The Ties that Bind: Railroad Gauge Standards and Internal Trade in the 19th Century U.S.

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Working paper – comments are welcome and encouraged.

Abstract:

Technology standards are pervasive in the modern economy, and a target for public and private investments, yet evidence on their economic importance is scarce. I study the conversion of 13,000 miles of railroad track in the U.S. South to standard gauge between May 31 and June 1, 1886 as a large-scale natural experiment in technology standards adoption that instantly integrated the South into the national transportation network. Using route-level freight traffic data, I find a large redistribution of traffic from steamships to railroads serving the same route that declines with route distance, with no change in prices and no evidence of effects on aggregate shipments, likely due to collusion by Southern carriers. Counterfactuals using estimates from a joint model of supply and demand for North-South freight transport suggest that if the cartel were broken, railroads would have passed through nearly 70 percent of their cost savings from standardization, generating a 20 percent increase in trade on the sampled routes. The results demonstrate the economic value of technology standards and the potential benefits of compatibility in recent international treaties to establish transcontinental railway networks, while highlighting the mediating influence of product market competition on the public gains to standardization.

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On November 10, 2006, seventeen Asian countries ratified the Trans-Asian Railway Network Agreement, under which they agreed to integrate into a continental railroad network by connecting lines but refrained from adopting standards for interoperability (UNTC 2006), namely a common gauge (track width). This agreement culminated over *50 years* of negotiations, during which proposals were "frustrated to a large extent by a lack of uniform railway gauge" across national boundaries (UNESCAP 1996), much like similar proposed treaties in Europe and in the Middle East (UNTC 1991, 2003). To this day, there are at least five distinct gauges in use across the proposed Asian network, necessitating costly transshipment where railroads meet.

Technology standards are not only a critical feature of transportation networks: they are pervasive in the modern economy, with their importance reflected in the abundance of standards and standards-setting organizations (SSOs) around the world today (Baron and Spulber 2015).[1,2] In theory, incompatibilities impose a tax on transactions, in the form of a fixed cost of interchange, but they also attract opportunists who invent adapters to reduce this cost by bridging the gap (Farrell and Saloner 1992). It is then ambiguous whether incompatibilities will materially affect economic activity or are sufficiently important to justify ex-post standardization of incompatible systems (Liebowitz and Margolis 1994, 1995; Spulber 2008). Due to the difficulty of tying economic outcomes to technology standards, and a scarcity of standards-adoption events at a large enough scale to be of economic significance, these questions remain unanswered.

This paper studies the conversion of all 13,000 miles of non-standardized railroad track in the U.S. South to a standard-compatible gauge on May 31 and June 1, 1886, as a large-scale natural experiment in standards adoption. In the 1860s, incompatibilities were characteristic of the U.S. railroad network, with railroads operating in at least 23 distinct gauges (Siddall 1969). By the 1880s, this count had effectively narrowed to two: 5′ 0′′ gauge in the South, and 4′ 8.5′′ ("standard") gauge

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[1] A significant economics literature has developed around technology standards over the last 30 years, due to the importance of compatibility to information and communications technology and in markets with network externalities. The theoretical literature traces back to the seminal contributions of Farrell and Saloner (1985, 1986, 1988, 1992) and Katz and Shapiro (1985, 1986), as well as early work by Economides (1989) and Matutes and Regibeau (1988). The empirical literature is considerably less developed, due a shortage of data (as noted by Baron and Spulber 2015). Previous empirical research has studied related topics, such as standards battles in consumer electronics (Augereau et al 2006) and the behavior and impacts of standards-setting organizations (Baron and Pohlmann 2013, Chiao et al 2007, Farrell and Simcoe 2012, Leiponen 2008, Rysman and Simcoe 2008, Simcoe 2012), but there are few papers that examine the impacts of standards directly. A third subliterature, primarily historical in nature, has emphasized path dependence in standards and technological lock-in, concentrating on the history of the QWERTY keyboard as an illustrative example (Arthur 1989, David 1985, Liebowitz and Margolis 1990).

