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ABSTRACT

Over the course of the nineteenth century manufacturing in the United States shifted from artisan shop to factory production. At the same time United States experienced a "transportation revolution", a key component of which was the building of extensive railroad network. Using a newly created data set of manufacturing establishments linked to county level data on rail access from 1850-70, we ask whether the coming of the railroad increased establishment size in manufacturing. Difference-in-difference and instrument variable estimates suggest that the railroad had a positive effect on factory status. In other words, Adam Smith was right -- the division of labor in nineteenth century American manufacturing was limited by the extent of the market.

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In the early years of the nineteenth century manufacturing production in the United States took place in artisan shops where a highly skilled worker – the artisan – crafted a good from start to finish perhaps with the help of an assistant or two. Such craftsmen used comparatively little in the way of physical capital – a building, hand tools, and not much else—and their operations were to be found everywhere in the country.

While artisan shops still constituted the majority of manufacturing establishments at mid century a new organizational form – the factory – had emerged in the preceding decades. Factories differed from artisan shops in several dimensions. The typical factory employed many more workers who specialized in production tasks rather than responsible for manufacturing output from start to finish as in the artisan shop. To facilitate the "division of labor" factory goods tended to be standardized in design rather than customized to meet the needs of particular consumers. Factories were also more likely to adopt inanimate sources of power such as water or steam (Atack, Bateman, and Margo 2008a). A fundamental consequence of these differences in organization and technology is that factories had higher labor productivity than artisan shops (Sokoloff 1984). As Andrew Ure (1835, p. 13) summarized, "[t]he term *Factory*, in technology, designates the combined operation of many orders of work-people, adult and young, in tending with assiduous skill a system of productive machines continuously impelled by a central power."

Over the second half of the nineteenth century resources in manufacturing – labor, capital, and raw materials – continued to shift towards the factory and away from the artisan shop. Overall, the manufacturing sector grew rapidly and country became the dominant player in many industries worldwide by the end of the century (Wright 1990; Broadberry and Irwin 2006).

What were the causes of the shift towards factory production? One classic answer invokes the role played by the "transportation revolution" (Clark 1916, p. 351; Taylor 1951). According to this argument, the market for artisan goods early on was generally limited to the immediate surrounding area because transport costs were very high relative to the value of the good at the point of production. Over time, transportation infrastructure spread and improved dramatically, lowering the costs of shipping goods domestically and internationally. Market size expanded thereby eroding local monopoly power. The increased competition compelled firms to raise productivity through division of labor-*cum*-mechanization. "The division of labor," said Adam Smith in one of the most famous passages in *The Wealth of Nations* "is limited by the extent of the market".

Adam Smith's reputation alone guarantees that the transportation revolution would make every economic historian's laundry list of the causes of the diffusion of the factory system. However, this laundry list would also include many other potential causes. Some of the earliest factories in America made use of water power. But available sites were limited, especially outside of New England, and often in locations that were distant from markets. The development of cheap, reliable steam power after 1850 offered budding factory owners an economically attractive "footloose" alternative to water power. Recent work has shown that steam power was adopted more quickly by larger-scale enterprises arguably because the positive impact of steam on labor productivity (relative to water or hand power) was increasing in establishment size (see Atack, Bateman and Margo 2008a)[1]. All else equal, factories would be more profitable if the wage of unskilled labor was low relative to skilled labor. Early factories in the Northeast, for example, made extensive use of the labor of young women and children, whose productivity in agriculture relative to the adult males was low due to the region's crop mix (Goldin and Sokoloff 1982). As the century progressed waves of immigration from Europe expanded the relative supply of unskilled labor, arguably fueling the growth of factories (Rosenbloom 2002).[2]

Assessing the relative importance of the transportation revolution as a causal factor in the diffusion of the factory has been hampered by a lack of suitable data potentially connecting the two along with a defensible identification strategy for establishing causality. In this paper we report on our preliminary efforts to bridge this gap using repeated cross-sections of establishments drawn from the 1850, 1860 and 1870 federal censuses of manufacturing that are linked to county-level information on transportation access derived from contemporary maps. Because the manufacturing data begins in 1850 we focus our attention on the impact of the diffusion of the railroad rather than other forms of man-made transportation such as canals, which was largely complete by 1850.[3]

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[1] Note that an improved transportation network would make it cheaper to transport steam engines and coal, lowered the costs of adopting steam. In this case the transportation revolution makes the factory more likely but not for the reason suggested by the Smith quotation.

[2] The factors in the paragraph hardly exhaust the laundry list of causes of the factory system; others include the development of financial markets (Rousseau and Sylla 2005) and legal changes in business organization (Lamoreaux 2006; Hilt 2008).

[3] Sokoloff's (1984) samples from the 1820 Census and from the 1832 McLane Report offer an earlier window into the American industrialization but neither is a representative random sample. Rather, each focuses on a narrow range of specific locations where manufacturing activities were particularly important and where reporting was

Following previous work (Craig, Palmquist, Weiss 1996; Haines and Margo 2008) we measure rail access as a dummy variable indicating whether a railroad passed through the boundaries of a particular county in a given census year. Some counties already had rail access in this sense in 1850 while others did not. Among the counties that did not have access in 1850, a subset gained access in the 1850s or in the 1860s. We adopt two identification strategies to assess causality. Our first strategy is to use a difference-in-differences (DID) estimator. This estimator measures whether factory status increased on average in counties that gained rail access over the course of the 1850s or 1860s – the "treatment" sample – as compared with a control sample (counties that did not gain access or already had access at the start of the decade).

