5 miles of transport	0.0169	0.0189	0.0236	0.0788	0.139	0.214
	(0.0920)	(0.0958)	(0.105)	(0.176)	(0.216)	(0.248)
log Market Access	4.356	5.727	7.468	8.333	9.183	10.02
	(4.139)	(4.102)	(3.226)	(2.869)	(2.186)	(1.427)

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Table 2.2: Means by Year, 1790-1900

	1850	1860	1870	1880	1890	1900
Total Population	17,807	23,409	27,733	34,788	41,701	49,693
	(25,405)	(36,546)	(46,763)	(59,165)	(82,606)	(111,868)
Number of Patents	1.978	8.642	26.44	25.49	42.12	36.06
	(11.20)	(47.26)	(128.1)	(129.6)	(210.6)	(183.5)
# NBER of Subcategories	3.255	4.389	6.834	6.220	7.271	6.265
	(3.550)	(4.308)	(5.742)	(5.595)	(6.399)	(5.934)
Speed, 10 Years	0.0104	0.00678	0.0136	0.0118	0.0142	
	(0.0559)	(0.0382)	(0.0621)	(0.0736)	(0.0755)	
Speed, All Years	0.00980	0.0317	0.0423	0.0271	0.0802	
	(0.0549)	(0.0929)	(0.0933)	(0.0853)	(0.119)	
# Words	833.8	1,035	1,986	1,823	2,518	
	(962.8)	(1,504)	(4,044)	(3,740)	(5,451)	
# Words Norm	-0.280	-0.612	-0.921	-1.093	-1.269	
	(0.931)	(1.119)	(1.238)	(1.304)	(1.443)	
% within 5 miles of transport	0.269	0.422	0.495	0.610	0.667	0.786
	(0.265)	(0.285)	(0.284)	(0.288)	(0.268)	(0.207)
log Market Access	10.51	11.09	11.33	11.70	11.92	12.12
	(1.278)	(1.138)	(1.117)	(0.977)	(0.886)	(0.815)

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Table 2.3: P-Values from the Kolmogorov-Smirnov Test for Equivalence of Distribution

Group	1850	1860	1870	1880	1890
One Patent Counties	0.865	0.321	0.595	0.031	0.196
Ten Patent Counties	0.795	0.005	0.003	0.000	0.000
Below the 25th percentile	0.865	0.321	0.597	0.042	0.000
Above the 75th percentile	0.066	0.000	0.000	0.000	0.000
Overall	0.395	0.002	0.000	0.000	0.000

All tests report that the real distribution is slower than the simulated one. The null is that the two distributions are the same.

Sources: Patent data from Westlaw and Google.

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Table 2.4: Log Words vs. Log Patents

	(1)	(2)	(3)	(4)	(5)	(6)
	Log Unique Words					
VARIABLES	1840	1850	1860	1870	1880	1890
log Patents	0.538***	0.572***	0.590***	0.677***	0.641***	0.645***
	(0.00227)	(0.00191)	(0.00186)	(0.00205)	(0.00192)	(0.00172)
Constant	6.069***	5.995***	5.841***	5.642***	5.838***	5.894***
	(0.0107)	(0.00863)	(0.00844)	(0.0102)	(0.00974)	(0.00875)
Observations	602	547	553	470	498	502
R-squared	0.989	0.994	0.995	0.996	0.996	0.996

Standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

Sources: Patent data from Westlaw and Google.

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Speed of Word Arrival

Table 2.5: The Effect of Local Transportation Access on the Speed of Word Arrival, 1850-1890

VARIABLES	(1) Speed 10 Years	(2) Speed All Years	(3) Speed 10 Years	(4) Speed All Years	(5) Speed 10 Years	(6) Speed All Years
% within 5 miles	-0.00354	0.0133***	-0.00559	0.00249	-0.00346	-0.00105
of transport	(0.00280)	(0.00471)	(0.00354)	(0.00504)	(0.00273)	(0.00481)
log Total Pop			0.0173***	0.0474***	0.0102**	0.0374***
			(0.00498)	(0.00554)	(0.00428)	(0.00527)
Included Controls	None	None	Population	Population	All	All
Region by Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Counties	1249	1249	1249	1249	1249	1249
Observations	6,240	6,240	6,240	6,240	6,240	6,240
R-squared	0.760	0.751	0.770	0.774	0.823	0.820

VARIABLES	(1) Speed 10 Years	(2) Speed All Years	(3) Speed 10 Years	(4) Speed All Years	(5) Speed 10 Years	(6) Speed All Years
% within 5 miles	-0.00437*	-0.00435	-0.00179	-0.00333	-0.00235	-0.00322
of transport	(0.00236)	(0.00366)	(0.00249)	(0.00380)	(0.00248)	(0.00383)
Mean Syn Speed	0.867***		0.927***		0.981***	
10 Years	(0.0860)		(0.0946)		(0.0920)	
Mean Syn Speed		0.814***		0.797***		0.823***
All Years		(0.0345)		(0.0368)		(0.0450)
log Total Pop			-0.00470*	0.00599**	-0.00513*	0.00230
			(0.00235)	(0.00289)	(0.00261)	(0.00320)
Included Controls	None	None	Population	Population	All	All
Region by Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Counties	1249	1249	1249	1249	1249	1249
Observations	6,240	6,240	6,240	6,240	6,240	6,240
R-squared	0.839	0.862	0.842	0.864	0.867	0.884

Robust standard errors in parentheses, standard errors clustered by county.
All specifications control for county dummies, year dummies, and pre-trends.
*** p<0.01, ** p<0.05, * p<0.1

Included in specifications with controls are, the percent of the county that is: employed in manufacturing, urban (2,500+), metropolitan (25,000+), literate, in school, born out of state, and foreign born, as well as the percent of farm land that is improved. Each variable is include at lagged values, and interacted with time dummies.

Sources: Patent data as described in the text, U.S. Census Data is from Haines (2010) (county boundaries harmonized to 1840 as in Hornbeck (2010)), transportation data from Atack (2013).

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Table 2.6: First Difference Speed of Word Arrival and Local Transportation Access with Interactions

VARIABLES	(1) FD Speed 10 Years	(2) FD Speed 10 Years	(3) FD Speed 10 Years	(4) FD Speed 10 Years
Lag Speed	-0.291***		-0.245***	-0.573***
	(0.0647))		(0.0649)	(0.0712)
FD % within 5 miles		-0.00159	0.00615***	0.00326*
of transport		(0.00249)	(0.00202)	(0.00192)
Lag Speed *X*			-1.690***	-1.453***
FD % within 5 miles			(0.325)	(0.373)
Marginal Effect of FD % 5 mi			-0.0123	-0.0126
			(0.00346)	(0.00374)
z-Stat.			-3.565	-3.375
Included Controls	None	None	None	All
Counties	1249	1249	1249	1249
Observations	4,992	4,992	4,992	4,992
R-squared	0.173	0.072	0.197	0.473

VARIABLES	(1) FD Speed All Years	(2) FD Speed All Years	(3) FD Speed All Years	(4) FD Speed All Years
Lag Speed	-0.321***		-0.296***	-0.679***
	(0.0313)		(0.0335)	(0.0449)
FD % within 5 miles		0.0142***	0.0258***	0.00780**
of transport		(0.00458)	(0.00392)	(0.00393)
Lag Speed *X*			-0.737***	-0.534**
FD % within 5 miles			(0.223)	(0.221)
Marginal Effect of FD % 5 mi			0.00492	-0.00731
			(0.00639)	(0.00605)
z-Stat.			0.770	-1.209
Included Controls	None	None	None	All
Counties	1249	1249	1249	1249
Observations	4,992	4,992	4,992	4,992
R-squared	0.293	0.217	0.297	0.551

Robust standard errors in parentheses, standard errors clustered by county.
All specifications control for year dummies, pre-trends,
and region by year fixed effects.
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

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Table 2.7: First Difference Speed of Word Arrival and Local Transportation Access with Interactions and Computed Means by Number of Patents

VARIABLES	(1) FD Speed 10 Years	(2) FD Speed 10 Years	(3) FD Speed 10 Years	(4) FD Speed 10 Years
Lag Mean Syn Speed	0.849***	-0.0112	0.826***	0.718***
	(0.0884)	(0.0501)	(0.0908)	(0.116)
Lag Speed	-0.961***		-0.919***	-0.901***
	(0.0825)		(0.0909)	(0.0774)
FD % within 5 miles of transport		-0.00159	0.000949	0.00350*
		(0.00249)	(0.00203)	(0.00188)
Lag Speed *X* FD % within 5 miles			-0.871**	-1.096***
			(0.364)	(0.368)
Marginal Effect of FD % 5 mi			-0.00858	-0.00848
			(0.00350)	(0.00361)
z-Stat.			-2.453	-2.350
Included Controls	None	None	None	All
R-squared	0.396	0.072	0.402	0.543

VARIABLES	(1) FD Speed All Years	(2) FD Speed All Years	(3) FD Speed All Years	(4) FD Speed All Years
Lag Mean Syn Speed	0.835***	-0.0822***	0.828***	0.553***
	(0.0645)	(0.0261)	(0.0648)	(0.0619)
Lag Speed	-1.038***		-1.015***	-0.997***
	(0.0634)		(0.0669)	(0.0527)
FD % within 5 miles of transport		0.0146***	0.0198***	0.00890**
		(0.00459)	(0.00377)	(0.00386)
Lag Speed *X* FD % within 5 miles			-0.487**	-0.480**
			(0.230)	(0.219)
Marginal Effect of FD % 5 mi			0.00602	-0.00466
			(0.00598)	(0.00583)
z-Stat.			1.005	-0.801
Included Controls	None	None	None	All
R-squared	0.413	0.222	0.416	0.582

Robust standard errors in parentheses, standard errors clustered by county.
All specifications control for year dummies, pre-trends,
and region by year fixed effects.

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Table 2.8: The Effect of Market Access on the Speed of Word Arrival, 1850-1890

VARIABLES	(1) Speed 10 Years	(2) Speed All Years	(3) Speed 10 Years	(4) Speed All Years	(5) Speed 10 Years	(6) Speed All Years
log Market Access	0.00669***	0.0117***	0.00271**	0.00102	0.00323***	0.00231
	(0.00196)	(0.00236)	(0.00113)	(0.00188)	(0.00106)	(0.00174)
log Total Pop			0.0211***	0.0518***	0.0103***	0.0381***
			(0.00576)	(0.00636)	(0.00415)	(0.00514)
Included Controls	None	None	Population	Population	All	All
Region by Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Counties	1249	1249	1249	1249	1249	1249
Observations	6,240	6,240	6,240	6,240	6,240	6,240
R-squared	0.748	0.743	0.759	0.765	0.817	0.818

VARIABLES	(1) Speed 10 Years	(2) Speed All Years	(3) Speed 10 Years	(4) Speed All Years	(5) Speed 10 Years	(6) Speed All Years
log Market Access	0.000484	0.00408***	0.00142*	0.00322***	0.00223***	0.00377***
	(0.000962)	(0.00133)	(0.000850)	(0.00118)	(0.000838)	(0.00124)
Mean Syn Speed	0.887***		0.940***		0.995***	
10 Years	(0.0902)		(0.0960)		(0.0916)	
Mean Syn Speed		0.816***		0.800***		0.827***
All Years		(0.0349)		(0.0378)		(0.0450)
log Total Pop			-0.00261	0.00893***	-0.00508*	0.00133
			(0.00268)	(0.00369)	(0.00260)	(0.00348)
Included Controls	None	None	Population	Population	All	All
Region by Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Counties	1249	1249	1249	1249	1249	1249
Observations	6,240	6,240	6,240	6,240	6,240	6,240
R-squared	0.836	0.860	0.839	0.862	0.864	0.883

Robust standard errors in parentheses, standard errors clustered by county.
All specifications control for county dummies, year dummies, and pre-trends.
*** p<0.01, ** p<0.05, * p<0.1

Included in specifications with controls are, the percent of the county that is: employed in manufacturing, urban (2,500+), metropolitan (25,000+), literate, in school, born out of state, and foreign born, as well as the percent of farm land that is improved. Each variable is include at lagged values, and interacted with time dummies.

Sources: Patent data as described in the text, U.S. Census Data is from Haines (2010) (county boundaries harmonized to 1840 as in Hornbeck (2010)), transportation data from Atack (2013).

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Table 2.9: First Difference Speed of Word Arrival and Market Access with Interactions

VARIABLES	(1) FD Speed 10 Years	(2) FD Speed 10 Years	(3) FD Speed 10 Years	(4) FD Speed 10 Years
Lag Speed	-0.226***		-0.357***	-0.760***
	(0.0682)		(0.0940)	(0.0931)
FD log Market Access		0.00247**	0.00434***	0.00176**
		(0.00108)	(0.00113)	(0.000873)
Lag Speed X			0.491*	0.525*
FD log MA			(0.278)	(0.294)
Marginal Effect FD log MA			0.00971	0.00750
			(0.00306)	(0.00299)
Included Controls	None	None	None	All
Counties	1249	1249	1249	1249
Observations	4,992	4,992	4,992	4,992
R-squared	0.113	0.037	0.122	0.450

VARIABLES	(1) FD Speed All Years	(2) FD Speed All Years	(3) FD Speed All Years	(4) FD Speed All Years
Lag Speed	-0.280***		-0.404***	-0.757***
	(0.0281)		(0.0462)	(0.0495)
FD log Market Access		0.00751***	0.00858***	0.00159
		(0.00174)	(0.00183)	(0.00151)
Lag Speed X			0.477***	0.264**
			(0.166)	(0.121)
Marginal Effect FD log MA			0.0221	0.00904
			(0.00462)	(0.00334)
Included Controls	None	None	None	All
Counties	1249	1249	1249	1249
Observations	4,992	4,992	4,992	4,992
R-squared	0.264	0.197	0.274	0.544

Robust standard errors in parentheses, standard errors clustered by county.
All specifications control for year dummies, pre-trends,
and region by year fixed effects.
*** p<0.01, ** p<0.05, * p<0.1

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Table 2.10: First Difference Speed of Word Arrival and Market Access with Interactions and Computed Means by Number of Patents

VARIABLES	(1) FD Speed 10 Years	(2) FD Speed 10 Years	(3) FD Speed 10 Years	(4) FD Speed 10 Years
Lag Mean Syn Speed	0.839***	-0.00726	0.830***	0.704***
	(0.0908)	(0.0491)	(0.0895)	(0.117)
Lag Speed	-0.893***		-0.968***	-1.032***
	(0.0855)		(0.0902)	(0.0857)
FD log Market Access		0.00257***	0.00240**	0.00214***
		(0.000893)	(0.000940)	(0.000802)
Lag Speed *X* FD log MA			0.306**	0.417**
			(0.134)	(0.193)
Marginal Effect FD log MA			0.00573	0.00669
			(0.00162)	(0.00208)
Included Controls None	None	None	All	
R-squared	0.332	0.037	0.336	0.521

VARIABLES	(1) FD Speed All Years	(2) FD Speed All Years	(3) FD Speed All Years	(4) FD Speed All Years
Lag Mean Syn Speed	0.817***	-0.0862***	0.807***	0.527***
	(0.0671)	(0.0261)	(0.0672)	(0.0646)
Lag Speed	-0.974***		-1.065***	-1.045***
	(0.0674)		(0.0681)	(0.0539)
FD log Market Access		0.00910***	0.00734***	0.00268*
		(0.00178)	(0.00160)	(0.00141)
Lag Speed *X* FD log MA			0.383***	0.234**
			(0.120)	(0.0924)
Marginal Effect FD log MA			0.0182	0.00929
Margin SE			(0.00347)	(0.00274)
Included Controls	None	None	None	All
R-squared	0.380	0.202	0.387	0.573

Robust standard errors in parentheses, standard errors clustered by county.
All specifications control for year dummies, pre-trends,
and region by year fixed effects.
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

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The Number of Words and Transportation

Table 2.11: The Effect of Local Transportation Access on the Number of Unique Words in a County, 1840-1890

VARIABLES	(1) log # Words	(2) log # Words	(3) log # Words
% within 5 miles of transport	1.204***	0.999***	0.867***
	(0.259)	(0.261)	(0.265)
log Total Pop		0.698***	0.894***
		(0.139)	(0.154)
Included Controls	None	Population	All
Counties	1249	1249	1249
Observations	7,489	7,489	7,489
R-squared	0.721	0.725	0.739

VARIABLES	(1) log # Words	(2) log # Words	(3) log # Words
% within 5 miles of transport	0.00496	0.00443	0.00319
	(0.0188)	(0.0190)	(0.0198)
log Mean Syn Words	0.978***	0.978***	0.978***
	(0.00110)	(0.00113)	(0.00120)
log Total Pop		0.000129	0.0130
		(0.00643)	(0.00759)
Included Controls	None	Population	All
Counties	1249	1249	1249
Observations	7,489	7,489	7,489
R-squared	0.999	0.999	0.999

*** p<0.01, ** p<0.05, * p<0.1

Robust standard errors in parentheses, standard errors clustered by county. All specifications control for county dummies, year dummies, pre-trends, and region by year fixed effects

Included in specifications with controls are, the percent of the county that is: employed in manufacturing, urban (2,500+), metropolitan (25,000+), literate, in school, born out of state, and foreign born, as well as the percent of farm land that is improved. Each variable is include at lagged values, and interacted with time dummies.

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Table 2.12: The Effect of Market Access on the Number of Unique Words in a County, 1840-1890

VARIABLES	(1) log # Words	(2) log # Words	(3) log # Words
log Market Access	0.357***	0.198*	0.177*
	(0.0957)	(0.101)	(0.105)
log Total Pop		0.620***	0.948***
		(0.137)	(0.155)
Included Controls	None	Population	All
Counties	1249	1249	1249
Observations	7,489	7,489	7,489
R-squared	0.725	0.729	0.741

Robust standard errors in parentheses, standard errors clustered by county. All specifications control for county dummies, year dummies, pre-trends, and region by year fixed effects.

VARIABLES	(1) log # Words	(2) log # Words	(3) log # Words
log Market Access	0.0114*	0.0104	0.00893
	(0.00665)	(0.00705)	(0.00747)
log Mean Syn Words	0.978***	0.978***	0.978***
	(0.00112)	(0.00114)	(0.00121)
log Total Pop		0.00502	0.00996
		(0.00745)	(0.00874)
Included Controls	None	Population	All
Counties	1249	1249	1249
Observations	7,489	7,489	7,489
R-squared	0.999	0.999	0.999

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Robust standard errors in parentheses, standard errors clustered by county. All specifications control for county dummies, year dummies, pre-trends, and region by year fixed effects

Included in specifications with controls are, the percent of the county that is: employed in manufacturing, urban (2,500+), metropolitan (25,000+), literate, in school, born out of state, and foreign born, as well as the percent of farm land that is improved. Each variable is include at lagged values, and interacted with time dummies.

Sources: Patent data as described in the text, U.S. Census Data is from Haines (2010) (county boundaries harmonized to 1840 as in Hornbeck (2010)), transportation data from Atack (2013).