[2] Technical standards for interoperability also have a long history: standardization was one of the hallmark features of the American system of manufacturing that propelled the U.S. to the forefront of industrialization in the 19th century and is now pervasive in the U.S. and abroad (Hounshell 1985). Even the adoption of a common currency can be interpreted as a technical standard for payments, yielding benefits from integration (Frankel and Rose 2002, Glick and Rose 2002, Rose and Engel 2002, Rose and van Wincoop 2001).

throughout the rest of the country. The "Great Gauge Change" instantly integrated the entire South into the national transportation network. Using historical freight traffic data from the Southern Railway & Steamship Association – a cartel of the major Southern railroads and steamship lines – this paper studies the effects of railroad gauge standardization on trade between the developing South and the industrial North at the end of the century.

I find that the gauge change triggered a significant redistribution of freight traffic from steamships to railroads but did not generate any increase in aggregate trade. Over this same period, records show that the cartel maintained its prices, implying that railroads did not pass through any of the cost-savings achieved by the conversion. I then estimate supply and demand for freight transport on the sampled routes and show that had the cartel been broken, the gauge change would have resulted in a 27 percent drop in rail freight tariffs and a corresponding 21 percent increase in aggregate shipments on the sampled routes. The effects of standardization were thus large but simultaneously hindered by the collusive conduct of the industry.

The first U.S. railroads were constructed as local and regional enterprises to serve local needs. At this time, opinions over the optimal gauge varied, and technical specifications of each railroad were in the hands of the chief engineer. Without the vision of a national network, distinct gauges were adopted by early railroads in different parts of the country, and subsequent construction tended to adopt the neighboring gauge – leading to the formation of nine different "gauge regions" in the U.S., and a tenth in eastern Canada, by the 1860s (Puffert 2000, 2009). As a national network began to emerge, the costs of these incompatibilities became too great to bear, and railroads gradually converged on a common gauge, through conversion and new construction.

By the 1880s, nearly all U.S. railroads had adopted the 4' 8.5'' gauge, except for those in the South. Data from both the U.S. Department of the Interior and Poor's Manual of Railroads confirm that whereas other regions had 95% or more of their track in standard gauge, 75% of that in Southern states was in an incompatible, 5' 0'' gauge (even more if excluding Virginia and North Carolina). Though adaptations had developed to overcome breaks in gauge, all were imperfect, and accounts suggest they were a substantial second-best to a fully integrated network.

In 1884 and 1885, two major 5' 0'' railroads connecting the South to the Midwest converted their tracks to standard gauge, increasing pressure on the remaining Southern railroads to follow suit and providing a template for execution. In early 1886, the members of the Southern Railway & Steamship Association (SRSA) cartel, which together comprised a majority of mileage in the South, agreed to convert all track to the standard-compatible gauge of 4' 9'' en masse over the two days of May 31 and June 1, 1886, with all traffic halting on May 30 and resuming by the evening of June 1, effortlessly traversing the former breaks in gauge.[3] Carefully planned, the conversion employed large quantities of temporary labor and was seamlessly executed.

The principal purpose of the cartel was to create and enforce noncompetitive pricing. It pursued this goal with rate maintenance agreements and an enforcement mechanism whereby members were allotted a fraction of route-level traffic, and those in excess of their allotment would have to pay the excess revenue into a central fund for redistribution to other members. To implement this mechanism, the SRSA administrative office collected, by submission and audit, records of freight traffic carried to and from the Southern cities where two or more cartel members operated, which were then circulated to member railroad and steamship carriers.

I use SRSA freight traffic and revenue data for individual carriers at the route- by year-level to estimate the effects of the gauge change on merchandise shipments from the North into the South. Invoking a variant on a triple-differences design, I compare within-route traffic borne by railroads versus steamships before and after the conversion to 4' 9'' gauge, relaxing the effects to vary with route distance. Steamships serve as a natural control for railroad traffic, as seaborne freight entirely circumvented the gauge breaks and was therefore operationally unaffected by the conversion to a compatible gauge. This framework identifies the elasticity of freight traffic with respect to the unit cost of a break in gauge, which will be inversely proportional to route length.