By design, the difference-in-differences estimator eliminates any "fixed effect" at the county level that, in a cross section, would have been correlated with rail access. However, the legitimacy of DID rests on the presumption that gaining access occurred through the equivalent of random assignment. One does not need to read very deeply in the literature of the transportation revolution to conclude that, at the margin, railroads were built purposefully rather than haphazardly. Consequently, we have supplemented our DID estimator with an instrumental variable (IV) estimator whose goal is to isolate exogenous variation in rail access.

Our instrumental variable derives from "straight lines" drawn between urban areas as of 1820 and the closest major coastal port. The presumption is that a county would have been

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more complete. However, while the non-random sample design suited Sokoloff's purposes it makes it more difficult to use to study the impact of transportation improvements. In particular, while none of the counties in Sokoloff's sample had rail access in 1820 but virtually all did in 1850. As a result, there is essentially no way to construct a control group of counties necessary for a difference-in-difference analysis.

more likely to gain rail access by 1850 if it lay on the straight line than if it did not. Judging by our first stage regression, this logic is correct: our “port” IV positively and significantly predicts rail access in the 1850 cross section of counties.

Our empirical findings suggest that that the coming of the railroad was a causal factor in the rise of factories. Both the DID and IV estimates are positive indicating that gaining access to a railroad was associated with an increase in establishment size. While the instrumental variable estimates are largely invariant to variations in sample definition, both the magnitude and statistical significance of the DID estimator is sensitive in this sense. If, however, we restrict attention to counties for which our rail access variable is likely to reflect true geographic proximity to a rail line then the two approaches yield estimates of causal impacts that are similar in magnitude.

1. The Division of Labor and the Extent of the Market

In this section we discuss the economics underlying the “Smithian” hypothesis that we are testing. Firms have access to a technology that incorporates division of labor as more workers are hired, at least up to some level of output. If markets are “small” or local in nature relative to this level of output, the number of firms serving the market will be small – possibly only one -- and division of labor limited. If transport costs fall the number of firms in the “market” will increase. Initially this number may be higher than can be supported in long-run equilibrium; how there will be more competition than in the initial equilibrium, “flattening” the demand curves facing each firm, leading them to produce more output. Given our assumption on costs, this will be achieved through an increase in division of labor and, therefore, in firm size.[4]

We begin by positing a long run cost curve of the form

$$C = F - aq + bq^2, q>0$$

We think of F as a (quasi)-fixed cost that is incurred provided output is positive – for example, the owner of the establishment has to be present when production starts in the morning and when it ends at night and this entails an opportunity cost that is independent of q. If we divide C by q, we get average cost,

$$AC = F/q - a + 2bq$$

This is minimized when $q_{min} = \sqrt{F/2b}$. Note that for values of $q < q_{min}$ average cost is decreasing in q.

We think of division of labor as the primary reason why average cost is decreasing over a range of output up to minimum average cost. To justify this, assume that one unit of the product is produced when (and only when) a set of T "tasks" is completed. There exists a reference technology called the "artisan technology" in which owner can hire a single worker (possibly himself) to perform each task. The artisan technology could be replicated for each unit of output to be produced during the production period – thus, for example, if completing all of

[4] Our model bears a close resemblance to the analysis in Bresnahan and Reiss (1991) who investigate how equilibrium market structure varies with market size but who do not emphasize the connection to division of labor as we do.

the tasks requires a full production period and two units of output are desired, two artisans would be hired.

Alternatively, the owner could hire two workers and assign each to a subset of tasks. We might imagine this being done on the basis of comparative advantage or after an initial period of "training" but in either case requires an additional cost that is embodied in F. The benefit of doing so, however, is that average cost is lower under division of labor than under the reference technology beyond some level of $q > q^*$(artisan). Further division of labor continues to reduce average cost up to the point where minimum AC is reached, as above.

Under what conditions will division of labor occur? Suppose that each market is so small that, in long run equilibrium, only a single establishment can survive at the margin. By definition, "survive at the margin" means that, price, p, must equal AC in the long run. However, if the firm is a monopolist, it must also be the case that p > MC (marginal cost). This can only happen if the firm produces less output than q_{min}. If the firm is a local monopolist and is producing less than minimum average cost output, it will either be using the reference (artisan) technology – in which case there is no division of labor -- or it will utilize division of labor to some extent, but not the extent that would be the case under perfect competition.

Next, we imagine that the N local markets are still completely segmented by high transport costs but that local demand for q increases. The increase in demand creates the potential for entry. In general, as entry occurs the demand curve facing each firm will "flatten" (become more price elastic at any given quantity) and cannot, if the equilibrium number of firms is greater than one, be below the long run average cost curve. This can only happen if, in equilibrium the quantity of output produced by each firm increases. For increase in demand that are sufficiently small it is possible that this could simply mean more artisans serving the market but eventually, output per firm will increase so that there is additional division of labor. In the limit, of course, if local demand increases enough, the equilibrium will converge to the competitive outcome (Bresnahan and Reiss 1991).

Thus, even in the absence of a transportation improvement that lowers transport costs between markets, it is possible for the separate markets to grow sufficiently in size such that each embraces the "factory" technology. That is, if markets vary in size, some may be served by factories, even in a world in which no trade occurs between markets.

What happens in this framework if there is a reduction in transport costs? As a point of departure imagine the extreme case where transport costs fall to zero from the initial equilibrium in which each market is served by a single firm. In the short run (that is, immediately after the reduction in transport costs) there will still be N firms, but now there is only one market. Under any reasonable theory of strategic interaction, because competition has increased, price will fall and the aggregate quantity demanded will increase. As above, the demand curve facing each firm will flatten; if the firm remains in business, output will necessarily be higher. [5] But if per-firm output is higher in the new equilibrium, there must be more division of labor than in the initial equilibrium.