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Table 2.13: First Difference Number of Unique Words in a County and Local Transportation Access with Interactions

VARIABLES	(1) FD log # Words	(2) FD log # Words	(3) FD log # Words	(4) FD log # Words
Lag Num Words	-9.41e-05***		-6.09e-05***	-0.000458***
	(2.61e-05)		(1.98e-05)	(7.91e-05)
FD % within 5 miles		0.933***	1.586***	1.384***
of transport		(0.277)	(0.316)	(0.325)
Lag Num Words *X*			-0.00150***	-0.00127***
FD % within 5 miles			(0.000268)	(0.000302)
Marginal Effect of FD % 5 mi			0.398	0.384
			(0.266)	(0.277)
Included Controls	None	None	None	All
Counties	1249	1249	1249	1249
Observations	6,240	6,240	6,240	6,240
R-squared	0.092	0.090	0.099	0.141

VARIABLES	(1) FD log # Words	(2) FD log # Words	(3) FD log # Words	(4) FD log # Words
lag log Mean Syn Words	-0.616***	-0.606***	-0.630***	-0.753***
	(0.0189)	(0.0187)	(0.0189)	(0.0194)
Lag Num Words	0.000114***		0.000111***	1.41e-05
	(2.32e-05)		(2.30e-05)	(3.92e-05)
FD % within 5 miles		1.972***	1.892***	1.198***
of transport		(0.232)	(0.260)	(0.251)
Lag Num Words *X*			0.000253*	-1.62e-05
FD % within 5 miles			(0.000138)	(0.000133)
Marginal Effect of FD % 5 mi			2.092	1.186
			(0.217)	(0.209)
Included Controls	None	None	None	All
Counties	1249	1249	1249	1249
Observations	6,240	6,240	6,240	6,240
R-squared	0.354	0.358	0.363	0.441

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Table 2.14: First Difference Number of Unique Words in a County and Market Access with Interactions

VARIABLES	(1) FD log # Words	(2) FD log # Words	(3) FD log # Words	(4) FD log # Words
Lag Num Words	-6.84e-05**		3.09e-05	-0.000432***
	(2.73e-05)		(4.79e-05)	(7.66e-05)
FD log Market Access		0.321***	0.462***	0.375***
		(0.102)	(0.115)	(0.119)
Lag Num Words *X* FD log MA			-0.000420**	-0.000238
			(0.000208)	(0.000234)
Marginal Effect of FD log MA			0.130	0.187
			(0.146)	(0.164)
Included Controls	None	None	None	All
Counties	1249	1249	1249	1249
Observations	6,240	6,240	6,240	6,240
R-squared	0.098	0.098	0.103	0.143

VARIABLES	(1) FD log # Words	(2) FD log # Words	(3) FD log # Words	(4) FD log # Words
lag log Mean Syn Words	-0.638***	-0.629***	-0.641***	-0.755***
	(0.0178)	(0.0174)	(0.0176)	(0.0186)
Lag Num Words	8.20e-05***		9.35e-05***	-3.71e-06
	(2.21e-05)		(2.83e-05)	(4.58e-05)
FD log Market Access		0.531***	0.523***	0.273***
		(0.0823)	(0.0872)	(0.0869)
Lag Num Words *X* FD log MA			-7.55e-05	1.43e-05
			(5.66e-05)	(6.06e-05)
Marginal Effect of FD log MA			0.463	0.285
			(0.0798)	(0.0798)
Included Controls	None	None	None	All
Counties	1249	1249	1249	1249
Observations	6,240	6,240	6,240	6,240
R-squared	0.373	0.375	0.378	0.446

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Chapter 3

Delivering the Vote: The Political Effect of Free Mail Delivery in Early Twentieth Century America
(with Steven Sprick Schuster)

The rollout of Rural Free Delivery (RFD) in the early twentieth century dramatically increased the frequency with which rural voters received information. This chapter examines the effect of RFD on voters' and Representatives' behavior using a panel dataset and instrumental variables. Communities receiving more routes spread their votes to more parties; there is no evidence it changed turnout. RFD shifted positions taken by Representatives in line with rural constituents, including increased support for pro-temperance and anti-immigration policies. These results appear only in counties with newspapers, supporting the hypothesis that information flows play a crucial role in the political process.

> *As the whole world has been drawn closer together by the inventions and uses of steam and electricity, so farmers may be drawn closer together by the universal practice of free delivery.*
>
> – Matthew Williams of Verndale, Minnesota as quoted in the 1900 Yearbook of the United States Department of Agriculture

3.1 Introduction

Changes to information flows affect the behavior of both the electorate and politicians. When deciding whether to vote and for whom to vote, coordinating with other voters, and interacting with their elected officials, potential voters rely on information from candidates, media sources and peers. However, information networks and access to mass media are usually endogenous to political activity, limiting researchers' ability to identify settings through which to measure the causal effects of information on political outcomes. Rural Free Delivery (RFD), which introduced daily mail to millions of rural homes at the turn of the twentieth century, provides a unique opportunity to explore this relationship.

The late nineteenth century and early twentieth century saw significant changes in how information was gathered and disseminated throughout the United States. The invention of the web rotary press made large-scale newspaper and magazine printing runs possible. The establishment of telegraph and telephone lines across the country increased the speed of interpersonal communication. These developments had great potential to affect the political process, as they changed the ability of individuals to acquire information, and of political candidates and parties to send messages to voters.

Advancements in information distribution were especially important for residents of rural areas, whose isolation was an acute concern for policy-makers.[1] This isolation was notably apparent in rural residents' lack of access to daily mail. Since 1863, city dwellers enjoyed either at-home mail delivery or close proximity to post offices, while rural residents had to travel several miles to the nearest post office. These concerns led to a push for the expansion of daily mail delivery to rural homes. Created on an experimental basis in 1896, and rolled out across the country during the first decade of the twentieth century, RFD changed the flow of information to rural communities and the information networks within them.

Any attempt to estimate the causal effect of voter information on political outcomes faces a severe endogeneity problem. People with more robust information networks will vote in different ways than will people with less robust information net-

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[1] In his 1903 Annual Message to Congress, President Theodore Roosevelt said, "Rural free delivery, taken in connection with the telephone, the bicycle, and the trolley, accomplishes much toward lessening the isolation of farm life and making it brighter and more attractive."

works due to unobserved characteristics, instead of a causal effect of information. We address this problem in two ways. First, RFD caused an almost immediate change in the availability of information to individuals affected by the service, which allows us to use a panel dataset to control for time-invariant county characteristics. Second, any RFD route required approval by the United States Post Office, which required that routes be placed along roads that were passable year-round. We therefore use a set of instrumental variables that capture pre-existing road quality to estimate the causal effect of RFD on political activity. While these variables are related to levels in political activity, we show that they are not associated with trends in political activity, which, in the presence of time and place fixed effects, is our primary identifying assumption.

We find results consistent with the hypothesis that an increase in information to rural voters increases their political power. Though we can rule out a large effect of RFD on voter turnout in Congressional elections, we find that RFD routes increased the competitiveness of Congressional elections and increased vote share for small parties (which in this era tended to support Populist causes). The observed effects are larger in communities with daily newspapers, providing support to the hypothesis that RFD changed voting behavior primarily by changing the level of information available to voters. We also find a change in the behavior of elected officials in response to RFD allocation. The policy positions of members of the House of Representatives shifted toward stances associated with rural communities, which were primary associated with Populist causes.

3.2 Motivation

According to contemporary reports, Rural Free Delivery led to large changes in the amount of mail sent and received and total newspaper circulation. Increased mail affected the bidirectional flow of information, while higher newspaper circulation changed the dissemination of information. Each of these effects changed the structure of networks and information flows in rural communities, and could have changed the way in which voters reached their decisions and their relationships with their Congressional Representatives.

Gentzkow et al. (2011) showed that the entry of the first newspaper in a county led to a small but significant increase in voter turnout. Using data from a field experiment, Gerber et al. (2009) showed that people in Virginia who received a newspaper, regardless of its political slant, were eight percent more likely to vote for a Democratic for governor in the 2005 elections.[2]

The expansion of local newspaper circulation associated with RFD affected the ability of rural voters to coordinate their votes behind individual parties or candidates, and to advocate for specific policies.[3] Small parties, including the Greenback and Populist parties, advocated farmer-friendly policies, while the Grange continued to be a strong unofficial political player.[4] RFD provided a mechanism through which these groups could more easily reach rural voters.

Research has consistently shown that social capital leads to an increased ability of voters to elicit favorable policies from elected officials. Strömberg (2004) found that

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[2] Prat and Strmberg (2011) surveys a number of other studies.

[3] The temperance movement was of specific interest to many of these smaller parties. The Grange was involved in the temperance movement since at least 1874 (Buck, 1913), and noted temperance advocate Mary Elizabeth Lease was an early Populist candidate.

[4] The National Grange of the Order of Patrons of Husbandry, founded in 1867, became a powerful force in the 1870s when falling prices for agricultural goods provided incentive for farmers to organize. The Grange was a farmers organization run by local farm families, providing education, social events, and political advocacy on all manner of issues about which farmers cared.

communities in the United States with increased access to radio broadcasts received greater relief funds from the federal government during the New Deal. In Strmberg's model, when one group becomes better informed, politicians change their behavior by choosing policies favored by the better informed group. Within the context of RFD, this translates to a prediction that Representatives in Congressional districts that receive more routes would shift their positions towards policies favored by rural communities.

Further supporting the idea that information about elected officials changes outcomes, Gentzkow et al. (2006) found the early twentieth century conversion of newspapers from being politically-affiliated to independent to be correlated with a decrease in political corruption. Using data from the late twentieth and early twenty-first century, Strömberg and Synder (2010) showed that in areas where newspaper markets and Congressional districts poorly overlap, voters are less able to recognize their elected officials, who in turn appear to be less responsive to those constituent.

The motivation for such empirical work lies in voting models of imperfect information and models outlining the social motivation for voting. The importance of well-informed voters goes back to Condorcet's Jury Theorem from 1785, which assumes that voters are well informed. In describing what they call the "Swing Voter's Curse," Feddersen and Pesendorfer (1996) illustrate the role of information on the potential voter's decision to participate in an election and his ability to influence the behavior of others. The "Bandwagon Effect" described by Simon (1954), Bowden (1987), and Mehrabian (1998), predicts that people will become more inclined to vote for a candidate as the candidate's odds of winning increase. Given that a voter's perception of a candidate's popularity with other voters most likely comes from media sources and polls, this too is a story of information.

In the political science literature, the concept of electoral connection (Mayhew,

1974) argues that office-motivated politicians use policies to increase their chance of re-election. This connection is dependent on potential voters being able to obtain information on their politicians' actions. While Mayhew's focus was post-WWII politics, Carson and Jenkins (2011) provide evidence that politicians throughout the period studied in this chapter were responsive to the will of voters.

This chapter contributes to two literatures: the relationship between information and political development, and historical studies of the effects of RFD. Fuller (1955, 1959, 1964) provides valuable historical context on the establishment of Rural Free Delivery, and several papers have used RFD to test economic or political science hypotheses. Carpenter (2000) investigated models of state building through several large-scale postal initiatives (including RFD), while Kernell (2001) considered the effect of the individual political gains that members of Congress believed they would receive with the implementation of RFD during the Post Office's transition from a system of patronage to a service. Feigenbaum and Rotemberg are studying the effect of RFD expansion of information on investment choices.

Research on the political economy effect of information and mass media includes the effect of newspapers (Gentzkow et al., 2011; Chiang and Knight, 2011), radio (Strömberg, 2004), television (Enikolopov et al., 2009; DellaVigna and Kaplan, 2007), and Internet (Falck et al., 2014). Although RFD rapidly changed millions of individuals' access to information, we are unaware of any research using RFD to explore causal effects of information acquisition on political outcomes, nor any that looks at how RFD affected the elected representatives' policy positions.

3.3 Rural Free Delivery

While rural daily mail delivery is often taken for granted today, the disparity in service quality between rural and urban households in the late nineteenth century was large. While people living in cities enjoyed close proximity to post offices or direct home delivery, rural homes could only receive or send mail by traveling long distances. Even in the best conditions, a trip to the post office for someone who lived five miles away would likely entail three and a half hours of travel.[5] Conditions were seldom ideal, making travel times much longer, and the mail itself was often delayed (Fuller, 1964, pg. 15).[6] In periods of bad weather, families living on farms would sometimes go weeks without mail.

RFD was promoted as a way to address this disparity in postal service by bringing free daily mail to rural residents.[7] Under the system, rural routes emanating from existing post offices were established and served daily by rural carriers. Any family wishing to be served by the system needed only to erect a weatherproof box along the route to receive mail. Early advocates of RFD highlighted its potential to alleviate the monotony of rural life. In 1900, Indiana State Senator Thomas J. Lindley wrote of RFD, "[the farmer] no longer feels the isolation of country life. I think the system will contribute largely to prevent the threatened congestion of population in our cities and towns" (Greathouse, 1901).

The first high profile call for RFD came in 1891, from Postmaster General John Wanamaker.[8] As Postmaster General he proposed a number of radical changes to

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[5] Taking walking speed to be 3.18 miles an hour, the preferred human walking speed found by Browning et al. (2006) and slightly faster than the speed used in Google maps.

[6] American rural roads in the time before the automobile were poor. Fuller (1955) notes that "only about seven per cent of the nation's roadways had been improved with gravel, shell, oil, or some other substance by 1906" (Fuller, 1964, pg. 180).

[7] The service was 'free' in the sense that in that there was no cost above postage.

[8] Wannamaker was the founder of a successful department store, and a staunch supporter of President Harrison's campaign.

the Post Office Departmentgovernment ownership of the telegraph and telephone lines, parcel post, and a postal savings bank—many of which angered established business interests (Fuller, 1964, pgs. 21, 24). Newspapers also saw the particular benefit to their business of RFD,[9] and newspaper owners became strong promoters of the program (Fuller, 1964, pg. 21).

Wanamaker proposed that RFD's feasibility be tested by the implementation of limited delivery in a few rural towns (Fuller, 1964, pg. 18). Wanamaker's successor, Wilson Bissell, opposed RFD in any form, and never used the fund allocated for Wanamaker's plan (Fuller, 1964, pg. 33).[10] In 1896, under Postmaster William Wilson, the first experimental routes (82 in all) were established (Fuller, 1964, pg. 39).

In Congress, RFD had broader support from Republicans than from Democrats. Kernell and McDonald (1999) argue that political competition from the Populist Party drove Republican lawmakers to support RFD in the 1890s. When President McKinley's administration took over in 1897, several RFD supporters were appointed to positions in the Post Office (Fuller, 1964, pg. 40). Assistant Postmaster Perry Heath and Superintendent of Free Delivery August W. Machen were politically savvy bureaucrats, and likely anticipated the pressure requests for routes would put on House members if they were sent to Representatives directly. Thus, in 1898 the Post Office formalized the mechanism for route allocation: communities wishing to receive a route were to petition their Representative, and route establishment required approval from both the Representative and Postmaster. Representatives were inundated with petitions from farm communities (Fuller, 1964, pg. 41). In the face of widespread constituent support for the program, even Representatives initially opposed to RFD were forced to support it (Carpenter, 2000).

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[9] At the time in-county newspapers had the privilege of being delivered for free.

[10] The position of Postmaster General was an appointed member of the President's Cabinet until 1971, and the position was often used as part of the system of patronage politics.

The 1903 Yearbook of the United States Department of Agriculture described the process of obtaining a route thus:

> The delivery of mails by rural carriers is extended in response to petitions presented by the people desiring the service upon forms prepared by the Department, which include a diagram of the proposed route. It is required that the route shall be from 20 to 25 miles in length, so laid out that the carrier will not have to traverse the same road on his return as on his outward trip, and so adjusted that at least 100 domiciles shall be included in the service. Such a petition, when presented to the Department with the approval of the Congressional Representative of the district or of one of the Senators from the State in which the service is asked for, is investigated by one of the special agents in the field, who transmits the papers, with a map of the route or routes to be followed, to the Superintendent in Washington for his adjudication.

These guidelines were determined by the feasibility and cost effectiveness of mail delivery and were the same as those outlined in 1898. One hundred families was deemed the minimum number of households necessary to justify a route, while 25 miles was viewed as the longest route mail carriers could reliably serve, and a route necessitated that roads were passable year-round (Fuller, 1964, pg. 182). These regulations applied equally to all communities; even if a town had the misfortune of featuring rough terrain or impassable roads, the Post Office did not exercise leniency in its decision to approve or reject a route. These official guidelines were largely unchanged during the duration of the rollout of RFD.[11]

Facing mounting pressure from rural communities, Congress made RFD a permanent program in 1902. Rapid expansion of RFD followed quickly. Between 1900 and 1908, the number of RFD routes increased from 1,259 to 39,277. Though many

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[11] In later years of the rollout (post-1904), the Post Office loosened the requirements to allow for routes serving as few as sixty families. However, this change appeared to be the results of increased Congressional funding and decreases in transportation costs. It is important for our identification strategy that these guidelines were not determined by Representatives, whose motivations were political. A map of a rural route can be seen in Figure 3·1; the local post office can be seen in the northwest corner of the map, with the route leaving from and terminating at that location. Maps such as these were included with petitions for routes.

communities were left unserved[12] and some are unserved to this day,[13] additional route allocation all but halted by 1908. By that year, more than 88 percent of routes that would ever be extant had been established (Kernell, 2001). During the 1910 Postal Appropriations hearing, Fourth Assistant Postmaster General P.V. De Graw claimed that all communities qualifying for RFD under the 1898 guidelines had received routes, and that only a liberalization of the rules regarding the number of houses served would allow for further route allocation (Post Office Appropriation Bill, 1912, pg. 462). In 1909, facing a deficit in the Treasury, President Taft ordered a dramatic cut in the Post Office budget, which made route creation significantly more difficult (Fuller, 1964, pg. 78). We omit the period of rollout for RFD (1901-1907), and only use the years before 1901 and after 1907 in our analysis.

In 1916 Congress passed legislation stating the goal of the postal service to "be extended so as to serve, as nearly as practicable, the entire rural population of the United States."[14] To move towards this goal, the post office codified the use of automobiles for RFD routes, and expanded the length of routes considerably. Our sample ends in 1916.

It was the contemporary belief that some were better able to secure new routes than others. Route allocation was correlated with a number of factors likely associated with different levels of political activity. Communities had to apply for routes; therefore, more motivated communities would have received routes more quickly. Additionally, because routes required sponsorship by a Representative, the speed at which a community received a route was in part a function of Representative characteristics. RFD was seen as a Republican project, and many believed that the Post Office was

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[12] The Post Office estimated in its 1916 report that 83 percent of the rural population was served in that year.

[13] Burlington, IL is one such rural community.

[14] Act of July 28, 1916, 39 Stat. 412, 423

more responsive to Republican requests, particularly Representatives facing competitive elections (Carpenter, 2000).

To address this endogeneity problem, we use both place and time fixed effects and a set of instrumental variables. However, the inclusion of fixed effects will not provide unbiased estimates. Therefore, we use a set of instruments correlated with route allocation. In the presence of place fixed effects, our identifying assumption is that the instruments are uncorrelated with trends in our outcome variables.

3.4 Effect on Voters

The estimation of the effect of RFD rollout on voter behavior proceeds in two parts: a fixed effects estimation (section 3.4.1) and an instrumental variables estimation (section 3.4.2).

3.4.1 Fixed Effects Estimation

To understand how counties that received more RFD routes changed compared to those that received fewer, we use a fixed effects model with year and place fixed effects to control for time and place-invariant characteristics. The basic specification for each of our county-level political outcomes is:

$$Y_{ct} = \beta Routes_{ct} + \gamma_c + \delta_t + \mu \mathbf{X_{ct}} + u_{ct} \tag{3.1}$$

where Y_{ct} are our political outcomes, such as voter turnout; γ_c and δ_t are a set of county and year dummies; $\mathbf{X_{ct}}$ is a vector of county characteristics: percent of the population living in communities of more than 2,500 people and the square of that value, the percent of farmland that was "improved," the percent of non-white residents, the percent of white, foreign-born residents,[15] the natural log of the population, and dummies for the presence of Jim Crow voting laws, whether women had the right to vote, direct election in party primaries, and secret (Australian) ballots; $Routes_{ct}$ is the number of routes in county c in year t. Therefore, β, the coefficient on the number of routes, is the estimate of the causal effect of RFD routes.

As mentioned earlier, we eliminate the years 1901 to 1907 from our analysis. Additionally, we hold the number of routes in all years 1908 and later constant at their 1908 values,[16] and all years 1900 and earlier fixed at their 1900 values. Due to the changes in the structure of the rural postal system after the 1916 legislation, we focus only on the five elections immediately following the rollout of RFD (1908-1916) and the five elections immediately before (1892-1900). Given the possibility of state-level shocks (such as Gubernatorial elections), we cluster standard errors at the state level.

Data

We compiled the county-level RFD route allocations using the 1908 U.S. Official Postal Guide, which listed the number of RFD routes emanating from each post office. This gives a measure of the intensity of RFD service within a county. This is, to our knowledge, the first attempt to compile statistics on the full allocation of routes. We also compiled the number of routes in 1900 for each county using the 1900 Report of the Postmaster General. Since the official establishment of the RFD came in 1902, very few routes existed in 1900.

Our voting data are from Clubb et al. (2006), which provides data on county-level

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[15] All percents are expressed as a number between 0 and 100.

[16] While some routes were created or expanded from 1908-1916, we argue that this was due largely to population changes, which created new communities that satisfied the Post Office's requirements for route allocation.

voting in each year, including total number of votes, turnout, and vote share for most major and minor parties in elections for the House of Representatives.[17] County characteristics data are from Haines (2010). We used the method described in Hornbeck (2010) to harmonize the county boundaries to their 1890 boundaries. In considering the behavior of elected officials, we use the DW-Nominate scores of Representatives (Poole and Rosenthal, 2001), as well as their specific votes on temperance and immigration, two of the most decisive issues of the time. Biographical data on elected officials are from McKibbin (1997).

We constructed our newspaper dataset by supplementing an existing dataset by Gentzkow et al. (2012), which provides circulation data on all English-language daily newspapers printed within a county, excluding professional or social publications. We added data on semi-weekly and three times weekly papers, using the *N.W. Ayer and Son's American Newspaper Annual*. This variable does not provide perfect data on newspaper readership, as all newspapers are attributed to the printing county. However, Gentzkow et al. (2012) estimated that more than 80 percent of current newspapers are read in the counties in which they were printed, and argue that this number is likely larger for our period of study.