The source material yields a balanced panel of 52 routes with inbound merchandise shipments data both pre- and post-standardization. Within this sample, I find sharp effects of standardization on rail-borne merchandise traffic from the North to the South, with a 175-250% relative increase in railroad traffic and revenue on short routes that decreases with distance; when split across the two all-rail pathways into the South, I find relatively larger increases for the less-trafficked path. Across all specifications, I find that the effects of conversion dissipate after about 700 to 750 miles. The results are robust to a variety of fixed effects and within assorted subsamples.

Market share models return similar results, showing a large redistribution of traffic from steamships to railroads, with effects dissipating at similar distances. However, I find no evidence of growth in

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[3] The gauge of 4' 9'' was selected to conform to that of the Pennsylvania Railroad – an important connecting line – and with the belief that a smaller change would reduce the expense of converting rolling stock, but it was understood to be compatible with the 4' 8.5'' standard (Taylor and Neu 1956, Puffert 2009). As Taylor and Neu write, "such a deviation was not considered a serious obstacle to through shipment." The U.S. Government similarly noted in 1880 that "gauges from 4' 9.375'' to 4' 8'' may be considered standard," as the same rolling stock may be used on either "without objection" (U.S. Department of the Interior 1883).

aggregate shipments through 1890: the effects appear to be limited to substitution across modes. To better understand the reasons for this result, I examine cartel pricing for several routes in the sample, finding that prices were stable over the sample period. While the gauge change affected quality of service by improving rail transit times and reducing the risk of property loss, it evidently was not sufficient to attract new traffic to the market absent price adjustments. The cartelization of Southern transportation is thus critical to interpreting these results.

To evaluate whether the consumer welfare gains were constrained by collusion, I estimate a joint model of supply and demand for freight transport over the sampled routes, and use the estimates to evaluate a counterfactual in which railroads and steamships compete. I find that if the cartel were broken, the conversion to a compatible gauge would have increased total traffic by roughly 20 percent, primarily due to a significant reduction in prices: in stark contrast to realized history, on average 70 percent of railroads' post-change cost savings are passed through to consumers in the counterfactual. However, it is important to note that in a competitive environment, the gauge change could itself come into question, as collusion or common ownership was required for railroads to internalize the potentially large external returns to standardization.

The results bear lessons for public and private investments in technology standards in the present. In a first-best world, incompatibilities will be avoided, but when agents lack foresight or are unable to coordinate, ex-post inefficient diversity may take root and persist (David 1985, Arthur 1989). In this case, an opportunity for intervention may exist, particularly when there are positive externalities to standardization (as in networked environments such as communications and transportation), but the scope for welfare gains depends on the incremental benefits of compatibility over available alternatives. This paper shows that despite widespread use of adapters at breaks, the standardization of railway gauge significantly influenced trading patterns in the U.S. South. Given the current shortage of evidence on the value of compatibility, this finding is among the principal contributions of the paper, with implications for the wide variety of other settings where compatibility is a design choice (most notably, Internet and communications technologies).

The paper also fills a gap in the literature relating compatibility standards to trade. According to the WTO (2005), "concern with how standards affect international trade has long been reflected in multilateral trade rules." While several studies have sought to relate country-level imports, exports, and bilateral trade flows to stocks of formal standards (i.e., those promulgated by governments or SSOs), such studies typically focus on standards that regulate quality or reduce product variety, rather than those establishing compatibility, or else do not distinguish between them (Swann 2010).

Indeed, excepting two recent studies on containerization in international shipping (Rua 2014, Bernhofen et al 2016), there is essentially "no empirical work on the relationship between compatibility standards and trade" (Gandal 2001). The present paper provides direct insight into the role that interoperability in transportation networks can play in promoting trade, and the findings acquire increased urgency in light of recent and ongoing international efforts to integrate domestic railways into international networks without standardizing the gauge.

Finally, the results introduce a tension between standardization and product market competition in networked environments: collusion (or consolidation) is necessary for developers to internalize the external returns to compatibility, but it also reduces the likelihood that resulting cost savings will be passed through to consumers, limiting the scope for welfare gains from standardization. It may be desirable to instead have a government simultaneously promote competition while mandating or subsidizing ex-post standardization, particularly if the social returns are believed to exceed the cost of conversion. To my knowledge, this tension has not yet been recognized, but further exploration is beyond the scope of the paper, and I leave it to future research.