[5] The number of firms in the new equilibrium may be less than N; that is, there may be some consolidation – fewer firms serve the (now) larger market, but each firm produces more output than before.

To summarize, our framework predicts that, at the margin, a reduction in transport costs provides an incentive for firms that are efficient enough to survive to engage in greater division of labor. This occurs because the demand facing each (surviving) firm is flatter than before and therefore at the point where entry is no longer profitable (zero economic profits) output is closer to minimum average cost. In the remainder of the paper we test this idea by examining whether the coming of the railroad in the antebellum United States led to an increase in establishment size in manufacturing.

2. Railroads and the Transportation Revolution

The United States experienced a "transportation revolution" in the nineteenth century (Taylor 1951; Goodrich 1961; Haites, Mak, and Walton 1975). The elements of the revolution are all well known: dredging and other improvements to harbors and natural inland waterways; improved all-weather roads for travel by wagon; the building of canals; the marine application of steam, and last, and perhaps of greatest importance, the diffusion of the railroad. In principle all of the features of this revolution could have affected the growth of manufacturing – and, undoubtedly did, in many different ways. For the purposes of this paper, however, we focus on the railroads because, as a practical matter, the timing of the manufacturing data used in this paper, beginning as it does with the 1850 federal census, overlaps only with a significant portion of the timing of the diffusion of the steam railroad. By then other forms of transportation improvements, such as canals and the western river steamboat, had largely been completed.

Although plans for railroads were first discussed in the United States in the early 1800s, it was not until the late 1820s that any steam railroads were actually built. The first American railroads were tramways used in mining and quarrying, such as the so-called "Granite Railroad" that commenced operations in Quincy, Massachusetts in 1826. But railroads in the modern sense really originate with the struggles of port cities like Baltimore, Boston, and Charleston that lacked adequate inland waterway connections that would enable greater volume of trade with the hinterland in competition with New York and its Erie Canal. By 1840 some 3,300 miles of track had been laid (of which about 2,800 miles were in operation), the majority of it in New England, the mid-Atlantic, and South Atlantic states, and almost all of it involving trips of short duration ("short line"). Further expansion in mileage took place in the 1840s, much of it again in New England, and also in New York. The South and Midwest were largely bypassed during this decade, except for the completion of a rail line linking Savannah and Chattanooga, and a rail line through Ohio from Sandusky to Cincinnati. By 1850, about 10,000 miles of railroad track were in operation but split between different gauges, several of which were incompatible with one another thus preventing through-haulage.

The 1850s witnessed a substantial wave of rail expansion (Stover 1978). Approximately 22,000 miles of track were laid between 1850 and 1860 such that, on the eve of the Civil War, total rail mileage exceeded over 30,000. Although the federal government had been involved in railroad expansion prior to 1850 in an indirect way by providing land surveys free of charge (from 1824, when the General Survey Bill was passed and immediately signed into law by President Monroe to 1838, when the law authorizing the surveys was repealed), direct subsidies in the form of land grants were first voted in 1850, and later extended several times during the decade (United States 1940). By 1860, in addition to substantial coverage in the Northeast, rail lines crossed Illinois, Indiana, and Ohio, with significant mileage in operation in Wisconsin and Iowa. The South was less well served, but it too experienced substantial growth in rail access in the 1850s and, later, in the aftermath of the Civil War (Wright 1986).

Economic historians have devoted considerable attention to measuring the impact of railroads on total output, or what Fogel (1964; see also Fishlow 1965, Williamson 1974, and Kahn 1988) called the "social savings" of the railroad. Attention has also been paid to the "backward linkages" that railroad expansion created with other manufacturing sectors (Fogel 1964); whether railroads were "built ahead of demand" (Fishlow 1965); and the impact of transportation improvements on regional economic development (Williamson 1974). Our goal in this paper is to add to this literature by examining another "treatment effect" of the railroad, that on factory status in manufacturing. To measure this treatment effect requires a data set linking the diffusion of railroads to the distribution of establishment sizes in manufacturing. We describe such a data set and our estimation strategy in the next section.

3. Data and Estimation

Our empirical analysis relies upon the modified Bateman-Weiss national samples of manufacturing establishments (Atack and Bateman 1999) which have been linked to a newly created database of transportation infrastructure for the nineteenth century United States. We briefly describe first the transportation database and then the linked sample.

The transportation database was created in two stages. In the first stage, we combined information from Goodrich (1961) and various nineteenth century sources to produce a county level dataset indicating whether a county had "access" to water transportation from 1850 onwards. Access here means a set of dummy variables indicating if a canal or navigable river passed through the county boundaries (or was, in the case of a river, the county boundary) or if the county bordered on one of the Great Lakes or had ocean frontage. For this purpose county boundaries were fixed as of a given census year (for example, 1850 or 1870) and the tracing of the water routes from the digitized maps is overlaid upon a geographic information system (GIS) boundary file (or "shapefile" in the language of GIS) of navigable waterways at specific dates (Figure 1).[6]

The second stage was to create similar access variables for railroad transportation. For this stage we assembled extant railroad maps from the nineteenth century that have been digitized, and can therefore be overlaid on shape-files of the historical county boundaries (Figure 2). This differs from the approach used by other scholars (for example, Craig, Palmquist, and Weiss 1996) who visually compared historical maps to county boundaries (which generally did not appear on the historical maps) and tried to integrate often contradictory maps into a single measure.