Table 3.1 shows the trends in most of our outcome and explanatory variables.[18] Voter turnout decreased and newspaper circulation increased significantly over our sample period. The increase in circulation was driven entirely by the expansion of daily papers (as expected from the work of Fuller (1964)). The average number of routes in 1908 was about 14, while 81 percent of all counties received at least one route.

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[17] Senate seats were assigned by state legislatures until 1914, and are therefore omitted from this analysis. All Congressional election outcomes refer only to elections for the House of Representatives.

[18] Although the table does not show statistics on mid-term election years, these years are included in our sample.

This period featured a number of changes to voting procedures. As Engstrom (2012) has shown, many of these changes affected the turnout of voters, and changes in electoral laws explain much of the decline in voter turnout in the late nineteenth and early twentieth century. Therefore, we include dummy variables for the presence of Jim Crow laws, secret (Australian) ballots, direct election in party primaries, and women's suffrage. Additionally, in Appendix 3.7.1, we include laws for office bloc ballots,[19] party column ballots,[20] and off-November elections. These data comes from Engstrom (2012). We omit these variables from the regressions shown here, as data on state laws are not available for all years. However, our findings are robust to their inclusion.

Fixed Effects Results

First, we consider voter turnout in congressional elections, using as our dependent variable the percentage of eligible, voting-age adults who cast a vote in elections. Table 3.2 shows the OLS regression results; an additional route is correlated with a 0.094 percent decrease in voter turnout in Congressional elections. However, this result is not precisely estimated. We also convert our route variable into a dummy variable equal to one if a county has a route, and zero otherwise. Receiving RFD at all is associated with a 2.70 percent, statistically significant, drop in voter turnout.

Next, we consider election competition. We constructed a set of variables that measure the number of candidates who receive vote shares above certain thresholds. Since any threshold is arbitrary, we use several (5, 10, and 20 percent).[21] We present

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[19] Ballots in which candidates are grouped by the office they are seeking, making split-ticket voting easier.

[20] Ballots that groups candidates by parties.

[21] For a small number of observations (136) zero candidates are reported as receiving at least 5 percent of votes. However, these represent uncontested elections. We impute values of 1 for the number of competitive parties, but our results are robust to dropping these observations completely.

only the results for the 10 percent threshold; other results are in an online appendix. We use this instead of the margin of victory, a more obvious measure of competitiveness. We do this because treatment (RFD routes) varies at the county level, while margins of victory vary only at the Congressional district level. This allows us to use within-district variation in RFD routes and political competitiveness.

The OLS regressions of RFD routes on the number of parties show that more routes are associated with broader support for parties, as seen in column 3 of Table 3.2. Counties that received more routes voted for a wider variety of parties.[22] Regardless of the threshold, the coefficient on RFD routes is precisely estimated, with an additional route being associated with an increase in the number of competitive parties within a county by 0.0055.

To better understand these findings, we consider the cumulative vote share of small parties, which we identify as any party other than Republican and Democratic. Lower information transmission costs may be more beneficial to small parties, whose low visibility may have made it difficult to attract votes before the introduction of RFD. Additionally, voters' ability to coordinate behind less visible candidates may have increased with the introduction of RFD.

The results are presented in column 4 of Table 3.2. The coefficient of 0.11 is statistically significant and means that a one standard deviation change in the number of routes is associated with a 0.12 standard deviation change in the vote share of small parties within a county. Taken along with the results from column 3, we can see that counties that received more routes changed their voting behavior by voting for a wider range of parties, to the benefit of smaller political parties.

Figure 3·2 shows the results of running a local polynomial smoothing on a number

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[22] In the North an additional route is associated with a lower Democratic vote share and in the South with a lower Republican vote share. Over all a greater number of routes are assorted with Populist and Progressive parties gaining vote share.

of voter outcomes by the number of RFD routes a county has in 1908. We consider the pre-rollout (1892-1900) and post-rollout (1908-1916) periods separately. Counties do not appear to differ in turnout between the pre- and post-rollout groups. However, counties with more routes show positive shifts in the values of the other outcome variables. Figure 3·3 plots the difference between the pre- and post-period averages of the residuals from the regression specified in Equation 3.1. For all outcomes but turnout this figure shows a pattern in the differences between the pre- and post-period averages that starts at zero for counties that received very few routes and that increases with number of routes. This suggests that routes are related to increases in the number of competitive parties, but not to levels of voter turnout.

Given the endogenous nature of route allocation, we cannot interpret the OLS estimates as unbiased; previous research suggests a downward bias to all of our estimates. Kernell and McDonald (1999) provide evidence that Representatives facing competitive elections prior to the establishment of RFD were more motivated to acquire routes for their districts. This echoes claims by Fuller (1964), who argued that motivated Representatives (especially Republicans) were able to obtain more routes leading up to contested elections. Voter turnout is typically higher in competitive elections, as is the number of competitive parties. This means that we should expect to see above average voter turnout and competitiveness in the years before RFD associated with high levels of route allocation. If these variables drop in the period after RFD, either because politicians have bought votes and reduced competition or because of regressions to the mean, OLS estimates will suffer from a downward bias.

Using a cross-section of our data (1908 values) we regressed the number of routes allocated to a county as a function of county characteristics and the level of election competition. We constructed a set of dummy variables, indicating whether a district had an election with a margin of victory of 20 percentage points or less or 10 points or less, in any of the three elections prior to the establishment of RFD (1896, 1898, 1900). Table 3.3 presents the results. Counties in competitive districts enjoyed between 0.84 and 1.27 more RFD routes, a 6 percent to 9 percent increase. These results support the claim of a downward bias in our OLS estimates.

There is a potential explanation for RFD to lead to a decrease in turnout. Kernell and McDonald (1999) point out that RFD routes eliminated thousands of fourth class post office positions. These were important patronage jobs, and postmasters were well-connected advocates for the Representative.[23] To the extent that postmasters were able to mobilize voters for the incumbent, the introduction of RFD could lead to a decrease in the turnout of voters and an increase in electoral competitiveness in counties. However, instead of being a source of bias in our fixed-effect estimates, this is a potential mechanism through which RFD could change our outcome variables.

RFD does not appear to be associated with observable economic agricultural variables. Regressing the number of routes on either the percent of farmland that is improved, or the acreage of farmland within a county, using the fixed-effects specification above, fails to find either economically or statistically significant results. For example, one more RFD route is associated with a statistically insignificant 0.006 percent decrease in the percent of farmland that was improved. If the bias of our OLS estimates were due to omitted economic variables, we would expect RFD routes to be associated with observable economic variables as well.[24]

3.4.2 Instrumental Variables Estimation

To address the bias of fixed effects coefficients, we use two sets of instruments for the number of routes a county receives. In choosing suitable instruments, we focus on

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[23] In contrast mail carriers were hired through an apolitical civil-service system.

[24] We also looked for changes in the number of banks, using county-level numbers of banks in 1900 and 1910. We also fail to observe a relationship between RFD and bank growth.

the requirement that routes be along passable roads. The ability for communities to successfully petition for an RFD route was a function of the quality of roads over that time period. With the existence of place fixed effects, our goal is to find variables uncorrelated with trends in our outcome variables. Therefore, even if the instrumental variable is correlated with levels of political activity, it will fall into the place fixed effect, and will be uncorrelated with the error term in our second stage regression.

The first is county-level spending of roads and bridges in 1890. At that time, counties and townships bore the brunt of road funding (Fuller, 1955). Because 1890 is well before the establishment of even the experimental RFD routes, it would have been impossible for county officials to have built roads in anticipation of preferential rural route allocation. Additionally, with the establishment of the Office of Road Inquiry, government responsibility for roads no longer fell on counties, so concerns of auto-correlation of county spending in years during our sample are minimized.

Our other instrument is a set of laws that outline the statutory environment in each state at the onset of RFD route allocation. Between 1888 and 1895, almost every state passed numerous laws related to roads.[25] These laws had lasting impacts on the ability of rural communities to establish roads. Therefore, these laws can be used as instruments for route allocation. We use these state-level laws in combination with the county-level instruments.

The dataset on county-level spending on roads and bridges was constructed using the *Report on Wealth, Debt, and Taxation.*[26] To determine the state laws passed with regards to local road construction, we used a unique set of documents that provide data on laws passed by state legislatures in the period immediately before

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[25] According to the Office of Road Inquiry, most state laws concerning the establishment of roads before 1885 were largely ineffectual.

[26] *Report on Wealth, Debt, and Taxation at the Eleventh Census, 1890: Valuation and Taxation.*

the establishment of the first RFD routes.[27] We found that relevant legislation fell into one of the following categories:

1. Outlining road quality rules, or establishing an office of overseer.
2. Establishment of road commissioners, or empowering county commissioners to govern roads; in smaller states this took the form of the establishment of state road offices.
3. Use of convict labor for road construction.
4. Allocation of state money for road construction.

We constructed a dataset with four dummy variables, each equal to one if a state passed a law, and zero otherwise. Southern states, where poor road quality was continually noted as an impediment to the approval of petitions for RFD routes, had few laws governing the construction of roads. Most Midwestern states passed at least one law, while Western states were particularly proactive in passing legislation.

Thus, the first stage of our two stage least squares estimation is:

$$Routes_{ct} = \phi Spending_c * Post_t + \eta \mathbf{Laws_c} * Post_t + \delta_t + \gamma_c + \beta \mathbf{X_{ct}} + e_{ct} \tag{3.2}$$

where $Routes_{ct}$ is the number of routes in county c and year t; $\mathbf{Laws_c}$ is the set of law dummies; $Spending_c$ is log of spending on roads in 1890; δ_t and γ_c are time and county fixed effects; $\mathbf{X_{ct}}$ is the set of covariates used in our second stage. We interact each of our instruments with a $Post_t$ dummy variable, equal to one if the year is 1908 or after, and zero otherwise.

Table 3.4 shows the results for this regression, performed separately for county and state-level variables. Increased spending on roads and bridges in 1890 is associated

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[27] *State Laws Relating to the Management of Roads: Enacted in 1888-1893,* and *State Laws Relating to the Management of Roads: Enacted in 1894-1895,*' both published by the U.S. Department of Agriculture, Office of Road Inquiry.

with increased RFD route allocation a decade later. Laws providing mechanisms for oversight and governance over the roads appears to increase the number of routes a county receives, laws allocating state funds, or the use of convict labor led to a decrease in the number of routes. These laws may have been aimed at the construction of highways, and diverted resources away from rural roads. As the F-statistics show, our county-level instrument is sufficiently strong, but the set of state laws are too weak to be used as an instrument by itself.[28] We use both county and state-level instruments together in all IV regressions.

Clearly, improved roads can affect rural life in several ways, including access to markets and travel times to urban centers, which may in turn affect political behavior completely independently of RFD. However, our instruments were chosen because they would have affected the quality of roads in both the pre- and post-rollout periods. If the effect of roads on our outcome variables is common in the pre- and post-rollout periods, it will be captured by the place fixed effect. This assumes that the instrumental variables do not place communities on different paths. Fortunately, this assumption can be evaluated, by looking for parallel trends in our outcome variables across different values of our instrumental variables.

If the instruments are valid, time shocks should be similar across different values of the instrument. To test this, we separate our sample into counties that spend positive amounts on roads and bridges in 1890, and counties that spent nothing. Figure 3·4 shows that the behavior of counties that spent positive amounts of money on roads and bridges appears to follow the same trends as counties that spent nothing.

We see from the fixed effects results that urbanization had an impact on voting behavior, and it is possible that the instrumental variables changed the density of rural communities. Using the 1900 and 1910 censuses, we regressed the increase in

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[28] We will present the Kleibergen-Paap Wald statistic with our IV regressions.

the percent of population living in urban areas in a county on our instruments. We find that none of our instruments affect in the rate of urbanization, as the estimates fail to be statistically significant.

One well-documented drawback to using IV involves the "intent-to-treat," which may limit the generalization of our findings. The effect that each of our instrumental variables may have on the allocation of routes depends on the region, climate, and a host of other factors. For example, the point estimate on spending on roads is positive in all regions of the country, but has a coefficient of 0.0000675 in Midwestern states and one that is more than 5.5 times higher (0.000372) in the South, though both point estimates are statistically significant.[29] This may have been due to the flat land in the Midwest, which required less grading to be passable. In the South, an area where the Postal Service repeatedly denied many petitions for routes due to poor roads, government action may have had more of an impact in determining where routes were allocated. These results also provide assurance that the IV estimates do not violate the monotonicity assumption. As Angrist et al. (1996) show, in order for IV regressions to provide an estimate of the local average treatment effect, the instrument cannot affect two different groups in opposite ways. This means that increased road spending should only affect the number of routes a community receives by increasing that number (monotonicity). However, we observe road spending to lead to more routes in all geographic regions.

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[29] Regions are using the five regions as defined in the census data.

IV Results

The results from the IV regression are presented in Table 3.5.[30] Column 1 shows the results using voter turnout as the dependent variable. The negative correlation seen in the OLS results disappears, and we now observe a positive coefficient. An additional route leads to a 0.13 percentage point increase in turnout, though this estimate is not precise.

The IV results for the number of parties receiving 10 percent of the vote, shown in column 2, match the OLS finding of a positive causal effect, and point estimates that are larger than those found in the OLS regressions. The point estimate of 0.0247, means that a one standard deviation increase in the number of routes leads to an increase of 0.55 in the number of parties competitive in an election. As before, we find a shift towards small parties with the rollout of RFD. The IV point estimate, 0.831, is very precisely estimated, and about 7.5 times larger than the OLS estimates. For all regressions, the Kleibergen-Paap Wald statistic is 10.4, indicating that weak instruments are not a concern with this specification.

We find that RFD increased competition, but failed to increase voter turnout in Congressional elections. For each of our measures of the distribution of votes across a county, the IV regressions are roughly consistent with the OLS findings, the point estimates are larger in the IV specification.

Because our treatment variable does not vary within the pre- and post-rollout time periods, an alternative specification to the fixed effects analysis described above is first-differences. One concern with the fixed effects analysis is that the accuracy of

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[30] IV regressions were done using STATA's xtivreg2 command (Schaffer, 2010). Residual sum of squares is calculated using the structural equation, instead of the residuals for second-stage regression. Therefore, the residual sum of squares could be greater than the total sum of squares, resulting in a negative model sum of squares, and therefore a negative r-squared. Wooldridge (2006) warns against making statistical judgments from r-squared in IV regressions, since its value does not have the standard interpretation of the squared correlation coefficient.

our estimates could derive from the numerous pre- and post-election observations for the same county, instead of from variation in the instrument or the number of routes. We calculate each variable by taking the average within a county over all elections held in 1908 and later, and subtracting from this value the average of all elections held in 1900 and before. Results of the IV regressions are presented in an online appendix. The previous findings for the effect of RFD do not significantly change. The results are similar to those found in Table 3.5.

3.4.3 Potential Mechanisms

Up to this point, we have not made any attempt to disentangle the mechanisms through which RFD affected political behavior. RFD could have potentially changed political behavior because of increases in the mail, a decrease in the number of fourth class postmasters, or some other reason.[31] Anecdotal evidence suggests that the introduction of rural routes increased the circulation of newspapers. One of the first reports from local postal carriers on the effect of RFD included the following statement by a postal worker in Oregon (Yearbook, 1903):

> Before free delivery was started there were 13 [subscriptions to] daily papers taken at Turner (OR) post office. Today there are 113. This shows that the farmers are getting in touch with the world and are quick to avail themselves of all educational facilities.

Using a dataset on newspapers, we find that one additional route is associated with a 1.77 percent increase in total newspaper circulation. The potential for newspapers to impact political behavior follows directly from their role as a conveyor of

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[31] Parcel Post was introduced in 1913. To see if its introduction drove the observed effect, we restricted our sample to just the post-rollout years (1908-1916), and ran the IV regression using 1908-1912 as the pre-treatment sample and 1914-1916 as the post-treatment sample. If RFD had a stronger effect after parcel post, we would expect a positive coefficient on routes. We do not observe a positive effect.

information about policy debates, news of social or political importance, and even candidates' behavior. Newspapers provided a wealth of information about political activity. For example, over a five-day period in 1904, the *Bemidji (MN) Daily Pioneer* included stories about the Wisconsin Secretary of State completing the state's ballot, an Indiana Senator speaking at Indiana University, and an illness contracted by a Minnesota gubernatorial candidate. Similarly, Kernell and Jacobson (1987) show that late nineteenth century newspapers provided extensive coverage of the daily behavior of Congress.

To test the hypothesis that newspapers were an important mechanism through which RFD routes affected political behavior, we compared the impact of RFD in counties with and without newspapers by estimating each group separately.[32] [33] Table 3.6 shows that the causal effect of RFD is larger in counties with daily newspapers. The estimate for turnout is positive in counties with newspapers, but mildly negative in counties without newspapers, though neither point estimate is statistically different from zero. For measures of competitiveness, the causal effect in counties with newspapers is at least four times as large as counties without newspapers, and though the point estimates for the vote share of small parties is similar in counties with and without newspapers (columns 5 and 9), it is only precisely estimated in counties with newspapers.[34] If RFD only affected political behavior only through the impact of better roads (or any other mechanism that was independent of newspapers), we would expect the coefficient on the number of routes to be identical for both groups. These results are suggestive, not conclusive, evidence that newspapers played a critical role

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[32] To ensure that our sub-samples do not change over time, we defined a county as having a newspaper only if it had a newspaper by 1900.

[33] We do this instead of interacting our Route variable, because doing so would have required using both our Route variable and the interaction term as instrumented variables, significantly decreasing the power of our instruments.

[34] These results are strongest in the North in places with Republican papers.

in the political changes that occurred because of RFD.

If RFD led to changes in economic outcomes, these changes could in turn affect political outcomes. We find no evidence that RFD led to changes in observable economic variables for rural areas. Specifically, using both (i) the amount of farmland in a county (both as a level, and as a percentage of total area), and (ii) the percent of improved farmland on farms, as our outcome variables in the IV regressions, we find that the number of routes has no effect on these outcomes. Using farmland as the outcome variable, the sign is negative but it is very imprecisely estimated, as it is when improved farmland is used as the outcome. RFD routes did not appear to have an effect on observable agricultural outcomes, providing further evidence that it was information, instead of some other mechanism, that is driving our results.

3.5 Congressional Representatives

With richer information networks, voters may select Representatives with different attributes, or they may elicit different actions from elected officials. We consider the potential effect that better-informed voters may have on Representatives. Voters may punish Representatives who act against the voters' wishes, but will only do so if they are aware of the Representative's actions. Therefore, if one subset of voters receives a positive shock in their access to information, we would expect to observe a shift in the policy positions of elected officials towards positions favorable to this better-informed subset. We estimate the impact of RFD on both the overall policy positions of Representatives and their support of several specific policies.

3.5.1 Policy Position Scores

Developed by Poole and Rosenthal, DW-Nominate assigns each member of the House of Representatives a score based on roll-call votes over two separate dimensions. The first dimension is interpreted as the traditional liberal-conservative stances and will be the focus of our analysis. We use this score as our dependent variable in both the OLS and IV specifications above, along with a political party dummy variables. Because the DW-Nominate score only varies at the congressional district level, we aggregate each of our county-level variables up to the district level.[35]

We first consider what stances were typically associated with rural communities over our sample period. Figure 3·5 shows the correlation between the percentage of urban residents in a district, and the policy stances of elected officials. Even when controlling for party membership, Representatives of rural districts feature more negative DW-Nominate scores. Therefore, we would expect RFD routes to result in a negative shift in the policy scores of elected officials.

Columns 1 and 2 in Table 3.7 show the effect of routes on the policy decisions of Representatives. No strong correlation is observed in the OLS results. Our instrumental variable results, however, show strong causal effects. Districts with more RFD routes see negative shifts in the DW-Nominate scores of their elected officials. Because we included dummies for party affiliation, this result cannot be the result of shifts from one party to another. The point estimate for the IV regression of -0.00103, which is significant at the 5 percent level, indicates that a one standard deviation change in the number of routes leads to a change of 0.68 standard deviations in the DW-Nominate score. This shift can be seen in Figure 3·5, which shows both

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[35] For counties that straddle more than one congressional district, we divided each variable into the number of districts into which the county was split, and distributed those values evenly across the districts.

the within-party means of DW-Nominate scores and the shift a one standard deviation change in the number of routes would cause from this mean. As a negative shift in DW-Nominate scores indicates more rural-friendly stances, an increased number of routes caused the elected officials adopt policies more in line with rural voters.

3.5.2 Temperance and Immigration

To illustrate shifts in Representatives' positions, we examine two issues that were particularly contentious in this period: pro-temperance policies and immigration restrictions. Pushes for immigration restrictions and the prohibition of alcohol were tied to the Nativist movement, which sought to restrict the spread of foreign in-migration and culture in America. Nativists, who were frequently rural Protestants, often took aim at Irish Roman Catholics and Jewish Americans, for whom alcohol was part of their culture. Although support for both policies came from a variety of groups, support was systematically greater in rural areas (Engs, 2003, pg. 263).