The paper is organized as follows. Section 1 reviews U.S. railroad history and the natural experiment at the heart of this paper. Section 2 introduces the data and describes the empirical strategy. Section 3 estimates the effects of the gauge change on mode traffic shares and combined shipments and explores potential explanations, highlighting the importance of the institutional environment. Section 4 then estimates supply and demand for freight transport, and Section 5 uses the results to evaluate the effect of the gauge change in a counterfactual with competition. Section 6 discusses the key lessons, particularly as related to (i) the benefits of interoperability and (ii) the mediating influence of product market competition, as well as implications for the design of international rail transportation agreements. Section 7 concludes.

1 History of U.S. Railroads and Gauge Standards

Diversity in gauge characterized U.S. railroads for most of the 19th century. The first railroads were built with a local, or at most regional, scope, and "there was little expectation that [they] would one day form an independent, interconnected" network (Puffert 2009), obviating any perceived benefits of coordinating on a common gauge. Gauges were instead chosen by each railroad's chief engineer, and without clear evidence of an optimal gauge standard, diversity proliferated. As Puffert (2009) recounts, the first wave of construction in the 1830s used four distinct gauges (4' 8.5'', 4' 9'', 4' 10'', and 5'0''), a second wave in the 1840s added three broader gauges to the mix (5'4'', 5'6'', 6'0''), and a "third wave of experimentation" in the second half of the century introduced several narrow gauges, the most common of which were 3'0'' and 3'6''. Amongst this set, only 4'8.5'' and 4'9'' were mutually compatible and allowed for seamless interchange of traffic.[4]

The industry nevertheless recognized the advantages of interoperability, as subsequent construction typically adopted the gauge of neighboring railroads. By the 1860s, a national network had begun to emerge, but it was plagued by breaks in gauge as well as minor gaps in the physical network – such that there were nine distinct "gauge regions" in the U.S. during the Civil War, and a tenth in Canada, each predominantly using a different gauge than neighboring regions. Panel (A) of Figure 1 gives a flavor of the state of U.S. railroads east of the Mississippi River at this time, showing lines in 4'8.5'' ("standard" gauge), 5'0'' ("Southern" gauge), and other widths.

[Figure 1 about here]

As early as the 1850s, breaks in gauge were recognized as costly: contemporaries believed that each break imposed a full-day delay on through shipments and incurred substantial labor and capital costs for transshipment, which at the time was performed manually, aided by cranes (Poor 1851, Taylor and Neu 1956). Moreover, diversity in gauge typically meant that railroads had to maintain a large fleet of idle rolling stock at breaks for transferring freight. Several adaptations developed from efforts to reduce the cost of these incompatibilities, such as bogie exchange (whereby each car would be hoisted, and its chassis removed and replaced with one of a different gauge), transporter cars (which carried cars of a different gauge), adjustable-gauge wheels, and multiple-gauge track. But all were a distant second-best to an integrated network: bogie exchange was time-consuming and yielded a mismatched car and bogie, which ran at reduced speeds and was prone to tipping on curves; transporter cars were difficult to load and similarly created instability; variable-gauge wheels often loosened, causing derailment; and third rails required a gauge differential of at least eight inches and were prohibitively expensive to construct and maintain.

After the Civil War, several pressures coincided to induce private efforts towards standardization, including growing demand for interregional freight traffic and increasing trade in perishable goods, which were heavily taxed by delays at breaks in gauge; competition within routes (to provide faster

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[4] See Puffert (2009) for a comprehensive discussion of the origins of U.S. railroad gauge. To this day, experts' opinion over the optimal gauge varies, though the choice is (i) understood to vary with operating conditions, and (ii) involves tradeoffs, such that there is no dominating standard. Even so, experts tend to agree that wider gauge is preferable to the modern standard (4'8.5'') for its speed, stability, and carrying capacity (Puffert 2009).