[6] Determination of what constituted a navigable waterway was subject to some interpretation. For example, Fogel's (1964) map of navigable waterways includes a number of East coast and Gulf rivers: the Coosa, the Conecuh and the Escambia in Alabama, the Edisto in South Carolina, the Black and the Northeast rivers in North Carolina and the Dan and Staunton rivers in Virginia. Nineteenth century traffic on most of these rivers, however, seems to have been by bateaux, carrying small amounts of cargo at relatively high cost, rather than by steamboat or barge. We have defined a navigable waterway as one which accommodated steamboats or canal barges on a regular basis. For this reason, we treat Shreveport as the practical head on navigation on the Red River and ignore navigation on rivers such as the Licking and Big Sandy Rivers in Kentucky where, according to Hunter, "small steamboats occasionally ran for short distances."

Regardless of the approach used, errors arise from multiple sources. First, the dates on the maps tend to be ambiguous. Most list their copyright date rather than the date represented by the data on the map. Mapmakers were attempting to capture a flow—railroad construction—as a snapshot. Moreover, few of the mapmakers had personal knowledge of all of the rail systems they were drawing. Surveys were imperfect (albeit improving), map projections were inaccurate. Last, and certainly not least, rail lines were not accurately and consistently drawn on maps with the result that railroads seemed to shift location from year to year. While a few railroads may have been realigned and re-graded, in most cases, once a railroad was built in a specific location, it stayed where it was because the bulk of the railroad's investment was not just fixed but also sunk (literally). For example, according to the 1880 Census, over 80 percent of railroad investment went into construction costs, of which only one or two percent represented the cost of the land itself; the rest went in surveying, grading, removing or bridging obstacles and laying the track. While ties, ballast and the rails might be reused and the land itself could be resold, the grading, cuttings, embankments, bridges, and drainage ditches had few alternative uses—especially in the nineteenth century.

Once a digitized railroad map has been overlaid upon a county boundary file, GIS methods can be used to create various indicators of transportation access. Following previous work (Craig, Palmquist and Weiss 1996; Haines and Margo 2008) we created a rail access dummy variable equal to one if a railroad passed through the county, and zero otherwise. For additional details on the transportation data base and its construction, see Atack, Bateman, and Margo (2008b).

The end result of the data collection process just described is a county-level data set showing if a county had rail (and/or) water access as of a particular date. The transportation data have been linked (at the county level) to samples of manufacturing establishments that were drawn from the 1850-70 manuscript censuses of manufacturing by Bateman and Weiss and modified and extended by Atack and Bateman.[7] Because of the timing of the census this linkage occurs at census year frequencies (1850, 1860 and 1870). The censuses of manufacturing recorded outputs and inputs along with other firm level characteristics and identified the location of each plant, including the county. For additional details on the manufacturing data, see Atack and Bateman (1999).

For the purposes of this paper we have chosen to follow the previous literature (Sokoloff 1984) and have defined a "factory" as an establishment with 16 or more workers.[8] Table 1 shows the fraction of establishments located in counties with rail transportation in each of the sample years and the distribution of factories. In 1850, slightly more than two-thirds of the sample establishments were located in counties with rail access. Rail access increased sharply in the 1850s, to 85 percent of the sample firms, and again in the 1860s, to 95 percent. In 1850 and 1860, the number of workers is the sum of male and female employees. In 1870, the number of workers is the sum of adult males, adult females, and child employees. We have

[7] Although data on manufacturing establishment in 1880 are also available, these are not used here as they undercount the number of factories which are a key component of our analysis here. The problem with the 1880 data is that the collection of data for certain key industries, including iron and steel, textiles and glass, was delegated to special agents rather than being a part of the regular census and these enumerations have since been lost. The 1880 data require special reweighting to be representative and we have yet to integrate the weights into the linked manufacturing-transportation sample.

[8] Our definition does not separately distinguish mechanized establishments because mechanized power, in principle, was a complement to division of labor (see Atack, Bateman, and Margo 2008a).

experimented with the adjustment of entrepreneurial labor suggested by Sokoloff (1984) which involves adding one person to the count of workers but as our substantive findings were not affected, we only report results using the unmodified census counts. Similarly, no adjustment has been made to render the number of employees comparable across establishments in terms of adult-male equivalents because at least some of the process of division of labor involved the substitution of women and children for adult men (Goldin and Sokoloff 1982).

As can be seen in Table 1, factories as we have defined them grew more common over time, garnering an ever larger share of the total manufacturing labor force. Indeed, even by 1850, fully 60 percent of all workers in our sample were employed in establishments with 16 or more workers; by 1870 the share was up to 72 percent. It is also clear that factories were common in counties that had rail access by from 5.9 to 9.4 percentage points, depending on the census year. The weighted average of these differences (the weights are the sample sizes in each year) produces an average "treatment effect" of 7.2 percentage points.

If we were to take this estimate seriously, then the diffusion of the railroad from 1850 to 1870 can explain all of the increase in the proportion of establishments that were factories. To see this, note that the proportion of counties with rail access grew by 27.8 percentage points from 1850 to 1870 (from 67.5% to 95.3%). If the treatment effect of rail access is 7.2 percentage points, the predicted increase in the proportion factory is 2.1 percentage points (=0.072 x 0.278 x 100%) compared with an actual increase in the proportion factory of 1.9 percentage points (see Table 1).