We chose these two issues for a number of reasons. First, unlike many hot topics of the time, they were salient through the whole period of 1892-1916.[36] Second, immigration restrictions and temperance are also plausibly exogenous to the issue of RFD. One would not expect a person's positions on ether issue to be directly affected by either receiving or not receiving RFD, unlike policies dealing with infrastructure or agricultural subsidies.

During our sample period, Congress voted many times on these two issues. For example, the 62nd and 63rd Congresses voted on temperance-related issues three times in each Congress, while the 64th Congress voted six times. Not counting procedural votes, we observe 28 votes on immigration restrictions and 27 votes on temperance.

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[36] Monetary policy was hotly debated during the early part of our period (e.g. William Jennings Bryan's "Cross of Gold" speech). However, after the U.S. formally adopted the gold standard in 1900, Congress only called a few votes on these issues.

The list of House floor votes and issue codes was taken from Poole and Rosenthal (2001). For each vote pertaining to temperance policies or immigration restriction, we used the Congressional Record to determine if a “yea” (or a “nay”) vote is a vote explicitly for or against, or if the voter was not clearly taking a position (i.e., a “present” vote).

Table 3.7 examines the relationship between RFD routes and votes supporting temperance or immigration restrictions; the “for” columns estimate the effect of RFD on the number of times a Representative voted explicitly for a temperance-related policy, whereas the “against” columns estimate the effect of RFD on the number of times a Representative explicitly voted against a temperance-related policy.[37] A one standard deviation increase in the number of RFD routes leads to 0.92 more votes for temperance and a decrease of 0.84 votes against it in a given district. The within-Representative increase in likelihood to vote for temperance explains about 40 percent of this within district change, with changes in the identity of the Representative explaining the rest. Similarly, Columns 5 and 6 examine the relationship between RFD routes and votes supporting immigration restriction. An increase of one standard deviation in the number of RFD routes leads to 0.63 more votes for immigration restrictions, and a decrease of 0.61 votes against immigration restrictions in a given district.

3.6 Concluding Remarks

Timely and affordable access to information is a major driver of both economic and political activity. In the late nineteenth and early twentieth century public information was largely conveyed through newspapers, making access to the public discourse

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[37] In each of these, absence from the vote or a “present” vote are coded as a zero.

contingent on timely and convenient access to the daily paper. The implementation of RFD dramatically increased rural America's connection to the outside world, making it feasible to get daily news, and reducing the cost of private communication. Using data on the number of RFD routes in a county, we estimate the impact of access to information on voters' and elected Representatives' behavior. In doing so, we shed light on how increased information flows changed political outcomes by increasing political participation and voice for rural areas.

RFD significantly increased the consumption of daily newspapers. We estimate that there was a 25 percent increase in the circulation of newspapers in areas which received the service. The rural resident became better-informed of the political goings on far from his farm gate, increasing their effective voice as citizens. It made rural voters better informed about political issues, and about the range of available parties, allowing them to better select their preferred candidates.

Our results suggest that RFD had a substantial effect on the political behavior of rural citizens. While rural mail routes did not lead to an increase in voter turnout, it broadened the number of political parties able to appeal to rural voters. A one standard deviation change in routes led to 0.4 additional parties receiving a competitive percentage of the votes. RFD routes also increased the vote share for smaller political parties, many of which were advocating for policies in line with rural tastes. These results are driven largely by counties which had newspapers by 1900.

RFD allowed farmers to more effectively monitor their elected Representatives, leading to a more effective political voice for rural residences. An increase of one standard deviation in routes led to a negative shift of 0.67 standard deviations in their Representative's DW-Nominate score, moving it towards positions popular in rural areas. In terms of specific policies, a one standard deviation in RFD routes led to 0.9 more votes for temperance and 0.6 more votes for immigration restrictions.

This suggests that support for several Populist causes that were taken up in the Progressive Era were strengthened by the existence of RFD.

Our results provide support to theories of political empowerment, as voters with increased access to mail and news elicit more favorable policies from their elected officials. RFD, in increasing individuals' access to information and newspapers, increased their social capital. The importance of social capital on the development and evolution of democracies has been well established (Lipset, 1959; Woolcock, 2001), as has the role of information networks and access to mass media (Blair, 2000). Through our study of RFD, we have been able to more fully explore the mechanisms through which this development occurs, and show the importance of information networks on the democratic process.

3.7 Appendices

3.7.1 Appendix A: State Election Laws

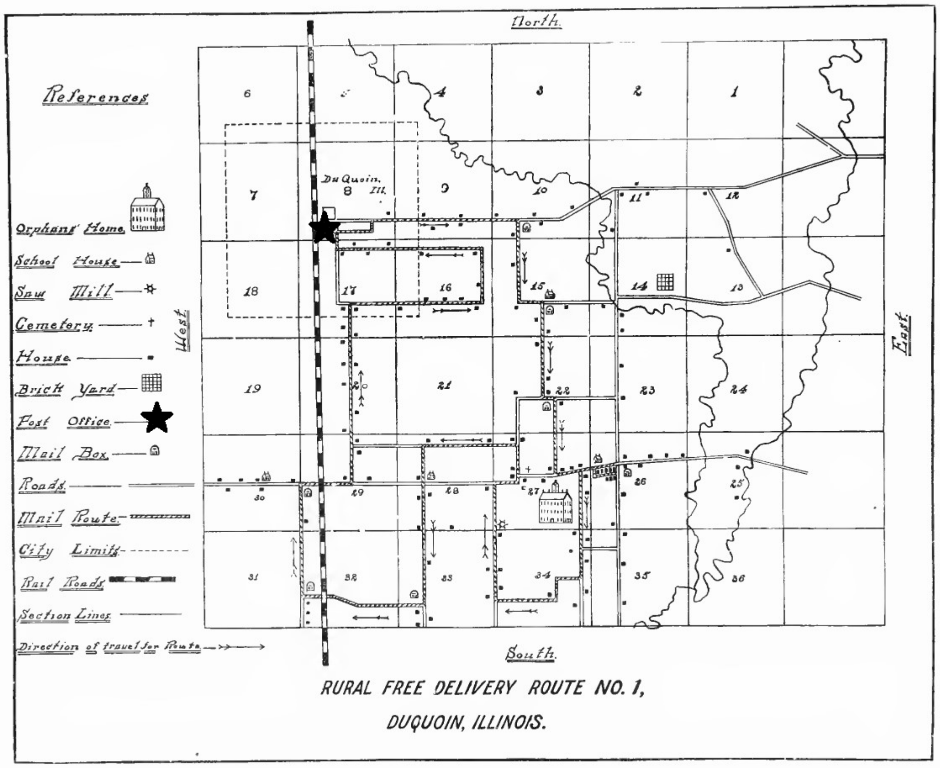
Table 3.8 replicates the results from Tables 3.5, with the inclusion of three state law variables: office block ballots, party column ballots, and off-November elections. These variables were omitted from the primary regressions because data was not available for all years. The point estimates are similar to those shown in Tables 3.5, though the estimates are not as precisely estimated. Regressions broken down by the presence of newspapers like those presented in Table 3.6 are not shown here, but are likewise similar.

3.7.2 Appendix B: Effects by Region

Table 3.9 shows our primary results split by region, presence of a paper and, in the South, race composition of a county. At this level of disaggregation the instrument is often weak. The variables measuring competition are positive in the North East and Midwest in counties with papers. There is no statistically significant effect of RFD on these outcomes in the South Central region and the West, though the point estimates are large in counties with papers in the West. In the South there is a negative effect in counties with papers. RFD helped rural voters coordinate, through papers. In the South there is a negative effect of RFD for both turnout and competition, primarily in counties with papers and with higher white populations. We also observe (not shown in the table) a drop in the vote share for the Republican party (and an increase in the vote share for the Democrats) in these largely white counties with newspapers. It appears that in the South, where the Democratic party is dominant (the average number of parties receiving 5 percent of the vote is less than 1.25), RFD lead to an increase in that dominance. Again, however, the low Wald statistics suggest that we should be cautious about claims.

3.8 Figures

Figure 3·1: RFD Route Map



Source: "Rural free delivery; its history and development. Extracts from the annual report of first Assistant postmaster-general Perry S. Heath for the fiscal year ended June 30, 1899" (Post Office Department, 1899).

Figure 3·2: Voter Outcomes vs. Number of RFD Routes in 1908

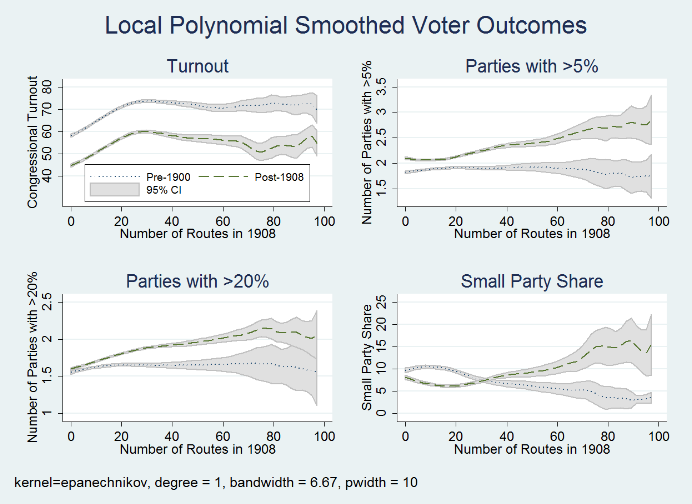
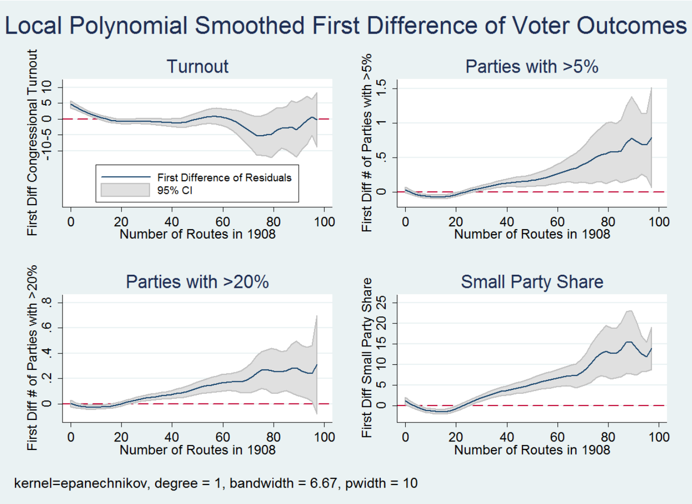
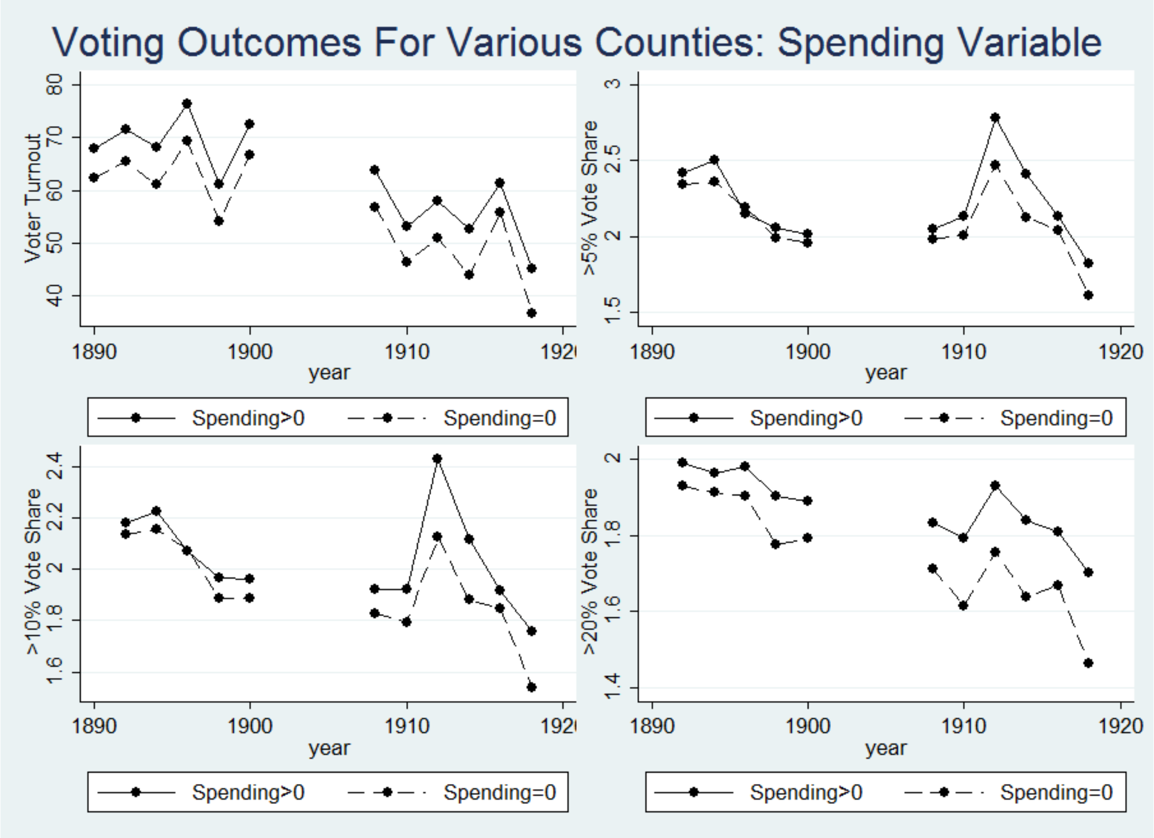


Figure 3·3: First Differences of Voter Outcomes vs. Number of RFD Routes in 1908



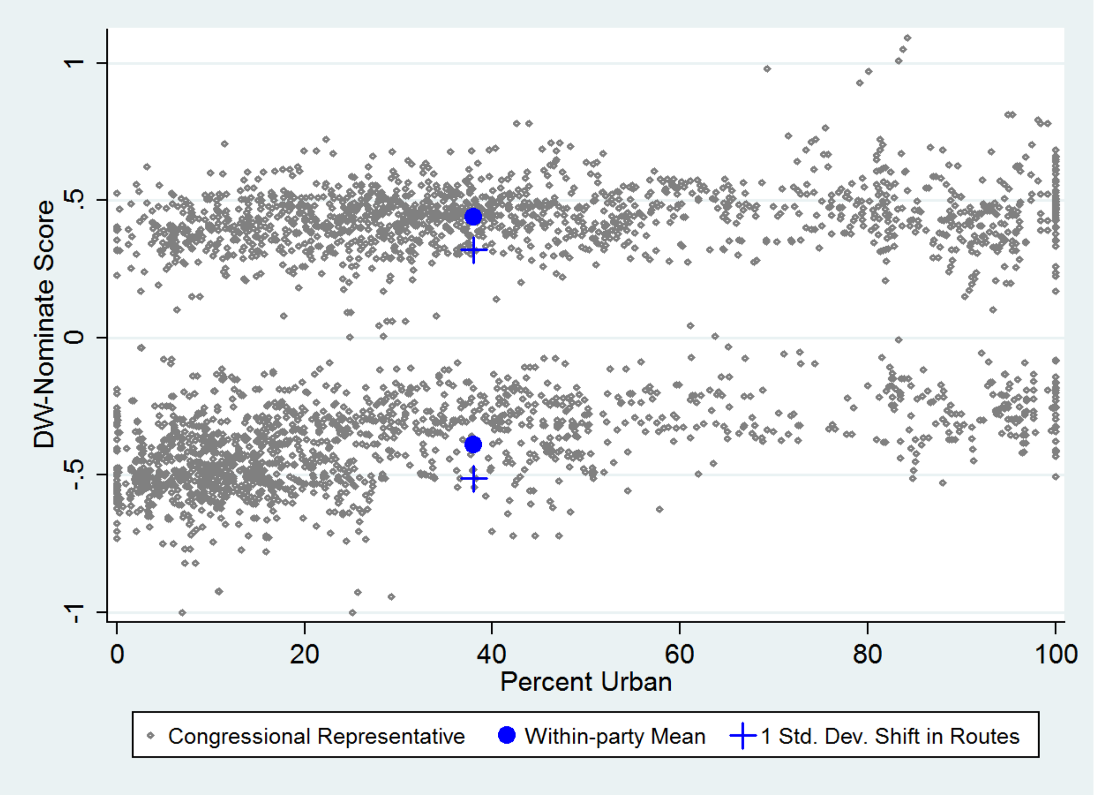
Sources: RFD routes from the 1908 United States Official Postal Guide; voting data are from Clubb et al. (2006); county characteristics are from Haines (2010) (county boundaries fixed at 1890 values as in Hornbeck (2010)).

Figure 3·4: Trends, Spending



Sources: Voting data are from Clubb et al. (2006); spending are collected from the "Report on Wealth, Debt, and Taxation" (Upton, J.K., 1895).

Figure 3·5: DW-Nominate Scores vs. Percent Urban



Sources: Data about elected officials from the DW-Nominate project; county characteristics are from Haines (2010).

3.9 Tables

Table 3.1: Summary Statistics: Means of County Level Variables by Year

YEAR	1892	1896	1900	1908	1912	1916
Congressional Turnout	68.02	72.15	68.96	60.55	54.56	58.87
	(22.21)	(21.59)	(22.97)	(24.17)	(21.93)	(21.38)
Candidates	2.39	2.19	1.98	2.02	2.62	2.07
	(0.58)	(0.47)	(0.37)	(0.53)	(0.92)	(0.62)
Parties >5	2.39	2.19	1.99	2.03	2.63	2.08
	(0.58)	(0.47)	(0.36)	(0.52)	(0.89)	(0.59)
Small Party Share	12.59	10.03	2.14	3.15	14.86	5.20
	(16.13)	(17.20)	(5.56)	(5.40)	(14.77)	(12.44)
Total Newspaper Circulation	1,774	2,207	4,356	7,391	9,039	10,988
	(9,869)	(12,097)	(42,102)	(72,529)	(88,091)	(102,439)
Daily Newspaper Circulation	1,746	2,176	4,312	7,350	9,001	10,968
	(9,848)	(12,083)	(42,098)	(72,529)	(88,077)	(102,440)
Percent Urban	12.46	12.69	14.22	15.98	18.35	19.13
	(20.92)	(21.21)	(21.44)	(22.77)	(23.62)	(24.25)
Percent Improved Farmland	55.64	52.90	52.82	56.14	56.51	57.35
	(22.59)	(23.56)	(24.80)	(24.21)	(24.41)	(23.82)
Percent Non-white	9.92	11.97	11.06	10.67	9.26	8.75
	(17.52)	(19.93)	(18.92)	(18.66)	(17.30)	(16.32)
Percent Foreign-born	11.59	10.77	9.63	9.21	9.38	8.73
	(12.41)	(11.52)	(10.47)	(9.78)	(9.40)	(8.73)
Ln(Population)	9.55	9.58	9.62	9.78	9.81	9.84
	(1.12)	(1.13)	(1.13)	(1.00)	(1.03)	(1.04)
Observations	2,162	2,249	2,308	2,342	2,191	2,148

Note: Because there are some missing counties in the election data, the number of observations is not identical for each year.

Sources: RFD routes from the 1908 United States Official Postal Guide; voting data are from Clubb et al. (2006); newspaper data are from the *N.W. Ayer and Son's American Newspaper Annual*, and Gentzkow et al. (2012); county characteristics are from Haines (2010) (county boundaries fixed at 1890 values as in Hornbeck (2010)).

Table 3.2: Fixed Effects Results for Voter Outcomes

VARIABLES	(1) Turnout	(2) Turnout	(3) >10 Percent	(4) Small Party Share
RFD Routes	-0.0935		0.00552***	0.113**
	(0.0600)		(0.00156)	(0.0441)
RFD Dummy		-2.679*		
		(1.378)		
Demographics	Yes	Yes	Yes	Yes
County F.E.	Yes	Yes	Yes	Yes
Year F.E.	Yes	Yes	Yes	Yes
Counties	2,403	2,403	2,403	2,403
Observations	22,433	22,433	22,433	22,433
R-squared	0.807	0.807	0.439	0.371

Additional controls include county and year fixed effects, the percent of the county that lives in an urban area and it's square, the percent of the county's farm land that is improved, the percent of the county that is not white, the percent of the county that is foreign born, the logarithm of the counties population, and dummy variables indicating the presence of Jim Crow laws, women's suffrage, secret ballots, and direct primaries. Standard errors, clustered at state level, in parentheses.