service); and consolidation across routes (internalizing externalities of conversion). Despite known technical shortcomings (Puffert 2009), 4' 8.5'' became the standard to which railroads conformed: not only did standard gauge comprise a majority of U.S. mileage in every decade since the first railroads were built, but it was also the principal gauge in the Northeast and Midwest, the loci of trade in manufactured and agricultural goods. By the early 1880s, the common-gauge regions using 4' 10'', 5' 6'', and 6' 0'' had all converted to standard gauge, effectively leaving only two gauges in widespread use: 5' 0'' in the South, and 4' 8.5'' in the rest of the country.[5]

1.1 The Southern Railway & Steamship Association

Concurrent with (but independent of) these trends, Southern freight carriers self-organized into the SRSA cartel in 1875, following a series of devastating rate wars. The cartel's express purpose was rate maintenance: the preamble to its charter asserts the intent of achieving "a proper correlation of rates," to protect both its members and consumers from "irregular and fluctuating" prices and "unjust discrimination" that favored certain markets over others (SRSA 1875). Membership was open to all railroads and steamships operating south of the Potomac and Ohio Rivers and east of the Mississippi and included nearly all major carriers in the region.

Though it had a rocky start, the SRSA grew into a sophisticated and highly successful organization that served as a model for the industry, and whose evolution and operation have been documented several times over (e.g., Hudson 1890, Joubert 1949, Argue 1990).[6] The cartel had its own central administration composed of representatives from its constituents, which had the responsibility of carrying out the terms of the cartel agreement, making new rules as necessary, and providing a venue for settling differences. The SRSA administration was thus effectively a miniature government for Southern freight carriers, with an executive, a legislature, and a judiciary.

The cartel administration included a Rate Committee, which determined prices for each route. The mechanism used to ensure that members adhered to these prices was apportionment: carriers

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[5] Concurrent with these conversions, physical gaps in the network were being closed around the country: cross-town connections between depots were being built (e.g., Richmond in 1867) and rivers were being bridged (e.g., the Ohio River at Louisville in 1868 and Cincinnati in 1877), such that differences in gauge were the only remaining obstacle to a physically integrated network. A third impediment to through traffic was the moral hazard inherent to relinquishing control over rolling stock on adjoining lines, or allowing other railroads' cars to use (and potentially damage) one's own tracks. These issues were resolved around the same time by contracting innovations that established joint ownership of rolling stock (Puffert 2009). Vertical relationships are discussed further in Appendix B.

[6] The SRSA in fact preceded, was the model for, and shared a common founder with the Joint Executive Committee, a cartel of railroads running between the Midwest and East Coast that has been widely studied in the economics literature (e.g., Ulen 1979, Porter 1983, Ellison 1994, and others).

serving a competed route were allotted a fixed proportion of traffic, determined by "the average amount of freight hauled in past years" (Joubert 1949). In the early years of the cartel, carriers who exceeded their allotment were required to submit the excess revenues to the cartel for redistribution to other members, less a half-cent per ton-mile allowance for the expense of carriage. This plan quickly unraveled when members reneged ex-post, and the agreement was amended to require members to deposit 20% of revenue with the cartel at the time of shipment, out of which these transfers would be made. To enforce the agreement, the cartel installed agents at stations to record carriers' daily traffic and revenue, appointed inspectors to ensure that freight was being properly weighed and classified, and regularly audited members' accounting records. These records were compiled into monthly tables reporting traffic and revenue by route and carrier, which were then circulated to members – and which have since been preserved.

The SRSA initially governed inbound merchandise shipments, and outbound cotton and textiles, between Atlanta, Augusta, Macon, and points in the North. Coverage soon grew to include several other interior Southern cities (e.g., Newnan, West Point, Opelika, Montgomery, Selma). In 1885, the cartel was expanded to cover passenger traffic on these routes, and in 1887, it folded rapidly-growing "Western" routes (between the South and the Midwest) into the agreement. Given the late addition of these routes to the cartel, this paper focuses on the effects of the gauge standardization on so-called "Eastern" traffic between the North and South.