Alternatively, we can assess the explanatory power of railroads by assuming that no counties had access in 1820 and compute the impact of the diffusion of rail access from 1820 to 1850, and compare the predicted change in the percent factory to the 1850 level shown in the table. The predicted change in percent factory from this calculation is 4.9 percentage points (=0.072 x 0.675 x 100%). This accounts for 58.3 percent of the proportion factory in 1850 (= 0.049/0.084 x 100%) but it underestimates the explanatory power since some establishments in existence in 1820 would have met our factory definition (see Sokoloff 1984) and therefore the increase in factory status between 1820 and 1850 was less than the 1850 level of 8.4 percent.[9]

This simple calculation suggests that the diffusion of the railroad could have been a major driving force behind the rise of the factory. But the calculation, of course, presumes that the cross-sectional difference in percent factory between counties with and without rail access in Table 1 is an unbiased estimate of the true treatment effect. It is easy to think of reasons why the difference in factory status by rail access shown in Table 1 merely reflects a correlation with other factors that influenced factory status – for example, urbanization, or characteristics of the local labor supply. Or there could have been reverse causality – places with a higher proportion of factories in 1850 may have had more factories before the railroad came, and because there were more factories, the railroad came. To address this problem, we have taken two different approaches to circumventing any endogeneity bias.

Difference-in-Differences Analysis

[9] In the 46 industrialized counties in his sample from the 1820 census of manufacturing, Sokoloff reports that 237 of the 1,457 firms in his sample (16.3%) had a workforce of 16 or more persons. Because of the specialized nature of the Sokoloff sample and the fact that the 1820 census undercounted small establishments (see Sokoloff 1984) the true percentage of factories in 1820 is far lower than this but obviously greater than zero.

One way to approach this is through a difference-in-differences (DID) analysis. Specifically, we examine whether counties that were "treated" with a railroad in either the 1850s or the 1860s witnessed an increase in the proportion of manufacturing establishments that were factories, according to our definition, relative to a control group of counties. This control group consists of those counties that already had rail access in place at the start of both decades and those which never gained rail access. This analysis, in effect, includes county and year fixed effects and therefore sweeps away many factors that made it more likely that a county got a railroad and also influenced (independently) the likelihood that manufacturing establishments were factories. In all of the various results that follow, the standard errors have been corrected for clustering at the county level.

The results of the DID analysis are shown in Table 2. In the first row we allow for a treatment effect to occur if the county received a railroad after 1850. If no establishment level controls are included in this regression, the estimated treatment effect is far smaller ($\beta = 0.027$) than the estimate derived from Table 1 and is statistically insignificant. However, if we allow the treatment effect to vary by decade, the DID estimate for the 1860s is only slightly smaller in magnitude than the average of the two cross-sectional treatment effects (1860 and 1870) shown in Table 1.

The remaining columns in Table 2 either include establishment level controls (urban status and two-digit SIC industry code) or else restrict the sample in various ways. Adding urban status and industry controls, for example, slightly lowers the estimated coefficient of rail access (column 5) but the coefficient remains statistically significant. Perhaps the most interesting estimate appears in the last column in which we restrict the sample to just urban establishments located in counties that had water access in 1850. Although we have not mapped the precise locations of the firms in the Atack-Bateman samples, the fact that the county had access to water transportation may have produced positive network externalities for running a rail line into the county, and the rail depots would have been situated in urban locations. In other words, firms in such counties would not likely have had to move goods very far in order to gain direct access to a rail depot – a major factor when hauling costs by wagon were very high, as was the case in 1850 (Fogel 1964).

Instrumental Variable Estimates

An alternative way of dealing with endogenity bias is to construct an instrumental variable for rail access. We have applied this approach to the 1850 cross section. The idea behind the IV approach is to find a variable that predicts rail access in 1850 but which otherwise does not have a direct effect the probability that an establishment was a factory.

To construct our instrumental variable we first identify all cities and towns of population 2,500 or more in the 1820 census (these are named in Figure 3). Next we identified nine major ports in 1820 from customs information. These ports were Baltimore, Boston, Charleston, New Orleans, New York, Norfolk, Philadelphia, Portland (ME), and Savannah. We then drew straight lines from each interior city/town to the nearest port. If a county lay along a straight line as drawn, our instrument takes the value one and zero otherwise (Figure 3).

The idea behind this IV is that costs mattered in the construction of a railroad. Specifically, all other factors held constant, (i) a lower cost rail network is preferable to a higher cost network (ii) a shorter line is less costly to build than a longer line and (iii) the shortest distance between two points is a straight line. Connecting interior places that had already established some level of economic activity in 1820 to the wider world (via ports in existence in 1820) clearly would make economic sense – if the transportation infrastructure were economically feasible. Places that happened to be on a straight line as just described would be at greater risk of gaining rail access earlier rather than later.

Table 3 shows the IV results for various sample specifications. The first stage coefficients are uniformly positive and highly significant, indicating that our IV does predict rail access in 1850 as hypothesized. The second stage estimates are all positive and significant and quantitatively large. In the first column, we use the full sample of establishments in 1850. According to the IV estimate, rail access increases the likelihood that an establishment is a factory by nearly 19 percentage points, a very large impact relative to the sample mean.

Although the IV results suggest a large positive effect of gaining rail access, the estimated effect will be biased upwards if the IV fails the exclusion test. It can be argued, for example, that our straight line IV captures access to any "line of communication" between the inland city and the nearest port and such counties might have developed larger markets (and large firm sizes) anyway (see Bannerjee, Duflo, and Qian 2008). In this regard, it is worth keeping in mind that our IV specification includes urban status and water transportation access, so we are already controlling, at least in part, for these alternative factors. In an effort to address this possible source of bias further, Column 2 exclude all observations located in the counties containing a major port. If this alternative hypothesis were valid we should see a smaller second-stage IV coefficient, and we do – however, the difference in magnitude between the column 2 and column 1 estimates is very small. As a further robustness check, in column 3 we exclude observations in states for which the instrument has a value of zero for all counties in the sample, to be sure that it is the set of set of states for which the IV was truly relevant geographically (that it, states where it was possible at all for our IV to predict rail access) matters. Again, this change slightly lowers the coefficient, but it remains large, positive, and statistically significant.