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Sources: RFD routes from the 1908 United States Official Postal Guide; voting data are from Clubb et al. (2006); county characteristics are from Haines (2010) (county boundaries fixed at 1890 values as in Hornbeck (2010))

Table 3.3: Determinants of Route Allocation

VARIABLES	(1) 20 Percent	(2) 10 Percent
Close Election	1.270**	0.843*
	(0.561)	(0.479)
Demographics	Yes	Yes
State F.E.	Yes	Yes
Counties/Observations	2,549	2,549
R-squared	0.634	0.616

Additional controls include state and year fixed effects, the percent of the county that lives in an urban area and it's square, the percent of the county's farm land that is improved, the percent of the county that is not white, the percent of the county that is foreign born, the logarithm of the counties population, and dummy variables indicating the presence of Jim Crow laws, women's suffrage, and secret ballots. Standard errors, clustered the Congressional District level, in parentheses.

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Sources: RFD routes from the 1908 United States Official Postal Guide; voting data are from Clubb et al. (2006); county characteristics are from Haines (2010) (county boundaries fixed at 1890 values as in Hornbeck (2010))

Table 3.4: First Stage Regression

VARIABLES	(1) Instrument: Spending	(2) Instrument: State Laws
Road Spending	0.000121***	
	(0.0000385)	
Oversight		2.713
		(2.35)
Governance		5.198*
		(2.949)
Convict Labor		-7.001***
		(2.497)
State Money		-6.865*
		(3.98)
F-Stat (excluded instruments)	9.93	3.56
Demographics	Yes	Yes
County/State F.E.	Yes	Yes
Year F.E.	Yes	Yes
Counties/States	2403	43
Observations	22,212	22,212
R-squared	0.768	0.775

Additional controls include county or state and year fixed effects, the percent of the county that lives in an urban area and it's square, the percent of the county's farm land that is improved, the percent of the county that is not white, the percent of the county that is foreign born, the logarithm of the counties population, and dummy variables indicating the presence of Jim Crow laws, women's suffrage, and secret ballots. Standard errors, clustered at the state level, in parentheses.

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Sources: RFD routes from the 1908 United States Official Postal Guide; county characteristics are from Haines (2010) (county boundaries fixed at 1890 values as in Hornbeck (2010)); spending are collected from the "Report on Wealth, Debt, and Taxation" (Upton, J.K., 1895); state laws information are from Stone (1894, 1896).

Table 3.5: IV Regression for Voter Outcomes

VARIABLES	(1) Turnout	(2) > 10 percent	(3) Small Party
RFD Routes	0.130	0.0247***	0.831**
	(0.321)	(0.00782)	(0.355)
F-Stat.	10.4	10.4	10.4
Demographics	Yes	Yes	Yes
County F.E.	Yes	Yes	Yes
Year F.E.	Yes	Yes	Yes
Counties	2,403	2,403	2,403
Observations	22,212	22,212	22,212
R-squared	0.147	-0.033	-0.107

Additional controls include county and year fixed effects, the percent of the county that lives in an urban area and it's square, the percent of the county's farm land that is improved, the percent of the county that is not white, the percent of the county that is foreign born, the logarithm of the counties population, and dummy variables indicating the presence of Jim Crow laws, women's suffrage, and secret ballots. Standard errors, clustered at state level, in parentheses. The cluster-robust Kleibergen-Paap Wald rk F statistic is reported.

*** p<0.01, ** p<0.05, * p<0.1

Sources: RFD routes from the 1908 United States Official Postal Guide; county characteristics are from Haines (2010) (county boundaries fixed at 1890 values as in Hornbeck (2010)); spending are collected from the "Report on Wealth, Debt, and Taxation" (Upton, J.K., 1895); state laws information are from Stone (1894, 1896).

Table 3.6: Effects By Newspaper Presence for Voter Outcomes

	(1) Turnout	(2) Turnout	(3) > 10 Percent	(4) > 10 Percent	(5) Small Party	(6) Small Party
Newspaper	NO	YES	NO	YES	NO	YES
RFD Routes	-0.181	0.0725	0.00692	0.0287***	0.563	0.577**
	(0.385)	(0.249)	(0.00941)	(0.00754)	(0.381)	(0.288)
F-Stat.	14.28	10.1	14.28	10.1	14.28	10.1
Demographics	Yes	Yes	Yes	Yes	Yes	Yes
County F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Year F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Counties	1685	718	1685	718	1685	718
Observations	15,214	6,998	15,214	6,998	15,214	6,998
R-squared	0.181	0.138	0.035	-0.121	-0.015	-0.067

*** p<0.01, ** p<0.05, * p<0.1

Additional controls include county and year fixed effects, the percent of the county that lives in an urban area and it's square, the percent of the county's farm land that is improved, the percent of the county that is not white, the percent of the county that is foreign born, the logarithm of the counties population, and dummy variables indicating the presence of Jim Crow laws, women's suffrage, and secret ballots. Standard errors, clustered at state level, in parentheses. The cluster-robust Kleibergen-Paap Wald rk F statistic is reported.

Sources: RFD routes from the 1908 United States Official Postal Guide; county characteristics are from Haines (2010) (county boundaries fixed at 1890 values as in Hornbeck (2010)); spending are collected from the "Report on Wealth, Debt, and Taxation" (Upton, J.K., 1895); state laws information are from Stone (1894, 1896).

Table 3.7: Policy Decisions and Route Allocation

Dependent Variable: Number of Votes For or Against

	DW Nominate		Temperance		Immigration Restriction	
VARIABLES	(1) DW Nominate OLS	(2) DW Nominate IV	(3) Votes For IV	(4) Votes Against IV	(5) Votes For IV	(6) Votes Against IV
Routes	0.000065	-0.00103**	0.0135***	-0.0123***	0.00916**	-0.00891*
	(0.000306)	(0.000505)	(0.00313)	(0.00284)	(0.00398)	(0.00461)
F-Stat.		6.81^{+}	3.91^{++}	3.91^{++}	5.03^{+++}	5.029^{+++}
Demographics	Yes	Yes	Yes	Yes	Yes	Yes
County F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Year F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Districts	368	359	359	359	359	359
Observations	2,795	2,785	2,053	2,053	2,053	2,053
R-squared	0.703	0.153	0.047	0.031	0.206	-0.023

$^{+}$ When standard errors are clustered at the district level the F statistic is 16.7.
$^{++}$ When standard errors are clustered at the district level the F statistic is 10.12.
$^{+++}$ When standard errors are clustered at the district level the F statistic is 13.42.

*** p<0.01, ** p<0.05, * p<0.1

Additional controls include county and year fixed effects, the percent of the county that lives in an urban area and it's square, the percent of the county's farm land that is improved, the percent of the county that is not white, the percent of the county that is foreign born, the logarithm of the counties population, and dummy variables indicating the presence of Jim Crow laws and secret ballots. Standard errors, clustered at state level, in parentheses. The cluster-robust Kleibergen-Paap Wald rk F statistic is reported.

Sources: RFD routes from the 1908 United States Official Postal Guide; county characteristics are from Haines (2010) (county boundaries fixed at 1890 values as in Hornbeck (2010)); spending are collected from the "Report on Wealth, Debt, and Taxation" (Upton, J.K., 1895); state laws information are from Stone (1894, 1896).

3.9.1 Appendix Tables

Table 3.8: IV Regression for Voter Outcomes: All Election Laws

	(1)	(2)	(3)
VARIABLES	Turnout	> 10 Percent	Small Party
RFD Routes	0.0943	0.0206**	0.719*
	(0.333)	(0.00820)	(0.371)
F-Stat.	10.7	10.7	10.7
Demographics	Yes	Yes	Yes
County F.E.	Yes	Yes	Yes
Year F.E.	Yes	Yes	Yes
Counties	2,403	2,403	2,403
Observations	21,663	21,663	21,663
R-squared	0.154	0.002	-0.069

*** p<0.01, ** p<0.05, * p<0.1

Additional controls include county and year fixed effects, the percent of the county that lives in an urban area and it's square, the percent of the county's farm land that is improved, the percent of the county that is not white, the percent of the county that is foreign born, the logarithm of the counties population, and dummy variables indicating the presence of Jim Crow laws, women's suffrage, and secret ballots. Standard errors, clustered at state level, in parentheses. The cluster-robust Kleibergen-Paap Wald rk F statistic is reported.

Sources: RFD routes from the 1908 United States Official Postal Guide; county characteristics are from Haines (2010) (county boundaries fixed at 1890 values as in Hornbeck (2010)); spending are collected from the "Report on Wealth, Debt, and Taxation" (Upton, J.K., 1895); state laws information are from Stone (1894, 1896).

Table 3.9: IV Regression for Voter Outcomes Split by Region

	(1) No Paper NE	(2) Paper NE	(3) No Paper MW	(4) Paper MW	(5) No Paper South Central	(6) Paper South Central
			Turnout			
RFD Routes	0.527	-0.289	-0.0997	0.108	-1.802**	-1.081***
	(0.725)	(0.201)	(0.462)	(0.394)	(0.754)	(0.257)
			Number of Parties with > 10 Percent			
RFD Routes	-0.00801	0.0193***	0.00923	0.0256**	0.0110	0.00559
	(0.00759)	(0.00209)	(0.00777)	(0.0104)	(0.0116)	(0.00426)
			Small Party Share			
RFD Routes	-0.271	0.429***	1.454***	1.224**	0.438	0.469***
	(0.232)	(0.0541)	(0.446)	(0.525)	(0.538)	(0.133)
Counties	76	138	647	372	591	97
Wald Stat.	3.738	50.97	7.581	5.343	11906	54.75

	(7)	(8)	(9)	(10)	(11)	(12)
	<13 Percent Nonwhite		>13 Percent Nonwhite			
	No Paper South	Paper South	No Paper South	Paper South	Paper West	No Paper West
			Turnout			
RFD Routes	-0.467***	-0.634***	3.015	0.773	-3.327***	-0.642**
	(0.152)	(0.243)	(2.676)	(1.226)	(0.479)	(0.266)
			Number of Parties with > 10 Percent			
RFD Routes	0.00476	-0.0130***	0.0181	-0.0258*	0.0568	-0.00289
	(0.00301)	(0.00456)	(0.0280)	(0.0138)	(0.104)	(0.0144)
			Small Party Share			
RFD Routes	0.214	-0.350***	2.946	0.365	-1.987**	-0.00193
	(0.150)	(0.0726)	(2.187)	(0.846)	(0.956)	(0.474)
Counties	68	15	147	32	156	64
Wald Stat.	33.91	-	2.141	7.350	11.46	101

Appendix A

Appendices

A.1 Population Density

Figure A·1 shows that U-shaped relationship between population growth and population density that Michaels et al. (2012) establishes in the twentieth century also holds in the nineteenth century. Figure A·1 plots the LOWESS smoothed series of the average population growth rate over twenty years versus the natural logarithm of population density at the beginning of this twenty year period. It shows five such twenty year periods, spanning the years 1790 to 1890. As in Michaels et al. (2012), there is a strong negative relationship between the population growth rate and the logarithm of population density when the the logarithm of population density is low, and a positive relationship at higher values. In the nineteenth century the break point in the logarithm of population density is approximately four (or about 55 people per square mile), and the relationship above that level is weak. Thus, it seems that agglomeration economies start at lower densities in the nineteenth century Untied States than in the twentieth century Untied States, but are much weaker than in the the twentieth century. There does not seem to be differences in the advantages that the small number of densest places (the top four or so) provide.

Tables A.1 through A.8 provide summary statistics split by density. Tables A.1 and A.5 show counties that currently have less than 55 people per square mile, whereas Tables A.2 and A.6 display the characteristics of counties that had less than 55 people per square mile twenty years prior. This means that the counties that are included in the 1790 column of Table A.1 are the counties that are in the 1810 column of Table A.2. Tables A.3 and A.7 and Tables A.4 and A.8 show places that are denser than 55 people per square mile, contemporaneously and twenty years prior, respectively.

To investigate the impact that expanding transportation had on the relationship between density and population growth, I use the specification:

$$\begin{aligned} GrowthRate^{20}_{it} &= \alpha + \beta_{1,2} LogDensity_{i(t-2)} \times \mathbf{I}^{D<4,D>4}_{i(t-2)} + \qquad \text{(A.1)} \\ &\beta_{3,4}\Delta_2 TransportMeasure_{it} \times \mathbf{I}^{D<4,D>4}_{i(t-2)} + \beta_{5,6} LogDensity_{i(t-2)} \times \Delta_2 T.M._{it} \times \\ &\mathbf{I}^{D<4,D>4}_{i(t-2)} + \varphi \mathbf{X_{i(t-1)}} + \gamma_i + \delta_t + Region \times \delta_t + T.M._{i(t-N)} \times \delta_t + \mathbf{I}^{D<4,D>4}_{i(t-2)} + \varepsilon \end{aligned}$$

where $GrowthRate^{20}_{it}$ is the population growth rate over the twenty years before t, $LogDensity_{i(t-2)}$ is the natural logarithm of population density two censuses (or 20 years) previous, $\mathbf{I}^{D<4,D>4}_{i(t-2)}$ is an indicator variable for whether the logarithm of population density two periods prior was above or below four, Δ_2 represents second differences, $TransportMeasure_{it}$ (abbreviated $T.M._{it}$) is the specified measure of transportation access, $\mathbf{X_{it}}$ are county level controls,[1] γ_i are county fixed effects, δ_t are year fixed effects, and $Region$ are fixed effects at the nine-region level; $t-N$ denotes the

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[1] Controls that maybe included (when noted) are the percent of the county that is: employed in manufacturing, urban (2,500+), metropolitan (25,000+), literate, in school, born out of state, and foreign born, as well as the percent of farm land that is improved. Each variable is include at lagged values, and interacted with time dummies. More precisely, a variable that is observed in year t takes on the value zero before year $t+1$, and takes on its value in year t for all years following year $t+1$. This variable is interacted with year dummies. This is a more complete way of controlling for observables since many of these variables are only observed for some census years, and often those years are non-consecutive.

use of all previously observed values.[2]

In column (1) of Table A.9, I confirm the overall relationship by including only the variables for the logarithm of population density and time, county, and time×region fixed effects. The expected relationships appear. Column (2) adds in pre-tends in transportation; column (3) includes only the second difference in the percent of a county that is with in five miles of transportation split by being low or high population density. Columns (4) and (5) add the interactions of the above. Overall there is very little impact of increases in transportation access, however, on places that are more dense there is a positive relationship that decreases with density. This suggests that transportation increases the attraction of the smallest places that are above the agglomeration cut-off. Using market access as the transportation variable of interests, Table A.10 suggests a different relationship between population growth and increased market access. It seems for both low and high density counties there is a positive main effect of increasing market access that decreases with increasing density; both things appear more strongly in less dense counties. The overall impact of increasing market access is negative in low density places, and near-zero in high density places.

This same specification can be used to examine the relationship between population density and changes in transportation access on things other than population growth. The tables that follow investigate patents per capita and the speed at which words arrive (described in Chapter 2). Table A.11 examines the growth rate in patents per capita over twenty years, in contrast to population the relationship between patenting

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[2] A variable that is observed in year t is interacted with year dummies such that several new variables are included. One that takes on the value of zero in all years before year t, and takes on its value in year t and then zero thereafter, another one that takes on the value of zero in all years before year $t+1$, and takes on the value from year t in year $t+1$ and then zero thereafter, etc. for all remaining years to $t+N=1900$.

and population density at low density is positive, and at high density is negative. Increasing transportation has a positive main effect in low density places, and a negative, but poorly estimated, one in high density places. However, the interaction between population density and increasing transportation goes the opposite way—the least dense places benefit the most from increased transportation access. Market access, shown in Table A.12, shows only a weak relationship to the growth of patenting, except in the positive main effect in low density places.

The relationship between the speed of word arrival and population density depends on how it is calculated. As seen in Table A.13, using only the last ten years worth of words, there is no relationship between density and change in speed in low density places, and a positive one in high density places. This suggests agglomeration effects at work in the densest places. When all years are used in the calculation of speed of word arrival, in Table A.14, the low density places also have a positive relationship between density and speed. With ether speed measure, increased transportation access decreases the advantage that the highest density places have. This negative coefficient in columns (4) and (5) of both tables, is consistent with the negative coefficient on changes in transportation access interacted with levels of patenting seen in Table 1.5. In Tables A.15 and A.16, it appears that when market access is used as the transportation variable of interest a similar pattern emerges.

Transportation serves to spread out the location of population, patenting, and the mention of new technologies in patents.

A.2 Notable Developments in Patent Law

United States federal patents were introduced in 1790, as allowed by the Constitution. Previously the colonies individually granted patents (Hrdy, 2013) in a manner more typical of the royal monopolies they emulated, with an *ad hoc* process of petitions. When federal patents were introduced, inventors were given the opportunity to apply for federal patents on things they had previously patented at the state level; the last state patent was issued in 1798. In 1790 federal patent applications were examined by the Secretary of State, the Secretary of War, and the Attorney General for both novelty and to see "if they deem the invention or discovery sufficiently useful and important." In practice this meant Thomas Jefferson examined patent applications. Patents were granted for a maximum of 14 years, the board was to determine the grant length of each patent, the fee was between $4 and $5. A specification and drawing were required, but a model was encouraged. There was no official channel to appeal decisions. The board of Secretaries (and, as noted above, in particular Thomas Jefferson) had trouble balancing their many other duties and examination of patent applications, which led to the removal of examination in 1793. It was reintroduced in 1836.

In 1793, the requirement that an invention be "sufficiently useful and important" was removed and patents were no longer examined for novelty.[3] The fee was increased to $30, and aliens were not allowed to obtain patents. In 1800, this requirement was changed so the aliens that have resided in the United States for 2 years and declare an intention of becoming a citizen may receive patents.

The next major change to patent law occurred in 1836, with the patent office

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[3] While the first patents may have been issued with an eye toward the legislative discretion used in chartered monopoly rights, patents were soon seen as themselves a "right" owed to any new invention. This right was due regardless of government judgment on criteria besides novelty and non-obviousness (e.g., utility) (Bracha, 2004).

established as a distinct bureau that is charged with examining patent applications (the patent office consisted of a commissioner, a chief clerk, an examiner, a machinist, two draftsmen, an inferior clerk, and a messenger). Patent office employees are forbidden to acquire any interest in a patent, and a library of scientific works for use by employees of the patent office is created. In addition to the grant length of 14 years, the option to apply for a 7 year extension is made available. The fee remained $30 for citizens, but foreigners are allowed to hold patents with fees of $500 for British subjects, $300 for all others. Applicants must file a specification, a drawing, and a model, and any appeals made be made to three “disinterested persons” appointed by the Secretary of State. That same year a fire in the patent office destroyed many of the previously issued patents.

The requirement of novelty was backed by the declaration in the 1790 Patent Act that the Patentee was supposed to be “the first and true inventor” anywhere in the world. The enablement requirement specified that a patent application disclose a claimed invention in sufficient detail for the notional person skilled in the art to carry out that claimed invention and, vitally for the use of this data, that this description of the invention be made available to the public immediately upon issue. Thus, patents themselves transmit information about new technological ideas. Though the enforcement of these requirements has fluctuated, legislation requires many of the same things today: novelty, non-obviousness, (nominally) utility, and enablement.

In 1839 the patent office is charged with collecting statistics on agriculture; this continues until the Department of Agriculture is created in 1862. In 1842 design patents become available.

The Act of March 2, 1861 extended the patent grant length to 17 years, while removing the possibility of extension. The fee structure was changed so the total was $35 in two payments, $15 at application and $20 on grant, to any person who was a citizen of a country “not discriminating against the US;” by 1924 this had increased to $40, $20 at application and $20 at issue. A permanent board of appeals consisting of three examiners was created. In August of 1861 the Confederate Patent Office granted its first patent; that office granted a total of 266 patents that present day historians are aware of.

In 1870 the filing requirements are changed so that a model only need be provided if requested; until 1880 models were generally requested. On September 24, 1877 a fire in the patent office destroyed many models. The commissioner was also given permission to print copies of patents for the public. In 1871 Congress discontinued its reports on patents issued that year, but distributed individual patents: “for the first time printed patent specifications became available to the public at a nominal charge. Hitherto, in order to study patents, it had been necessary to consult original drawings and specifications in the Patent Office or have copies made at considerable expense.” Continuing this movement toward information distribution, in 1872 the Patent Office starts publishing weekly excerpts from patents and law in the Official Gazette of the United States Patent Office.

In 1887 the United States joins the International Convention for the Protection of Industrial Property that had been formed in Paris in 1883. That same year the question of the first inventor of the telephone draws wide public attention.

On June 10, 1898 a Classification Division is formed to reclassify all patents—though the first classification had been published many years before in 1830. It consisted of sixteen categories; it was updated and expanded to 22 categories in 1847 and then several times thereafter.