The amended mechanism proved so effective that in 1887, the cartel reported that "since 1878, all balances have been paid and rates thoroughly maintained," excepting one month in 1878 (Hudson 1890) – a sharp contrast to frequent pre-cartel rate wars. There are several reasons why the cartel was successful, beginning with the mechanism itself, which muted carriers' incentives to cut prices to capture a greater share of traffic. Railroads that refused to join the cartel were denied through traffic, which effectively amounted to a boycott. And the SRSA demonstrated early on that when carriers (members or not) deviated from cartel prices, it would act quickly and decisively by cutting rates to destructively low levels until the deviator complied.[7]

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[7] The passage of the Interstate Commerce Act (ICA) in February 1887 presented a new kind of threat to the cartel. The ICA prohibited traffic pooling, making the cartel's apportionment mechanism illegal, however the act "by no means put an end to the power of the Association" (Hudson 1890). The cartel instead transitioned to a system of fines for price deviations, with mileage-based deposits, and it continued collecting and disseminating members' traffic and revenue. The SRSA continued to operate in this way until 1890, when the Sherman Act delivered the lethal blow by prohibiting combinations in restraint of trade. Though it took several years for the courts to resolve initial ambiguities over whether the SRSA met this definition, by 1897 the cartel had dissolved.

1.2 The Gauge Change

As trade between the South and other regions accelerated during Reconstruction, incompatibilities became increasingly costly: by the 1880s, “not a prominent point could be found on the border [of the South] without its hoist and acres of extra trucks” (Hudson 1887), and the total cost of delays were growing one-for-one with volume. The first cracks in the 5' 0'' network developed in 1884 and 1885, when two major lines linking the South to the Midwest (the Illinois Central and the Mobile & Ohio) converted their tracks to standard gauge, increasing pressure on their Southern competitors and connections to follow suit, and providing a template for execution.

On February 2-3, 1886, cartel members convened to discuss the compatibility problem and agreed to convert all of their track to a 4' 9'', standard-compatible gauge on May 31 and June 1 of that year.[8] The gauge change was carefully planned and seamlessly executed: in the weeks leading up to the event, railroads removed the ties on their tracks and took a subset of their rolling stock (rail cars, locomotives) out of service to adjust its gauge; then, on the evening of May 30, all traffic halted, and teams of hired labor worked up and down each line, removing remaining ties, shifting one rail 3'' inwards, resetting ties, and moving to the next segment. By midday on June 1, 13,000 miles of track had been converted to 4' 9'', and traffic had resumed, with freight now moving freely across Southern borders in a physically integrated railroad network.[9]

To verify the scale of the conversion, I collect individual railroads’ gauges and mileage from Poor’s Manual of Railroads (1882-1890), an annual compendium listing the universe of U.S. railroads. Table 1 shows the miles of railroad in 4' 8.5-9'', 5' 0'', and other gauges by region and year throughout the 1880s. Whereas other regions generally had 95% of their track in standard or standard-compatible gauge by 1881, nearly 70% of Southern railroad mileage began the decade in 5' 0'' gauge. The discrepancy remained until the year of the gauge change: between 1885 and 1887, the total in 5' 0'' gauge declined by 13,006 miles, and the fraction of Southern railroad in standard or standard-compatible gauge discretely jumped from 29% to 92%. Panels (B) and (C) of Figure 1 show the updated gauge of the 1861 railroad network as of 1881 and 1891, respectively (omitting new construction), illustrating the geographic scope of the conversion.

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[8] The 4' 9'' gauge was selected to match the Pennsylvania Railroad system, an important connection in the Mid-Atlantic, and because it was thought that smaller adjustments were less costly (Puffert 2009).

[9] The execution of the gauge change is covered in greater depth by several other sources. For extended summaries, see Taylor and Neu (1956) or Puffert (2009). For a detailed, contemporary discussion of the nuts and bolts of the planning and execution, see Hudson (1887). Extrapolating from the costs of converting the Louisville & Nashville system (detailed in its 1886 annual report) to all 5' 0'' mileage, the total cost of the gauge change was likely around \$1.2 million in 1886, equivalent to \$31 million today. To put the cost in perspective, the L&N’s expenditure on conversion was roughly 30% of its investment in infrastructure in 1886 and 37% of net income.