While these robustness checks do not rule out the possibility that our IV might not be excludable, they do suggest that any such bias is arguably small. If we take the column 3 IV coefficient to be the true treatment effect of being in geographic proximity to a railroad it is not very different from our DID estimate, provided that we restrict attention to urban firms in counties that had water access – recall that we argued that, if such a county gained rail access, it was likely that the firms in this (restricted) sample of counties probably did benefit because they were reasonably close to the rail depot to begin with.

As a final robustness check we substitute a different dependent variable, the percentage of workers who were female. Goldin and Sokoloff (1982) demonstrate that the percentage of women (and boys) among all workers is a useful measure of the extent to which firms substitute unskilled for skilled labor in the process of capturing economies of scale associated with division of labor. As can be seen in Table 4, the IV estimates are again positive and highly significant. Firms that were located in counties that gained rail access were more likely to employ women relative to men, a sign that they were engaging in division of labor.

4. Concluding Remarks

In the nineteenth century the United States experienced a transportation revolution and an industrial revolution. In this paper we report on a preliminary investigation of a particular link between the two revolutions – whether improved access to transportation networks increased the proportion of manufacturing establishments that were factories. The idea here, a very old one in economics, is that establishments that operated in larger markets were more likely to engage in division of labor.

Our empirical analysis derives from a newly created and linked sample of county level data on transportation access and establishment level data from the 1850-70 censuses of manufacturing. The transportation database has been created from digitized 19th century transportation maps that have been overlaid on maps showing county boundaries, enabling us to measure whether or not, in particular, a railroad operated in a county in a given census year.

Using two separate identification strategies, we showed that rail access was positively and significantly associated with the probability that an establishment was a factory, which we identify to be establishments with sixteen or more workers. The first identification strategy is a difference-in-difference analysis applied to repeated cross sections of establishments, while the second is an instrumental variable estimation applied to the 1850 sample of firms. Although the magnitudes of the coefficients vary, all are positive and many are large and statistically significant -- large enough, indeed, to attribute a quantitatively significant fraction of the rise in factory establishments to the coming of the railroad.

While this paper has provided some preliminary evidence in favor of Adam Smith's division-of-labor dictum it is important not to overstate the significance of the results. Our measure of rail access, in particular, is crude and it would be worthwhile to refine it, for example, by measuring the actual number of rail miles in each county. It would also be a worthwhile extension to develop additional instrumental variables, which would enable us to compute an over-identification test of the excludability restriction. Lastly, it would be desirable to extend the analysis to other forms of transportation improvements, such as canals. That said, our results do provide a prima-facie case that the transportation revolution was an important factor behind a key feature of America's industrial revolution, the rise of the factory.

Table 1: Sample Statistics

Year	1850	1860	1870
% of establishments in counties with rail` access	67.5% {89.0%}	85.3% {93.9%}	95.3% {98.0%)
% factory, establishments in counties with no rail access	3.9%	4.7%	1.3%
% factory, establishments in counties with rail access	10.6%	10.6%	10.7%
Difference, Row 3-Row 2, percentage points	6.7	5.9	9.4
% factory (≥ 16 workers)	8.4% [60.3%]	9.7% [67.1%]	10.3% [71.6%]
N(establishments)	5,492	5,210	4,746

Unit of observation is the manufacturing establishment. County has rail access =1 if railroad passes through county boundary (1850 boundaries). {}: county has rail or water access (canal, river, ocean or Great Lakes border). []: percent of workers employed in factories.

Table 2: Difference-in-Differences Estimates: Manufacturing Establishments, 1850-70

County gains rail access in:	No Controls	No Controls	No Controls, Sample restricted to urban establishments	Urban + 2 digit SIC controls	Urban + 2 digit SIC controls	2-digit SIC controls, Sample restricted to urban establishments	2-digit SIC controls , Sample restricted to Urban establishments with water access
1850s	0.018 (0.017)			0.006 (0.017)			
1860s	0.069* (0.022)			0.056* (0.021)			
After 1850		0.027 (0.016)	0.080 (0.065)		0.015 (0.016)	0.098 (0.059)	0.124* (0.063)
N	15,488	15,488	4,062	15,488	15,488	4,062	3,762

Observations pooled from 1850-70 samples. All regressions include year and county fixed effects. Urban = 1 if establishment is located in town/village/city of population 2,500 or more. Standard errors (in parentheses) are clustered at county level. *Significant at 5 percent level or better. Column 8: sample restricted to urban observations in counties with water access (canal or river passes through county, or ocean or Great Lakes frontage). In this sample, % of establishments in counties with rail access increases from 87.6 percent in 1850 to 98.3 percent in 1870.

Table 3: Instrumental Variables Estimates: Factory Status in 1850

Dependent Variable	Full Sample	Port Cities Excluded	Port Cities and States with IV = 0 Excluded
Factory = 1	0.189* (0.062)	0.165* (0.058)	0.159* (0.061)
First Stage	0.241* (0.042)	0.247* (0.043)	0.224* (0.043)
Sample mean, factory = 1	0.084	0.076	0.087
N	5,492	5,238	3,986

Dependent variable =1 if number of workers (men + women) >=16. Coefficient estimates are virtually unchanged if one (Sokoloff 1984) is added to the count of workers. Independent variables: urban status (pop>2,500), presence of natural waterway in county (river, ocean access, Great Lakes), presence of canal, 2-digit industry, census region. IV = 1 if county lies on straight line between town/city with 2,500 or more population in 1820 and nearest major port (see previous slide). *significant at 5 percent level or better. Standard errors corrected for clustering at county level.