A.3 Splits by Region and Other Differences by Type of County

A.3.1 Differences by Region

Transportation changes are differently correlated with patenting increases in counties with different levels of development, at different times, and in different regions. While access to transportation is strongly correlated with patenting per capita in less developed areas, it is being geographically close to large populations that has a stronger relationship with patenting in more developed places. These positive relationships occur in the Northeast between 1810 and 1830, in the Midwest after 1850, and in the south only after the Civil War. This is despite the similar increases in local transportation access and estimated market access in the antebellum South and the Midwest in the 1850s. The experience of the South suggests a further condition—the types of economic activities that benefit from patentable innovation need be a salient feature of the economy of an area. Despite some well publicized innovations in cotton, it is likely that much of the antebellum South's economy was not of this type.[4]

The sample is split by region and year in Table A.17;[5] it shows estimates with region-year fixed effects and pre-trends of transportation access included. The Northeast has a positive relationship between the increase in local transportation and patenting early on that tapers off by the time that most of the region is well served by transportation. In contrast, the Midwest does not see a strong positive relationship until the 1850s. The South and the Midwest are very comparable in the land area

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[4] The South, however, should not be believed to be an area where innovations were considered unimportant. The speed with which the Confederate government set up its own patent office after secession—the Confederate Patent Office issued its first patent less than six months after delegates first met to form a Confederate government—attests to this.

[5] Table A.18 preforms the same splits with estimated market access. The only decade that doesn't, overall, have a precisely estimated relationship between estimated market access and patenting is the 1850s, however there is one in the Midwest during this decade.

that is near transportation through 1850, however the South does not see a strong correlation between changes in transportation and patenting until the 1860s.[6]

A.3.2 Differences by Development Level

Splitting the sample into places that are part of the more developed core versus those that are not allows for different relationships between patenting and transportation access in these two types of places. Table A.19 shows splits based on when places received transportation access, and when they started patenting. The top panel shows two groups of counties, those that received local transportation between 1810 and 1830, and those that received local transportation between 1850 and 1870; the bottom panel splits the country between counties that had patented by 1830 and those that had not. When no controls are added, the coefficient on local transportation in more developed locations is larger. This changes once all controls are added. As seen in Table A.20, market access seems to have no relationship in ether type of place.

The same split is used with the speed of word arrival as the dependent variable in Tables A.21 and A.22. Local transportation access continues to only have a relationship to the speed with which words arrive in a county when speed is computed using all words, and this does not servive the addition of controls. Market access also only has an unclear relationship with word arrival speed in these groups.

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[6] The first known patent issued by the Confederate Patent Office was dated August 1861. From that point until the end of 1864 there are 266 known patents issued by that office. Compare this number to the approximately 14,500 patents issued by the United States patent office 1861-1864, of which about 500 were issued to foreigners. In 1860 about 400 patents were issued to residents of states that would join the Confederacy (West Virgina is excluded from this count), in 1866 about 140 patents were issued, and in 1867 about 400 were again issued to residents of these states.

The set of locations that that received local transportation between 1810 and 1830 and the set of locations that received local transportation between 1850 and 1870 are examined further in Tables A.23 and A.24. For the counties that were connected during the canal building era, there is a strong relationship between local transportation and patenting in and after 1840 (when these counties would start receiving railroads). In counties that did not have transportation in 1850 but had revived it by 1870, local transportation has a strong relationship with patenting in all years. Market access is not consistently related to patenting, however dropping region-year fixed effects changes that result. While both canals and railroads provide options for low cost transportation for goods, they are quite different in many ways. The cost of laying rail is much less than digging an equivalent length of canal, thus the railroad network was much denser and rail was sometimes laid to spare the cost incurred in transshipment.[7] Both forms of transport were desired not just for moving goods cheaply, but for their ability to expedite passenger transportation and mail delivery. Along these dimensions railroads were clearly superior, they increased speed and did not freeze in the winter.[8] Newly developing places in the Midwest are the main beneficiaries of increased local transportation access.

A.4 Innovation and Market Access: A Simple Framework

I develop here a very simple framework to motivate my empirical analysis. Imagine indexing every idea so that each idea is represented by an integer. Each person's knowledge is a vector of zeros and ones, where an entry of one represents that person knowing about or "having" a particular idea. Further, each idea can be combined

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[7] These costs were substantial, see Hung (2015) for a detailed exploration of transshipment costs' importance.

[8] It is much easier to plow snow on land than too break ice in a waterway.

with any other idea to form a third distinct idea that is also a member of the idea set (so the set is closed).[9]

When people interact they transfer ideas–a random draw from the set of ideas, I_i, that person i has is given to person j. The probability of I_k being transferred is $1/N_{P_i,t}$ if $I_k \in I_{P_i,t}$ and zero otherwise,[10] where N_{P_i} is the number of ideas that person i has. People interact with probability $p(c)$, a function of the cost of interacting. Cost, $c_{P_i,P_j,t}$ is a constant for any two people at a point in time and is also increasing with the distance between them.

When an idea is transferred from P_i to P_j, P_j has a probability, q, of randomly choosing an idea they currently hold and combining it with the new idea that they just received. If this happens P_j now knows the combination idea. Some fraction of combination ideas will be "novel"—new additions to the stock of ideas and also may be commercially viable.

This framework is set up so the rate of new ideas will change if c decreases, that is $\sum\limits_j c_{P_i,P_j,t}$ is a market access, or an access to new ideas. This framework talks only about idea creation and not expression or commercialization of the idea. Yet, it also makes clear that the cost of patenting itself, of knowing how to navigate the system as well as the official cost, are very important to the decision to patent. It is the choice to pay this fixed cost that the Bustos (2011) and Lileeva and Trefler (2010) extensions to the Melitz (2003) model speak to. Thus, lowering the cost of travel might have two important effects on people's propensity to patent, both making it more worthwhile to pay the fixed cost, and by raising the rate of arrival of new ideas by lowering the cost of interacting with others who do not live nearby. Increased urbanization, which Atack et al. (2011) showed that railroads encouraged, also will

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[9] This is equivalent to the way the integers recombine to form the rationals.

[10] I am assuming that only one idea will be transferred per interaction.

lower the cost of interacting and may lower the costs of participating in the patent system.

A.5 Appendices' Figures and Tables

Figure A·1: The Population Growth Rate vs. Previous Population Density

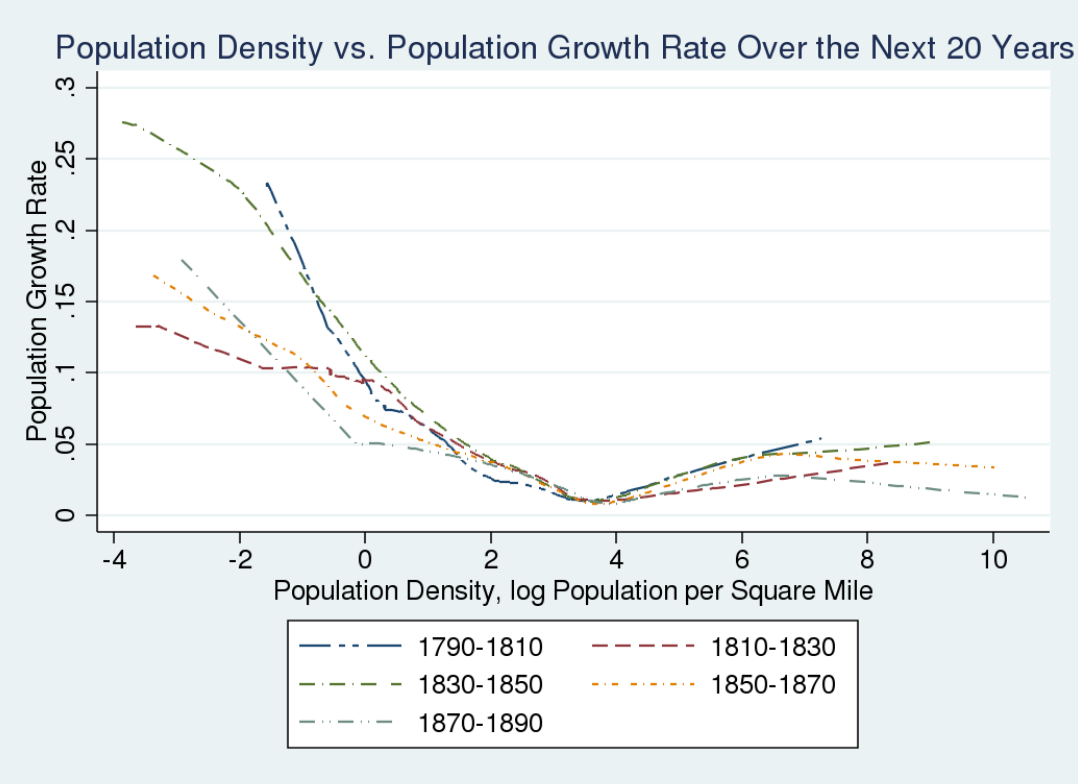

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Table A.1: Means by Year for Counties with Less than 55 People per Square Mile, 1790-1840

	1790	1800	1810	1820	1830	1840
Total Population	6,639	6,809	6,445	7,562	8,793	10,631
	(7,598)	(7,681)	(8,275)	(9,086)	(9,658)	(9,430)
Number of Patents	0.0168	0.0152	0.187	0.0735	0.363	0.325
	(0.155)	(0.145)	(1.096)	(0.364)	(1.599)	(0.975)
Patent per 10K	0.00883	0.00950	0.0850	0.0420	0.211	0.194
	(0.0836)	(0.108)	(0.382)	(0.363)	(1.245)	(0.650)
# of NBER Subcategories						1.737
						(1.191)
% Urban, 2500+	0.00562	0.00470	0.00557	0.00410	0.00606	0.00852
	(0.0342)	(0.0354)	(0.0467)	(0.0302)	(0.0416)	(0.0528)
% Urban, 25K+	9.89e-05	0.000119	0.000115	0.000120	0.000307	0.000301
	(0.00229)	(0.00306)	(0.00355)	(0.00389)	(0.0104)	(0.0103)
Pop per Square Mile	12.59	12.58	11.62	13.28	15.06	17.55
	(13.62)	(12.89)	(13.16)	(13.86)	(14.14)	(13.49)
% within 1.5 miles of transport	0.00408	0.00286	0.00349	0.0249	0.0407	0.0597
	(0.0262)	(0.0191)	(0.0242)	(0.0701)	(0.0734)	(0.0820)
% within 5 miles of transport	0.0259	0.0195	0.0188	0.0795	0.130	0.185
	(0.0979)	(0.0787)	(0.0800)	(0.170)	(0.204)	(0.225)
% within 15 miles of transport	0.106	0.0891	0.0791	0.216	0.337	0.464
	(0.248)	(0.226)	(0.218)	(0.344)	(0.382)	(0.398)
log Market Access	8.638	9.004	8.615	8.994	9.288	9.851
	(1.609)	(1.792)	(2.176)	(1.982)	(1.787)	(1.326)
% Manufacturing				0.0215		0.0257
				(0.0205)		(0.0290)
% Literate						0.872
						(0.120)
% Pop in School						0.0676
						(0.0818)

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Table A.2: Means by Year for Counties that had Less than 55 People per Square Mile 20 Years Prior, 1790-1840

	1810	1820	1830	1840
Total Population	11,159	11,679	11,016	12,789
	(9,996)	(10,416)	(11,575)	(11,934)
Number of Patents	0.482	0.146	0.652	0.563
	(1.976)	(0.527)	(2.368)	(1.600)
Patent per 10K	0.185	0.0848	0.299	0.252
	(0.575)	(0.512)	(1.390)	(0.705)
# of NBER Subcategories				2.103
				(1.570)
% Urban, 2500+	0.0143	0.00990	0.0120	0.0154
	(0.0790)	(0.0500)	(0.0628)	(0.0702)
% Urban, 25K+	0.00147	0.000194	0.00150	0.000334
	(0.0296)	(0.00495)	(0.0323)	(0.0109)
Pop per Square Mile	20.93	20.88	19.28	21.51
	(21.34)	(15.81)	(18.21)	(17.79)
% within 1.5 miles of transport	0.00790	0.0222	0.0444	0.0706
	(0.0400)	(0.0560)	(0.0745)	(0.0909)
% within 5 miles of transport	0.0356	0.0791	0.143	0.215
	(0.120)	(0.170)	(0.211)	(0.239)
% within 15 miles of transport	0.124	0.225	0.369	0.514
	(0.269)	(0.350)	(0.392)	(0.402)
log Market Access	9.954	9.922	9.658	10.12
	(1.228)	(1.497)	(1.703)	(1.332)
% Manufacturing		0.0267		0.0285
		(0.0217)		(0.0301)
% Literate				0.872
				(0.121)
% Pop in School				0.0761
				(0.0902)

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Table A.3: Means by Year for Counties with More than 55 People per Square Mile, 1790-1840

	1790	1800	1810	1820	1830	1840
Total Population	21,937	29,878	31,442	34,633	39,434	45,168
	(19,240)	(21,195)	(25,286)	(27,431)	(33,956)	(42,729)
Number of Patents	1.533	0.704	8.121	4.617	11.46	8.911
	(4.373)	(1.489)	(13.72)	(11.06)	(24.48)	(19.69)
Patent per 10K	1.145	0.647	1.861	0.890	1.983	1.465
	(3.482)	(2.587)	(2.111)	(1.386)	(2.202)	(1.378)
# of NBER Subcategories						4.767
						(3.557)
% Urban, 2500+	0.319	0.265	0.298	0.258	0.235	0.235
	(0.373)	(0.344)	(0.353)	(0.315)	(0.297)	(0.283)
% Urban, 25K+	0.102	0.0751	0.0952	0.0953	0.0617	0.0622
	(0.283)	(0.230)	(0.271)	(0.261)	(0.222)	(0.219)
Pop per Square Mile	191.2	214.0	277.4	258.3	268.2	289.2
	(352.4)	(502.9)	(745.0)	(810.8)	(1,074)	(1,399)
% within 1.5 miles of transport	0.115	0.101	0.101	0.0931	0.124	0.221
	(0.130)	(0.134)	(0.167)	(0.133)	(0.139)	(0.165)
% within 5 miles of transport	0.517	0.420	0.365	0.348	0.401	0.560
	(0.345)	(0.346)	(0.344)	(0.303)	(0.284)	(0.243)
% within 15 miles of transport	0.903	0.795	0.716	0.717	0.819	0.943
	(0.142)	(0.285)	(0.341)	(0.355)	(0.284)	(0.155)
log Market Access	9.608	10.64	10.90	11.13	11.52	12.03
	(1.285)	(1.346)	(1.233)	(1.204)	(1.083)	(0.941)
% Manufacturing				0.0629		0.0787
				(0.0255)		(0.0396)
% Literate						0.970
						(0.0329)
% Pop in School						0.159
						(0.0964)

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Table A.4: Means by Year for Counties that had More than 55 People per Square Mile 20 Years Prior, 1790-1840

	1810	1820	1830	1840
Total Population	34,881	41,391	45,798	54,101
	(33,554)	(33,104)	(45,532)	(58,045)
Number of Patents	12.27	7.333	18.15	14.36
	(18.72)	(14.04)	(34.32)	(27.69)
Patent per 10K	2.541	1.143	2.482	1.919
	(2.606)	(1.507)	(2.414)	(1.683)
Num NBER Subcategory				6.098
				(4.346)
% Urban, 2500+	0.396	0.335	0.366	0.346
	(0.397)	(0.358)	(0.344)	(0.331)
% Urban, 25K+	0.164	0.122	0.0998	0.134
	(0.358)	(0.304)	(0.280)	(0.308)
pop_SqMi	506.9	413.6	497.9	536.0
	(1,077)	(1,074)	(1,556)	(2,035)
% within 1.5 miles of transport	0.144	0.111	0.143	0.253
	(0.208)	(0.161)	(0.168)	(0.193)
% within 5 miles of transport	0.525	0.426	0.473	0.619
	(0.342)	(0.310)	(0.309)	(0.267)
% within 15 miles of transport	0.909	0.847	0.853	0.955
	(0.145)	(0.234)	(0.275)	(0.159)
log Market Access (Over 3.8) Own Pop	10.21	10.99	11.18	11.90
	(1.319)	(1.203)	(1.257)	(1.239)
% Manufacturing		0.0696		0.0910
		(0.0237)		(0.0490)
% Literate				0.971
				(0.0336)
% Pop in School				0.133
				(0.0764)

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Table A.5: Means by Year for Counties with Less than 55 People per Square Mile, 1850-1900

	1850	1860	1870	1880	1890	1900
Total Population	13,423	17,031	19,052	23,702	26,896	30,121
	(9,866)	(11,582)	(17,805)	(28,226)	(41,920)	(55,746)
Number of Patents	0.530	2.652	7.425	6.180	9.059	8.006
	(1.496)	(4.960)	(14.59)	(13.31)	(28.63)	(29.51)
Patent per 10K	0.265	1.325	2.909	2.076	2.604	2.142
	(0.703)	(4.030)	(3.977)	(2.684)	(3.037)	(2.275)
# of NBER Subcategories	1.971	3	4.825	4.178	4.681	3.755
	(1.462)	(2.499)	(3.905)	(3.491)	(3.792)	(3.155)
% Urban, 2500+	0.0160	0.0266	0.0383	0.0472	0.0657	0.0745
	(0.0709)	(0.0818)	(0.0927)	(0.0972)	(0.113)	(0.115)
% Urban, 25K+	0.00113	0.00117	0.00115	0.00201	0.00296	0.00388
	(0.0270)	(0.0276)	(0.0262)	(0.0286)	(0.0321)	(0.0391)
Pop per Square Mile	21.25	25.70	27.76	31.85	33.60	35.38
	(13.11)	(12.81)	(13.29)	(13.01)	(12.14)	(11.37)
% within 1.5 miles of transport	0.0735	0.128	0.154	0.203	0.225	0.301
	(0.0859)	(0.105)	(0.112)	(0.134)	(0.133)	(0.133)
% within 5 miles of transport	0.225	0.373	0.437	0.536	0.586	0.723
	(0.234)	(0.263)	(0.265)	(0.277)	(0.262)	(0.215)
% within 15 miles of transport	0.553	0.766	0.828	0.887	0.927	0.981
	(0.390)	(0.327)	(0.275)	(0.228)	(0.171)	(0.0754)
log Market Access	10.30	10.88	11.09	11.43	11.64	11.83
	(1.144)	(1.021)	(1.001)	(0.856)	(0.742)	(0.623)
% Manufacturing	0.0134	0.0131	0.0193	0.0149	0.0195	0.0228
	(0.0196)	(0.0172)	(0.0230)	(0.0193)	(0.0228)	(0.0246)
% Acres Improved	0.367	0.406	0.429	0.470	0.512	0.523
	(0.151)	(0.178)	(0.192)	(0.206)	(0.200)	(0.195)
% Literate	0.858		0.877			
	(0.111)		(0.0958)			
% Pop in School	0.150		0.136			
	(0.0835)		(0.0860)			
% Born Out of State	0.236		0.197	0.166		
	(0.197)		(0.155)	(0.130)		
% Foreign Born	0.0421	0.0517	0.0455	0.0398	0.0371	0.0308
	(0.0779)	(0.0814)	(0.0711)	(0.0676)	(0.0668)	(0.0547)

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Table A.6: Means by Year for Counties that had Less than 55 People per Square Mile 20 Years Prior, 1850-1900

	1850	1860	1870	1880	1890	1900
Total Population	15,077	18,492	20,982	25,075	27,652	31,948
	(12,613)	(13,761)	(21,321)	(27,501)	(39,048)	(52,968)
Number of Patents	0.864	3.465	10.45	7.875	10.90	9.340
	(2.755)	(7.107)	(31.79)	(15.09)	(28.99)	(29.11)
Patent per 10K	0.340	1.480	3.357	2.462	3.092	2.361
	(0.811)	(4.022)	(4.523)	(3.189)	(3.676)	(2.520)
# of NBER Subcategories	2.341	3.425	5.481	4.751	5.209	4.121
	(1.858)	(2.911)	(4.353)	(3.892)	(4.117)	(3.435)
% Urban, 2500+	0.0257	0.0390	0.0556	0.0643	0.0868	0.101
	(0.0909)	(0.106)	(0.120)	(0.117)	(0.132)	(0.140)
% Urban, 25K+	0.00214	0.00270	0.00457	0.00456	0.00419	0.00681
	(0.0368)	(0.0418)	(0.0515)	(0.0469)	(0.0396)	(0.0536)
Pop per Square Mile	24.70	28.46	30.84	35.35	37.38	39.88
	(18.32)	(17.19)	(19.51)	(16.49)	(15.53)	(18.26)
% within 1.5 miles of transport	0.0837	0.137	0.164	0.221	0.246	0.320
	(0.0946)	(0.113)	(0.118)	(0.142)	(0.142)	(0.140)
% within 5 miles of transport	0.251	0.392	0.455	0.568	0.619	0.745
	(0.249)	(0.271)	(0.271)	(0.282)	(0.264)	(0.210)
% within 15 miles of transport	0.585	0.779	0.838	0.899	0.936	0.984
	(0.391)	(0.321)	(0.269)	(0.218)	(0.162)	(0.0702)
log Market Access	10.44	10.96	11.16	11.52	11.72	11.88
	(1.205)	(1.051)	(1.014)	(0.860)	(0.745)	(0.624)
% Manufacturing	0.0161	0.0151	0.0217	0.0176	0.0233	0.0263
	(0.0234)	(0.0209)	(0.0249)	(0.0230)	(0.0276)	(0.0280)
% Acres Improved	0.384	0.420	0.444	0.495	0.535	0.540
	(0.160)	(0.183)	(0.195)	(0.210)	(0.204)	(0.195)
% Literate	0.862		0.881			
	(0.111)		(0.0940)			
% Pop in School	0.156		0.141			
	(0.0851)		(0.0863)			
% Born Out of State	0.221		0.197	0.167		
	(0.188)		(0.153)	(0.127)		
% Foreign Born	0.0466	0.0579	0.0544	0.0460	0.0396	0.0329
	(0.0814)	(0.0875)	(0.0819)	(0.0721)	(0.0653)	(0.0564)

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Table A.7: Means by Year for Counties with More than 55 People per Square Mile, 1850-1900

	1850	1860	1870	1880	1890	1900
Total Population	53,101	63,574	69,511	72,183	80,910	87,844
	(60,656)	(84,057)	(95,451)	(104,098)	(134,766)	(169,388)
Number of Patents	13.66	46.41	115.9	90.68	129.7	90.73
	(31.16)	(120.7)	(290.4)	(260.0)	(386.6)	(305.5)
Patent per 10K	1.851	5.160	11.89	7.955	10.03	6.447
	(1.733)	(4.145)	(9.420)	(7.798)	(8.806)	(5.743)
# of NBER Subcategories	5.664	9.392	13.78	11.59	12.94	10.18
	(4.840)	(5.570)	(5.655)	(6.473)	(7.240)	(7.045)
% Urban, 2500+	0.258	0.301	0.351	0.337	0.382	0.384
	(0.274)	(0.276)	(0.248)	(0.255)	(0.250)	(0.250)
% Urban, 25K+	0.0883	0.102	0.120	0.128	0.143	0.148
	(0.239)	(0.247)	(0.255)	(0.263)	(0.276)	(0.279)
Pop per Square Mile	339.7	427.2	423.7	345.5	372.9	347.2
	(1,947)	(2,757)	(2,859)	(2,021)	(2,345)	(1,952)
% within 1.5 miles of transport	0.251	0.323	0.359	0.435	0.452	0.493
	(0.154)	(0.158)	(0.155)	(0.157)	(0.149)	(0.152)
% within 5 miles of transport	0.618	0.731	0.781	0.863	0.883	0.910
	(0.234)	(0.211)	(0.176)	(0.143)	(0.127)	(0.110)
% within 15 miles of transport	0.968	0.984	0.995	0.999	0.999	1.000
	(0.0946)	(0.0710)	(0.0229)	(0.00701)	(0.00558)	(0.00250)
log Market Access	12.24	12.42	12.50	12.63	12.66	12.69
	(0.945)	(0.917)	(0.885)	(0.773)	(0.801)	(0.848)
% Manufacturing	0.0663	0.0632	0.0739	0.0683	0.0836	0.0750
	(0.0527)	(0.0555)	(0.0528)	(0.0607)	(0.0627)	(0.0559)
% Acres Improved	0.655	0.675	0.687	0.723	0.730	0.696
	(0.133)	(0.140)	(0.135)	(0.121)	(0.136)	(0.156)
% Literate	0.951		0.932			
	(0.0389)		(0.0355)			
% Pop in School	0.210		0.200			
	(0.0618)		(0.0470)			
% Born Out of State	0.142		0.149	0.142		
	(0.104)		(0.102)	(0.0912)		
% Foreign Born	0.133	0.163	0.165	0.126	0.120	0.0950
	(0.110)	(0.114)	(0.108)	(0.0949)	(0.100)	(0.0935)

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Table A.8: Means by Year for Counties that had Less than 55 People per Square Mile 20 Years Prior, 1850-1900

	1850	1860	1870	1880	1890	1900
Total Population	67,414	80,670	82,340	95,950	105,214	109,553
	(80,373)	(105,931)	(113,747)	(128,551)	(161,823)	(201,806)
Number of Patents	21.55	69	155.4	136.5	188.5	126.2
	(41.85)	(154.7)	(350.1)	(327.9)	(476.9)	(366.6)
Patent per 10K	2.330	6.160	13.35	9.455	12.04	7.786
	(1.955)	(4.530)	(10.40)	(8.965)	(9.771)	(6.159)
# of NBER Subcategories	7.734	11.16	15.03	13.69	15.50	12.13
	(5.691)	(6.107)	(6.330)	(6.854)	(7.200)	(7.248)
% Urban, 2500+	0.340	0.358	0.388	0.423	0.463	0.442
	(0.320)	(0.307)	(0.270)	(0.269)	(0.257)	(0.261)
% Urban, 25K+	0.159	0.158	0.160	0.197	0.216	0.208
	(0.306)	(0.295)	(0.288)	(0.309)	(0.318)	(0.315)
Pop per Square Mile	604.0	689.3	622.2	533.1	554.5	482.5
	(2,727)	(3,614)	(3,565)	(2,597)	(2,952)	(2,367)
% within 1.5 miles of transport	0.286	0.356	0.393	0.475	0.488	0.523
	(0.181)	(0.170)	(0.160)	(0.172)	(0.156)	(0.152)
% within 5 miles of transport	0.662	0.772	0.817	0.881	0.905	0.929
	(0.245)	(0.195)	(0.160)	(0.144)	(0.116)	(0.104)
% within 15 miles of transport	0.980	0.994	0.998	0.999	1.000	1.000
	(0.0779)	(0.0330)	(0.00834)	(0.00364)	(0.00263)	(0.000403)
log Market Access	12.36	12.61	12.76	12.87	12.89	12.94
	(1.133)	(1.011)	(0.860)	(0.851)	(0.869)	(0.849)
% Manufacturing	0.0825	0.0768	0.0853	0.0874	0.103	0.0884
	(0.0589)	(0.0611)	(0.0599)	(0.0663)	(0.0656)	(0.0587)
% Acres Improved	0.706	0.715	0.718	0.737	0.750	0.724
	(0.142)	(0.137)	(0.130)	(0.128)	(0.126)	(0.149)
% Literate	0.950		0.935			
	(0.0384)		(0.0303)			
% Pop in School	0.188		0.194			
	(0.0579)		(0.0429)			
% Born Out of State	0.0971		0.118	0.121		
	(0.0632)		(0.0764)	(0.0777)		
% Foreign Born	0.141	0.173	0.161	0.145	0.153	0.119
	(0.114)	(0.110)	(0.102)	(0.0959)	(0.102)	(0.0961)

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Table A.9: Population Growth vs. Population Density and Increasing Transportation Access, Split by Population Density

Lag, Difference = 20 years

VARIABLES	(1) Pop Growth Rate	(2) Pop Growth Rate	(3) Pop Growth Rate	(4) Pop Growth Rate	(5) Pop Growth Rate
< 4, Lag log Pop/SqMi × Diff % within 5 miles				0.00219	0.00328
				(0.00476)	(0.00494)
> 4, Lag log Pop/SqMi × Diff % within 5 miles				-0.0163**	-0.0144**
				(0.00655)	(0.00632)
< 4, Diff % within 5 miles			0.00213	-0.00700	-0.00812
			(0.00295)	(0.0153)	(0.0158)
> 4, Diff % within 5 miles			-0.00263	0.0690**	0.0641**
			(0.00223)	(0.0283)	(0.0269)
< 4, Lag log Pop/SqMi	-0.0230***	-0.0235***		-0.0188***	-0.00848***
	(0.000710)	(0.000714)		(0.000722)	(0.00138)
> 4, Lag log Pop/SqMi	0.00719***	0.00508*		0.00423	0.00196
	(0.00181)	(0.00275)		(0.00276)	(0.00333)
< 4, Marginal Effect of Diff % 5 mi				0.00518	0.00776
				(0.0113)	(0.0117)
z-stat.				0.459	0.663
> 4, Marginal Effect of Diff % 5 mi				-0.00630	-0.00236
				(0.00275)	(0.00308)
z-stat.				-2.287	-0.766
Included Controls	None	None	None	None	All
Pre-trends	No	Yes	Yes	Yes	Yes
Counties	1249	1249	1249	1249	1249
Observations	10,728	10,728	10,697	10,697	10,697
R-squared	0.602	0.607	0.298	0.423	0.457

Variables interacted with an indicator for being above or below 55 people per square mile ($\ln(55) \approx 4$).

Robust standard errors in parentheses, standard errors clustered by county.

*** p<0.01, ** p<0.05, * p<0.1

Included in specifications with controls are, the percent of the county that is: employed in manufacturing, urban (2,500+), metropolitan (25,000+), literate, in school, born out of state, and foreign born, as well as the percent of farm land that is improved. Each variable is include at lagged values, and interacted with time dummies.

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Table A.10: Population Growth vs. Population Density and Increasing Market Access, Split by Population Density

Lag, Difference = 20 years

VARIABLES	(1) Pop Growth Rate	(2) Pop Growth Rate	(3) Pop Growth Rate	(4) Pop Growth Rate
$<$ 4, Lag log Pop/SqMi × Diff log Market Access			-0.00978***	-0.0102***
			(0.000548)	(0.000400)
$>$ 4, Lag log Pop/SqMi × Diff log Market Access			-0.00229	-0.00546
			(0.00244)	(0.00333)
$<$ 4, Diff log Market Access		0.0231***	0.0345***	0.0383***
		(0.00170)	(0.00163)	(0.00125)
$>$ 4, Diff log Market Access		0.00693	0.0184	0.0332*
		(0.00605)	(0.0153)	(0.0192)
$<$ 4, Lag log Pop/SqMi	-0.0156***		-0.0173***	-0.0238***
	(0.000758)		(0.000784)	(0.000913)
$>$ 4, Lag log Pop/SqMi	0.00473**		0.00443**	0.00449**
	(0.00189)		(0.00188)	(0.00212)
$<$ 4, Marginal Effect of Diff log Market Access			-0.0231	-0.0240
			(0.00130)	(0.000946)
z-stat.			-17.84	-25.40
$>$ 4, Marginal Effect of Diff log Market Access			0.00784	0.00808
			(0.00602)	(0.00550)
z-stat.			1.302	1.468
Included Controls	None	None	None	All
Counties	1249	1249	1249	1249
Observations	10,697	10,697	10,697	10,697
R-squared	0.432	0.456	0.579	0.676

Variables interacted with an indicator for being above or below 55 people per square mile ($\ln(55) \approx 4$).

Robust standard errors in parentheses, standard errors clustered by county.
*** p<0.01, ** p<0.05, * p<0.1

Included in specifications with controls are, the percent of the county that is: employed in manufacturing, urban (2,500+), metropolitan (25,000+), literate, in school, born out of state, and foreign born, as well as the percent of farm land that is improved. Each variable is include at lagged values, and interacted with time dummies.

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Table A.11: Growth in Patents per Capita, Local Transportation Access and Population Density with Interactions

Lag, Difference = 20 years

VARIABLES	(1) Pat per 10K Ppl Growth Rate	(2) Pat per 10K Ppl Growth Rate	(3) Pat per 10K Ppl Growth Rate	(4) Pat per p10K Ppl Growth Rate	(5) Pat per p10K Ppl Growth Rate
$<$ 4, Lag log Pop/SqMi × Diff % within 5 miles				-0.0271*	-0.0164
				(0.0144)	(0.0141)
$>$ 4, Lag log Pop/SqMi × Diff % within 5 miles				0.00305	0.0886
				(0.0811)	(0.147)
$<$ 4, Diff % within 5 miles			0.139***	0.198***	0.139***
			(0.0350)	(0.0459)	(0.0451)
$>$ 4, Diff % within 5 miles			-0.173	-0.192	-0.473
			(0.119)	(0.400)	(0.662)
$<$ 4, Lag log Pop/SqMi	0.0113***	0.0131***		0.0119***	0.0238***
	(0.00290)	(0.00319)		(0.00319)	(0.00414)
$>$ 4, Lag log Pop/SqMi	-0.0156***	-0.0525***		-0.0533***	0.00396
	(0.00569)	(0.0107)		(0.0107)	(0.0289)
$<$ 4, Marginal Effect of Diff % 5 mi				-0.0638	-0.0389
				(0.0339)	(0.0333)
z-stat.				-1.879	-1.168
$>$ 4, Marginal Effect of Diff % 5 mi				-0.178	-0.0652
				(0.113)	(0.125)
z-stat.				-1.567	-0.522
Included Controls	None	None	None	None	All
Pre-trends	No	Yes	Yes	Yes	Yes
Counties	1249	1249	1249	1249	1249
Observations	10,728	10,728	10,728	10,728	10,697
R-squared	0.166	0.183	0.184	0.185	0.230

Variables interacted with an indicator for being above or below 55 people per square mile ($\ln(55) \approx 4$).
Robust standard errors in parentheses, standard errors clustered by county.
*** p<0.01, ** p<0.05, * p<0.1

Included in specifications with controls are, the percent of the county that is: employed in manufacturing, urban (2,500+), metropolitan (25,000+), literate, in school, born out of state, and foreign born, as well as the percent of farm land that is improved. Each variable is include at lagged values, and interacted with time dummies.

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Table A.12: Growth in Patents per Capita, Market Access and Population Density with Interactions

Lag, Difference = 20 years

VARIABLES	(1) Pat per 10K Ppl Growth Rate	(2) Pat per 10K Ppl Growth Rate	(3) Pat per 10K Ppl Growth Rate	(4) Pat per p10K Ppl Growth Rate
< 4, Lag log Pop/SqMi × Diff log Market Access			-0.000458	-0.000828
			(0.00301)	(0.00312)
> 4, Lag log Pop/SqMi × Diff log Market Access			-0.00455	0.0581
			(0.0314)	(0.0625)
< 4, Diff log Market Access		0.0368***	0.0390***	0.0372***
		(0.0121)	(0.0113)	(0.0113)
> 4, Diff log Market Access		0.0816	0.107	-0.241
		(0.0644)	(0.178)	(0.333)
< 4, Lag log Pop/SqMi	0.00901***		0.0105***	0.0200***
	(0.00344)		(0.00346)	(0.00436)
> 4, Lag log Pop/SqMi	-0.00458		-0.00861	0.0682***
	(0.00695)		(0.00690)	(0.0211)
< 4, Marginal Effect of Diff log Market Access			-0.00108	-0.00195
			(0.00709)	(0.00734)
z-stat.			-0.152	-0.266
> 4, Marginal Effect of Diff log Market Access			0.0860	0.0270
			(0.0667)	(0.0832)
z-stat.			1.290	0.324
Included Controls	None	None	None	All
Counties	1249	1249	1249	1249
Observations	10,728	10,728	10,728	10,728
R-squared	0.197	0.198	0.198	0.230

Variables interacted with an indicator for being above or below 55 people per square mile ($\ln(55) \approx 4$).

Robust standard errors in parentheses, standard errors clustered by county.
*** p<0.01, ** p<0.05, * p<0.1

Included in specifications with controls are, the percent of the county that is: employed in manufacturing, urban (2,500+), metropolitan (25,000+), literate, in school, born out of state, and foreign born, as well as the percent of farm land that is improved. Each variable is include at lagged values, and interacted with time dummies.

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Table A.13: First Differences of the Speed of Word Arrival, 10 Years, Local Transportation Access and Population Density with Interactions

	Lag, Difference = 10 years				
	(1)	(2)	(3)	(4)	(5)
VARIABLES	FD Speed	FD Speed	FD Speed	FD Speed	FD Speed
<4, Lag log Pop/SqMi × Diff % within 5 miles				0.000709	0.00185
				(0.00152)	(0.00197)
>4, Lag log Pop/SqMi × Diff % within 5 miles				-0.202***	-0.202***
				(0.0773)	(0.0646)
<4, Diff % within 5 miles			0.000965	-0.00112	-0.00441
			(0.00144)	(0.00410)	(0.00574)
>4, Diff % within 5 miles			-0.00635	0.858***	0.843***
			(0.0224)	(0.330)	(0.273)
<4, Lag log Pop/SqMi	-6.73e-05	-0.000128		-0.000179	-0.00157
	(0.000458)	(0.000392)		(0.000363)	(0.000964)
>4, Lag log Pop/SqMi	0.0734***	0.0859***		0.0934***	0.0470***
	(0.0116)	(0.0110)		(0.0119)	(0.0128)
<4, Marginal Effect of Diff % 5 mi				0.00218	0.00571
				(0.00469)	(0.00608)
z-stat.				0.466	0.939
>4, Marginal Effect of Diff % 5 mi				-0.0771	-0.0913
				(0.0340)	(0.0315)
z-stat.				-2.264	-2.895
Included Controls	None	None	None	None	All
Pre-trends	No	Yes	Yes	Yes	Yes
Counties	1249	1249	1249	1249	1249
Observations	4,987	4,987	4,987	4,987	4,987
R-squared	0.296	0.333	0.230	0.343	0.494

Variables interacted with an indicator for being above or below 55 people per square mile ($\ln(55) \approx 4$).
Robust standard errors in parentheses, standard errors clustered by county.
*** p<0.01, ** p<0.05, * p<0.1

Included in specifications with controls are, the percent of the county that is: employed in manufacturing, urban (2,500+), metropolitan (25,000+), literate, in school, born out of state, and foreign born, as well as the percent of farm land that is improved. Each variable is include at lagged values, and interacted with time dummies.

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Table A.14: First Differences of the Speed of Word Arrival, All Years, Local Transportation Access and Population Density with Interactions

Lag, Difference = 10 years

VARIABLES	(1) FD Speed	(2) FD Speed	(3) FD Speed	(4) FD Speed	(5) FD Speed
< 4, Lag log Pop/SqMi × Diff % within 5 miles				0.00115	-0.00158
				(0.00477)	(0.00487)
> 4, Lag log Pop/SqMi × Diff % within 5 miles				-0.0964	-0.224***
				(0.108)	(0.0730)
< 4, Diff % within 5 miles			0.0161***	0.0114	0.0169
			(0.00350)	(0.0142)	(0.0146)
> 4, Diff % within 5 miles			-0.00279	0.398	0.917***
			(0.0347)	(0.465)	(0.311)
< 4, Lag log Pop/SqMi	0.00421***	0.00304***		0.00218**	-0.00608***
	(0.00109)	(0.00104)		(0.00105)	(0.00183)
> 4, Lag log Pop/SqMi	0.0866***	0.109***		0.112***	0.0457***
	(0.0148)	(0.0129)		(0.0136)	(0.0152)
< 4, Marginal Effect of Diff % 5 mi				0.00355	-0.00485
				(0.0147)	(0.0150)
z-stat.				0.241	-0.324
> 4, Marginal Effect of Diff % 5 mi				-0.0481	-0.117
				(0.0484)	(0.0402)
z-stat.				-0.994	-2.905
Included Controls	None	None	None	None	All
Pre-trends	No	Yes	Yes	Yes	Yes
Counties	1249	1249	1249	1249	1249
Observations	4,987	4,987	4,987	4,987	4,987
R-squared	0.367	0.427	0.371	0.429	0.572

Variables interacted with an indicator for being above or below 55 people per square mile ($\ln(55) \approx 4$).

Robust standard errors in parentheses, standard errors clustered by county.

*** p<0.01, ** p<0.05, * p<0.1

Included in specifications with controls are, the percent of the county that is: employed in manufacturing, urban (2,500+), metropolitan (25,000+), literate, in school, born out of state, and foreign born, as well as the percent of farm land that is improved. Each variable is include at lagged values, and interacted with time dummies.