Table 4: Instrumental Variables Estimates: Percent Female in Workforce, 1850 Sample

Dependent Variable	Full Sample	Port Cities Excluded	Port Cities and States with IV = 0 excluded
Percent Female	0.070* (0.028)	0.066* (0.027)	0.054** (0.029)
First Stage	0.241* (0.042)	0.247* (0.043)	0.224* (0.043)
Sample mean, Percent Female	0.054	0.048	0.056
N	5,492	5,238	3,986

Dependent variable = women/(men+ women). See notes to previous table for independent variables.
**significant at 10 percent level.

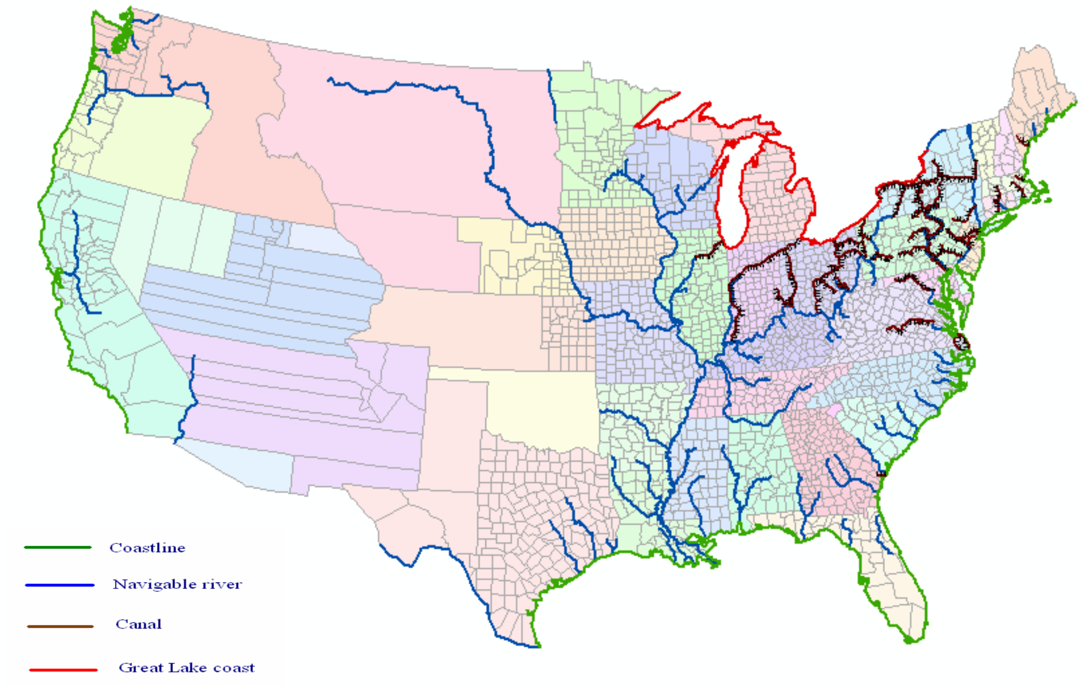
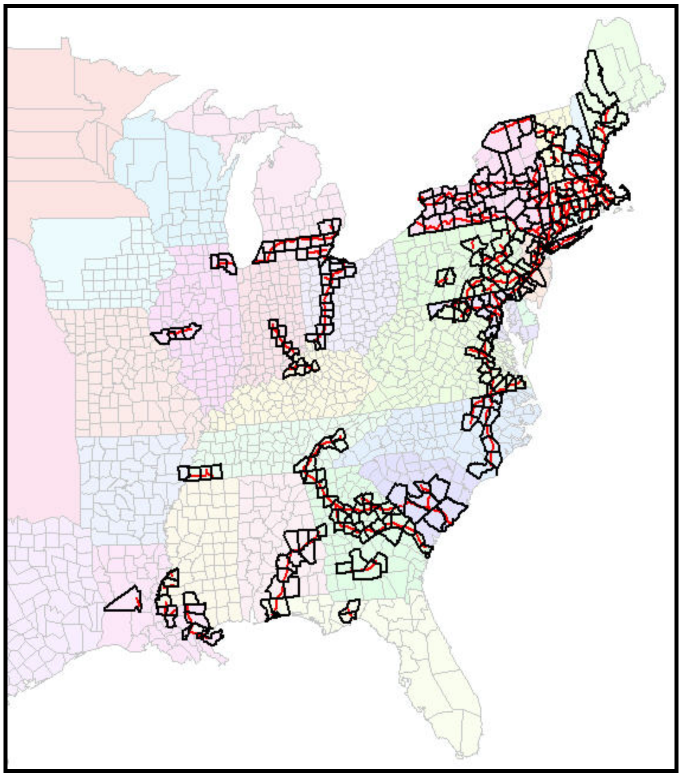
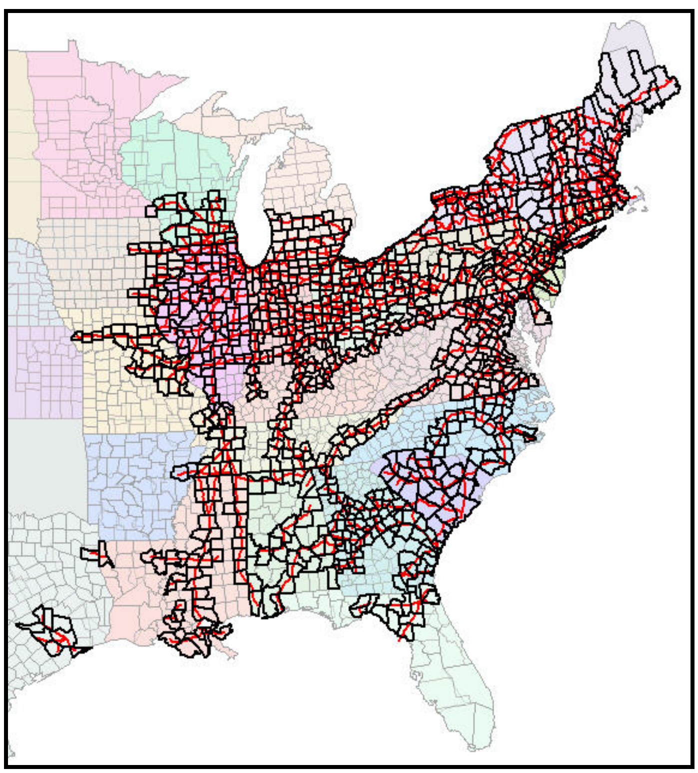