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Table A.15: First Differences of the Speed of Word Arrival, 10 Years, Market Access and Population Density with Interactions

Lag, Difference = 20 years

	(1)	(2)	(3)	(4)
VARIABLES	FD Speed	FD Speed	FD Speed	FD Speed
$<$ 4, Lag log Pop/SqMi × Diff log Market Access			-1.60e-05	0.000527
			(0.000301)	(0.000499)
$>$ 4, Lag log Pop/SqMi × Diff log Market Access			-0.00860	-0.00434
			(0.0133)	(0.00919)
$<$ 4, Diff log Market Access		0.000721	0.000414	-0.00144
		(0.000614)	(0.000864)	(0.00145)
$>$ 4, Diff log Market Access		0.0362***	0.0509	0.0351
		(0.0100)	(0.0604)	(0.0418)
$<$ 4, Lag log Pop/SqMi	0.000198		0.000186	3.22e-05
	(0.000437)		(0.000579)	(0.00112)
$>$ 4, Lag log Pop/SqMi	0.0725***		0.0744***	0.0406***
	(0.0114)		(0.0121)	(0.0109)
$<$ 4, Marginal Effect of Diff log Market Access			-4.94e-05	0.00162
			(0.000926)	(0.00154)
z-stat.			-0.0534	1.056
$>$ 4, Marginal Effect of Diff log Market Access			0.0111	0.0150
			(0.00750)	(0.00647)
z-stat.			1.485	2.324
Included Controls	None	None	None	All
Counties	1249	1249	1249	1249
Observations	4,987	4,987	4,987	4,987
R-squared	0.340	0.224	0.341	0.486

Variables interacted with an indicator for being above or below 55 people per square mile ($\ln(55) \approx 4$).

Robust standard errors in parentheses, standard errors clustered by county.
*** p<0.01, ** p<0.05, * p<0.1

Included in specifications with controls are, the percent of the county that is: employed in manufacturing, urban (2,500+), metropolitan (25,000+), literate, in school, born out of state, and foreign born, as well as the percent of farm land that is improved. Each variable is include at lagged values, and interacted with time dummies.

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Table A.16: First Differences of the Speed of Word Arrival, All Years, Market Access and Population Density with Interactions

Lag, Difference = 20 years

VARIABLES	(1) FD Speed	(2) FD Speed	(3) FD Speed	(4) FD Speed
< 4, Lag log Pop/SqMi × Diff log Market Access			-0.00280***	0.00262**
			(0.000827)	(0.00122)
> 4, Lag log Pop/SqMi × Diff log Market Access			-0.0257**	-0.0161*
			(0.0128)	(0.00972)
< 4, Diff log Market Access		0.00504***	0.0125***	-0.00729*
		(0.00141)	(0.00244)	(0.00405)
> 4, Diff log Market Access		0.0485***	0.146**	0.104**
		(0.0138)	(0.0662)	(0.0517)
< 4, Lag log Pop/SqMi	0.00336**		0.00479***	-0.00210
	(0.00142)		(0.00163)	(0.00195)
> 4, Lag log Pop/SqMi	0.0806***		0.0870***	0.0460***
	(0.0135)		(0.0136)	(0.0125)
< 4, Marginal Effect of Diff log Market Access			-0.00862	0.00808
			(0.00255)	(0.00375)
z-stat.			-3.382	2.152
> 4, Marginal Effect of Diff log Market Access			0.0268	0.0298
			(0.0137)	(0.0128)
z-stat.			1.956	2.335
Included Controls	None	None	None	All
Counties	1249	1249	1249	1249
Observations	4,987	4,987	4,987	4,987
R-squared	0.430	0.379	0.432	0.576

Variables interacted with an indicator for being above or below 55 people per square mile ($\ln(55) \approx 4$).

Robust standard errors in parentheses, standard errors clustered by county.
*** p<0.01, ** p<0.05, * p<0.1

Included in specifications with controls are, the percent of the county that is: employed in manufacturing, urban (2,500+), metropolitan (25,000+), literate, in school, born out of state, and foreign born, as well as the percent of farm land that is improved. Each variable is include at lagged values, and interacted with time dummies.

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Table A.17: Patents per Capita and Local Transportation Access by Year and Region

	Overall	1810-30	1840-50	1850-60	1860-70	1870-80
Overall						
% Tran 5.0 mi		0.183	0.373	1.007*	3.327***	0.542
		(0.142)	(0.239)	(0.603)	(0.692)	(0.506)
# Counties		1192	1250	1250	1250	1250
Beginning Mean Pat per 10K		0.14	0.29	0.44	1.85	4.46
Beginning Mean Tran		0.0236	0.214	0.269	0.422	0.495
Northeast						
% Tran 5.0 mi	0.997*	1.723**	0.150	-1.413	5.976**	1.730
	(0.555)	(0.678)	(0.532)	(1.574)	(2.740)	(2.090)
# Counties	192	192	192	192	192	192
Beginning Mean Pat per 10K		0.59	1.04	1.55	4.71	11.3
Beginning Mean Tran		0.0979	0.337	0.445	0.566	0.651
Midwest						
% Tran 5.0 mi	1.954***	-0.0667	0.578	2.695***	7.228***	2.917***
	(0.315)	(0.438)	(0.384)	(0.644)	(1.454)	(0.947)
# Counties	379	362	379	379	379	379
Beginning Mean Pat per 10K		0.01	0.25	0.38	2.13	6.40
Beginning Mean Tran		0.00558	0.170	0.240	0.488	0.590
South						
% Tran 5.0 mi	0.555***	-0.0301	0.490	0.144	1.360***	0.812**
	(0.119)	(0.0696)	(0.343)	(0.989)	(0.518)	(0.394)
# Counties	678	638	679	679	679	679
Beginning Mean Pat per 10K		0.05	0.11	0.17	0.91	1.50
Beginning Mean Tran		0.0132	0.206	0.236	0.346	0.399

Robust standard errors in parentheses, standard errors clustered by county.
*** p<0.01, ** p<0.05, * p<0.1
Region by Year FE included for regions at the nine-devision level.

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Table A.18: Patents per Capita and Market Access by Year and Region

	Overall	1810-30	1840-50	1850-60	1860-70	1870-80
Overall						
log Market Access		0.109**	0.126*	-0.154	0.925**	0.740***
		(0.0522)	(0.0652)	(0.503)	(0.430)	(0.269)
log Total Pop		-0.0361	-0.0114	-0.000939	0.124**	0.199***
		(0.0315)	(0.0197)	(0.0543)	(0.0535)	(0.0602)
# Counties		1192	1250	1250	1250	1250
Beginning Mean Pat per 10K		0.14	0.29	0.44	1.85	4.46
Beginning Mean log MA		7.47	10.02	10.51	11.09	11.33
Northeast						
log Market Access	0.435	0.665***	-0.00417	4.44e-05	2.851**	4.356***
	(0.311)	(0.183)	(0.287)	(0.555)	(1.168)	(1.603)
log Total Pop	0.846**	-0.0831	-0.0611	0.0259	0.339***	0.589***
	(0.361)	(0.0849)	(0.0717)	(0.0775)	(0.123)	(0.188)
# Counties	192	192	192	192	192	192
Beginning Mean Pat per 10K		0.59	1.04	1.55	4.71	11.3
Beginning Mean log MA		10.48	11.42	11.80	12.08	12.30
Midwest						
log Market Access	-0.0373	0.0829	0.125	0.581***	1.092	0.905
	(0.166)	(0.0950)	(0.108)	(0.190)	(0.709)	(0.605)
log Total Pop	0.361**	-0.0420	-0.00592	0.0683*	0.183***	0.229***
	(0.174)	(0.0635)	(0.0345)	(0.0360)	(0.0673)	(0.0813)
# Counties	379	362	379	379	379	379
Beginning Mean Pat per 10K		0.01	0.25	0.38	2.13	6.40
Beginning Mean log MA		5.71	9.54	10.33	11.33	11.71
South						
log Market Access	-0.0122	0.0286	0.125**	-0.711	0.393	0.122
	(0.0619)	(0.0381)	(0.0614)	(0.789)	(0.267)	(0.136)
log Total Pop	0.107	-0.00422	0.000757	-0.115	-0.0562	-0.00944
	(0.205)	(0.00747)	(0.00878)	(0.130)	(0.100)	(0.0906)
# Counties	678	638	679	679	679	679
Beginning Mean Pat per 10K		0.05	0.11	0.17	0.91	1.50
Beginning Mean log MA		7.73	9.94	10.28	10.69	10.87

Robust standard errors in parentheses, standard errors clustered by county.
*** p<0.01, ** p<0.05, * p<0.1
Region by Year FE included for regions at the nine-devision level.

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Table A.19: Patents per Capita and Local Transportation Access, Split by Development Level

VARIABLES	(1) 1830 Trans Pat per 10K Ppl	(2) 1850 No Trans Pat per 10K Ppl	(3) 1830 Trans Pat per 10K Ppl	(4) 1850 No Trans Pat per p10K Ppl
% within 5 miles of transport	1.198***	1.161***	0.599***	0.778**
	(0.281)	(0.351)	(0.214)	(0.343)
Included Controls	None	None	All	All
Counties	390	320	390	320
Observations	4,160	3,327	4,160	3,327
R-squared	0.722	0.718	0.845	0.785

VARIABLES	(1) Pat 1830 Pat per 10K Ppl	(2) No Pat 1830 Pat per 10K Ppl	(3) Pat 1830 Pat per 10K Ppl	(4) No Pat 1830 Pat per 10K Ppl
% within 5 miles of transport	1.132**	0.806***	0.397	0.439***
	(0.488)	(0.149)	(0.372)	(0.144)
Included Controls	None	None	All	All
Counties	234	1015	234	1015
Observations	2,741	10,496	2,741	10,496
R-squared	0.769	0.620	0.891	0.719

Robust standard errors in parentheses, standard errors clustered by county.
*** p<0.01, ** p<0.05, * p<0.1

Included in specifications with controls are, the percent of the county that is: employed in manufacturing, urban (2,500+), metropolitan (25,000+), literate, in school, born out of state, and foreign born, as well as the percent of farm land that is improved. Each variable is include at lagged values, and interacted with time dummies.

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Table A.20: Patents per Capita and Market Access, Split by Development Level

VARIABLES	(1) 1830 Trans Pat per 10K Ppl	(2) 1850 No Trans Pat per 10K Ppl	(3) 1830 Trans Pat per 10K Ppl	(4) 1850 No Trans Pat per p10K Ppl
log Market Access	-0.332*	0.156	0.0350	0.0457
	(0.186)	(0.120)	(0.106)	(0.120)
log Total Pop	0.684***	0.0289	0.0940	0.00136
	(0.169)	(0.144)	(0.0815)	(0.137)
Included Controls	None	None	All	All
Counties	390	320	390	320
Observations	4,160	3,327	4,160	3,327
R-squared	0.725	0.706	0.845	0.776

VARIABLES	(1) Pat 1830 Pat per 10K Ppl	(2) No Pat 1830 Pat per 10K Ppl	(3) Pat 1830 Pat per 10K Ppl	(4) No Pat 1830 Pat per 10K Ppl
log Market Access	0.264	0.0776	-0.0429	0.0860
	(0.235)	(0.0737)	(0.153)	(0.0682)
log Total Pop	0.933**	0.125	0.153	-0.101
	(0.378)	(0.122)	(0.228)	(0.0930)
Included Controls	None	None	All	All
Counties	234	1015	234	1015
Observations	2,741	10,496	2,741	10,496
R-squared	0.757	0.613	0.890	0.709

Robust standard errors in parentheses, standard errors clustered by county.
*** p<0.01, ** p<0.05, * p<0.1

Included in specifications with controls are, the percent of the county that is: employed in manufacturing, urban (2,500+), metropolitan (25,000+), literate, in school, born out of state, and foreign born, as well as the percent of farm land that is improved. Each variable is include at lagged values, and interacted with time dummies.

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Table A.21: Speed of Word Arrival and Local Transportation Access, Split by Development Level

VARIABLES	(1) 1830 Trans Speed	(2) 1850 No Trans Speed	(3) 1830 Trans Speed	(4) 1850 No Trans Speed
10 Years				
% within 5 miles of transport	-0.00342	-0.00315	0.000968	-0.00286
	(0.00573)	(0.00342)	(0.00469)	(0.00321)
R-squared	0.657	0.319	0.815	0.378
All Years				
% within 5 miles of transport	0.0175*	0.00307	0.00460	-0.00191
	(0.00967)	(0.00622)	(0.00934)	(0.00623)
R-squared	0.715	0.624	0.832	0.721
Included Controls	None	None	All	All
Counties	390	320	390	320
Observations	1,950	1,600	1,949	1,597

VARIABLES	(1) Pat 1830 Speed	(2) No Pat 1830 Speed	(3) Pat 1830 Speed	(4) No Pat 1830 Speed
10 Years				
% within 5 miles of transport	-0.00765	-0.00169	0.00849	-0.00118
	(0.0166)	(0.00189)	(0.0193)	(0.00156)
R-squared	0.806	0.501	0.881	0.707
All Years				
% within 5 miles of transport	0.00802	0.0130***	-0.0104	0.00163
	(0.0248)	(0.00383)	(0.0297)	(0.00376)
R-squared	0.790	0.613	0.866	0.725
Included Controls	None	None	All	All
Counties	234	1015	234	1015
Observations	1,170	5,075	1,169	5,071

Robust standard errors in parentheses, standard errors clustered by county.
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Included in specifications with controls are, the percent of the county that is: employed in manufacturing, urban (2,500+), metropolitan (25,000+), literate, in school, born out of state, and foreign born, as well as the percent of farm land that is improved. Each variable is include at lagged values, and interacted with time dummies.

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Table A.22: Speed of Word Arrival and Market Access, Split by Development Level

VARIABLES	(1) 1830 Trans Speed	(2) 1850 No Trans Speed	(3) 1830 Trans Speed	(4) 1850 No Trans Speed
10 Years				
log Market Access	0.00395	-0.000111	0.00199	0.000180
	(0.00575)	(0.000953)	(0.00484)	(0.000893)
log Total Pop	0.0133**	0.00632***	0.00383	0.00556**
	(0.00593)	(0.00190)	(0.00519)	(0.00239)
R-squared	0.654	0.324	0.810	0.372
All Years				
log Market Access	-0.00417	0.00400*	-0.00313	0.00288
	(0.0105)	(0.00205)	(0.00684)	(0.00222)
log Total Pop	0.0586***	0.0343***	0.0287***	0.0383***
	(0.0163)	(0.00677)	(0.00976)	(0.00700)
R-squared	0.725	0.629	0.831	0.680
Included Controls	None	None	All	All
Counties	390	320	390	320
Observations	1,949	1,597	1,949	1,597

VARIABLES	(1) Pat 1830 Speed	(2) No Pat 1830 Speed	(3) Pat 1830 Speed	(4) No Pat 1830 Speed
10 Years				
log Market Access	0.00488	0.00114	0.0191**	0.000374
	(0.00658)	(0.00102)	(0.00834)	(0.000694)
log Total Pop	0.0804***	0.0146**	0.0380	0.00528**
	(0.0187)	(0.00671)	(0.0239)	(0.00213)
R-squared	0.805	0.495	0.877	0.700
All Years				
log Market Access	0.00999	0.00255	0.0172	0.000887
	(0.0107)	(0.00165)	(0.0120)	(0.00160)
log Total Pop	0.139***	0.0418***	0.0966***	0.0315***
	(0.0257)	(0.00708)	(0.0367)	(0.00526)
R-squared	0.784	0.629	0.860	0.708
Included Controls	None	None	All	All
Counties	234	1015	234	1015
Observations	1,169	5,071	1,169	5,071

Robust standard errors in parentheses, standard errors clustered by county.
*** p<0.01, ** p<0.05, * p<0.1

Included in specifications with controls are, the percent of the county that is: employed in manufacturing, urban (2,500+), metropolitan (25,000+), literate, in school, born out of state, and foreign born, as well as the percent of farm land that is improved. Each variable is include at lagged values, and interacted with time dummies.

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Table A.23: Patents per Capita and Local Transportation Access, Split by Development Level and by Year

Counties that Received Transportation Access between 1810 and 1830.

VARIABLES	(1) 1830 Patents per 10K People	(2) 1840 Patents per 10K People	(3) 1850 Patents per 10K People	(4) 1860 Patents per 10K People	(5) 1870 Patents per 10K People	(6) 1880 Patents per 10K People
% Tran 5.0 mi	-0.0401	0.710**	1.124*	1.721**	4.066***	1.543
	(0.121)	(0.313)	(0.670)	(0.731)	(1.341)	(1.003)
Counties	387	390	390	390	390	390
Observations	1,431	1,821	2,211	2,601	2,990	3,380
R-squared	0.536	0.540	0.537	0.627	0.712	0.688

Robust standard errors in parentheses, standard errors clustered by county.
*** p<0.01, ** p<0.05, * p<0.1

Counties that Received Transportation Access between 1850 and 1870.

VARIABLES	(1) 1860 Patents per 10K People	(2) 1870 Patents per 10K People	(3) 1880 Patents per 10K People	(4) 1890 Patents per 10K People
% Tran 5.0 mi	0.941**	1.972*	1.767**	3.163
	(0.447)	(1.110)	(0.894)	(2.984)
Counties	320	320	320	320
Observations	2,050	2,367	2,687	3,007
R-squared	0.463	0.674	0.673	0.676

Robust standard errors in parentheses, standard errors clustered by county.
*** p<0.01, ** p<0.05, * p<0.1
Region by Year FE included for regions at the nine-devision level.

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Table A.24: Patents per Capita and Market Access, Split by Development Level and by Year

Counties that Received Transportation Access between 1810 and 1830.

VARIABLES	(1) 1830 Patents per 10K People	(2) 1840 Patents per 10K People	(3) 1850 Patents per 10K People	(4) 1860 Patents per 10K People	(5) 1870 Patents per 10K People	(6) 1880 Patents per 10K People
log Market Access	0.0896	0.143	0.449*	-0.145	-0.357	0.984
	(0.0607)	(0.154)	(0.239)	(0.544)	(1.839)	(0.631)
log Total Pop	0.0186	-0.00172	0.0209	0.0458	0.139**	0.187***
	(0.0258)	(0.0206)	(0.0195)	(0.0303)	(0.0610)	(0.0695)
Counties	387	390	390	390	390	390
Observations	1,431	1,821	2,211	2,601	2,990	3,380
R-squared	0.533	0.538	0.535	0.617	0.693	0.689

Robust standard errors in parentheses, standard errors clustered by county.
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Counties that Received Transportation Access between 1850 and 1870.

VARIABLES	(1) 1860 Patents per 10K People	(2) 1870 Patents per 10K People	(3) 1880 Patents per 10K People	(4) 1890 Patents per 10K People
log Market Access	0.148	0.191	0.209	4.383**
	(0.135)	(0.432)	(0.458)	(2.124)
log Total Pop	0.0580	0.124*	0.145*	0.203**
	(0.0424)	(0.0692)	(0.0776)	(0.0915)
Counties	320	320	320	320
Observations	2,050	2,367	2,687	3,007
R-squared	0.452	0.668	0.672	0.680

Robust standard errors in parentheses, standard errors clustered by county.
** $p<0.01$, * $p<0.05$, + $p<0.1$
Region by Year FE included for regions at the nine-devision level.

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"Who Used Postal Savings? A Description of the First Federally Insured Savings Institution" (with Matt Jaremski and Steven Sprick Schuster)

"Credit Access and Patenting Activity in Nineteenth Century America" (with Matt Jaremski)

“Superstars and Scale: The Effect of Market Size on Top Income Inequality” (with Peter Sims)
“Nineteenth Century Moral Laws’ Impact on Innovation”
“The Formation and Persistence of Gay San Francisco” (with Eric Golson and Casey Petroff)
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Conferences and External Presentations

2015: Northeast Universities Development Consortium Conference, Brown University; Harvard; NBER Productivity Seminar; NBER Summer Institute; Alexander Hamilton Center for Political Economy at NYU; Australian National University; University of Warwick; Economic History Association, Nashville TN; World Economic History Congress, Kyoto, Japan

2014: LSE; UC Berkeley; Harvard; NBER Productivity Seminar; Carleton; NBER Summer Institute (poster); Social Science History Association, Toronto, Canada; Western Economic Association International, Denver CO; Economic and Business History Society, Manchester UK;

2013: Yale Law School; University of Essex; University of Nottingham; Seventh World Congress of Cliometrics, Honolulu, Hawai’i

2012: World Economic History Congress, Stellenbosch, South Africa

2011: UC Irvine; Harvard; University of Warwick

Work Experience

Senior Research Assistant, Capital Markets, Federal Reserve Board, 2007-2009

Teaching Experience

Instructor, Economic Institutions in Historical Perspective, Department of Economics, Boston University, Spring 2012, Fall 2012

Teaching Fellow, Introductory Microeconomic Analysis, Department of Economics, Boston University, Fall 2010, Fall 2011, Fall 2013

Teaching Fellow, Introductory Macroeconomic Analysis, Department of Economics, Boston University, Spring 2011, Spring 2014

Teaching and Laboratory Assistant, Department of Physics, Carleton College, Fall 2004-Spring 2006

Intermediate Price Theory Tutor, Department of Economics, Carleton College, Fall 2004

Computer Skills: Stata, Python (NLTK, scikit-learn), ArcGIS, SAS, R, MS Office, and LaTeX

Citizenship: USA

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