Figure 1: Navigable Waterways Mapped Against 1860 County Boundaries



1850 (Base map: Phelps)



1860 (Base map: Colton)

Figure 2: Counties with Rail Access in 1850 and 1860

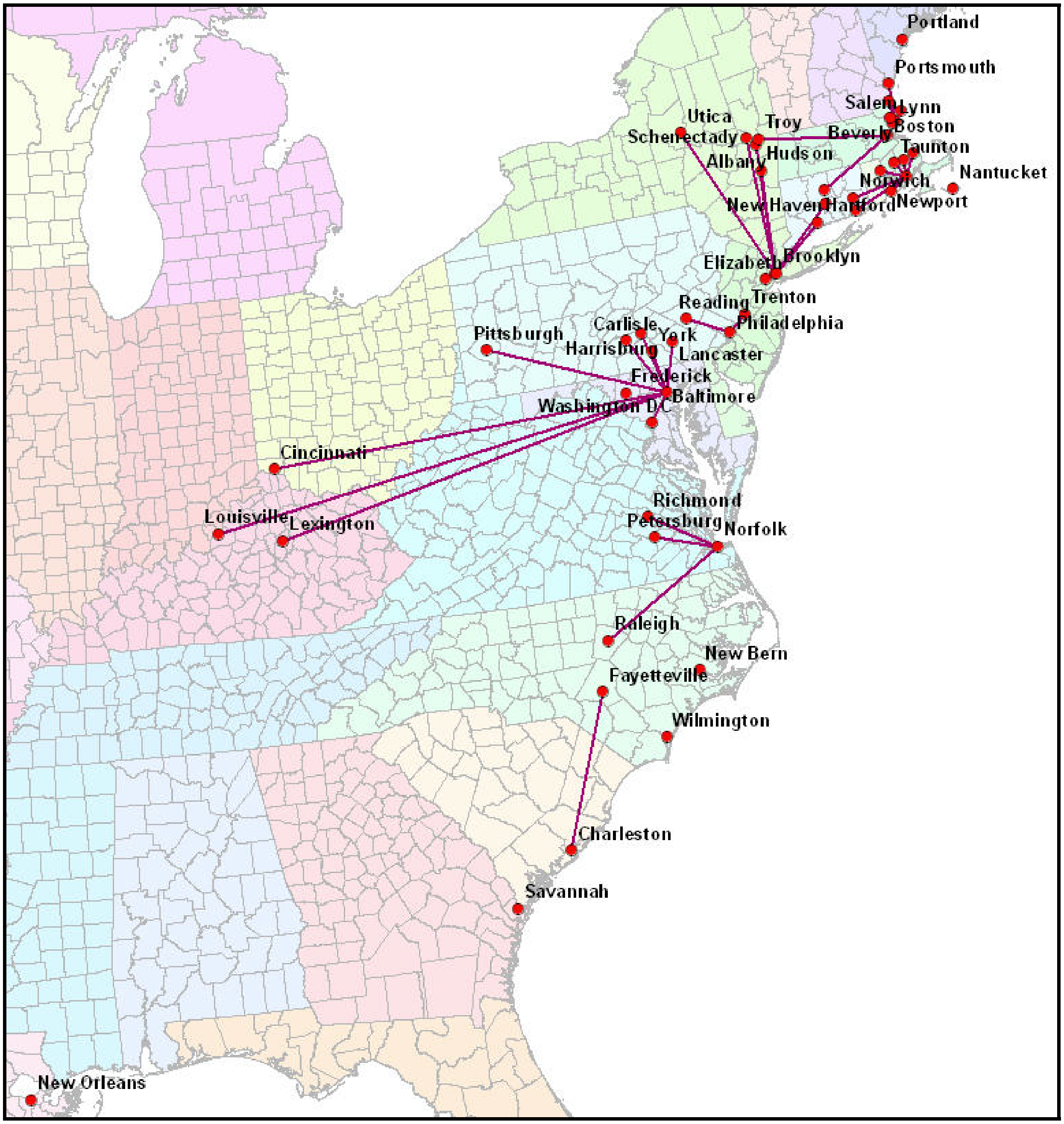


Figure 3: Interior Urban Centers (Population > 2,500) in 1820 Connected to Closest Major Port City

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