[Table 1 about here]

The historical record indicates that network externalities were important in propelling the gauge change and were recognized by contemporaries. The returns to adopting a compatible gauge were low for railroads on the periphery if interior neighbors did not follow – the effect would be to shift the break from the top to the bottom of the line, with no benefits to through traffic – and negative for interior railroads acting alone. But the gains to all parties were high under a coordinated, regional conversion. Because the returns to conversion were increasing in the size of the standard gauge network, one large system could also induce a cascade of standardization.[10]

The cartel served two important roles that enabled conversion to take place. First, it provided an institutional venue for coordinating on a common gauge and organizing the conversion, similar to SSOs today. More importantly, collusion internalized the externalities to adopting the common standard. Without either collusion or consolidation, the gauge change itself would be in question, and integration would likely have been significantly retarded.

2 Data and Empirical Strategy

I use the SRSA records of freight traffic to and from the South via railroad and steamship to study the effects of the gauge change. I restrict attention to annual totals of merchandise shipments from Northern port cities to the interior South, as cotton shipments in the reverse direction comprise a smaller sample and may be confounded if destined for foreign markets.[11] The sample throughout the paper consists of 52 North-South routes formally apportioned and monitored by the cartel both before and after the gauge change (4 origins x 13 destinations), and a sample period spanning the 1883-84 to 1889-90 fiscal years. Table 2 lists, and Figure 2 maps, the origins and destinations in the sample. The gauge change coincides precisely with the end of the 1885-86 fiscal year, such that the pre-period consists of FY84 to FY86, and the post-period FY87 to FY90.

[Table 2 and Figure 2 about here]

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[10] As one contemporary noted, once the Louisville & Nashville (the largest railroad in the South at the time, with over 2,000 miles) determined that it must adopt a standard-compatible gauge to compete for interregional traffic, other large systems recognized that they "must move with the Louisville and Nashville," and smaller railroads then "had no choice in the matter but to join ranks" (Hudson 1887, p. 668).

[11] Invoking the annual data smooths out higher-frequency fluctuations and significantly simplifies the data collection, while still providing enough variation to identify the effects of the gauge change. The choice to restrict attention to merchandise shipments is further motivated by the fact that outbound cotton shipments were dwindling over the period, diverted by growing demand from Southern textile manufacturers as the region industrialized, and by the fact that SRSA merchandise revenue consistently exceeded cotton revenue (by multiples).

Due to the diffuse ownership of the network, shipments to the interior South necessarily traversed multiple railroads, or a steamship and a railroad, to reach their destination. The SRSA tables report sequence-specific traffic and revenue, which I aggregate up to mode: all-rail versus steamship. I include separate observations for the two all-rail paths into the South, the "Atlantic Coast Line" (ACL) and the "Piedmont Air Line" (PAL, see Appendix A), each of whose constituent railroads shared a common owner, and which are explicitly denoted in the SRSA tables. The primary sample thus has 1,092 ($= 52 \cdot 3 \cdot 7$) observations at the route-mode-year level.[12]

The empirical strategy compares all-rail and steamship traffic within routes before and after the gauge change. Because seaborne freight bypassed breaks in gauge, steamships were not directly affected by the conversion and accordingly provide a control group for the treated all-rail mode. In all cases, I relax the effects to vary with distance: breaks in gauge imposed a fixed cost on through traffic, such that the per ton-mile unit costs were inversely proportional to route length. The first set of specifications thus take the following form:

$$\begin{aligned}\ln(Q_{mrt}) = \beta_0 + \beta_1 Rail_{mrt} + \beta_2 Post_t + \beta_3 Rail_{mrt} Post_t \\ + \beta_4 Rail_{mrt} Post_t Dist_r + X_{mrt}\gamma + \varepsilon_{mrt} \;, \qquad (1)\end{aligned}$$

where Q_{mrt} is pounds of traffic carried by mode m, on route r, in year t; $Rail_{mrt}$ is an indicator for the all-rail mode (ACL and PAL); $Post_t$ indicates the post-period; and $Dist_r$ is the distance from origin to destination. Throughout the analysis, I measure distance as straight-line distance, rather than traveled distance, which is not observed (contemporary sources indicate the two are in roughly fixed proportion; see Appendix A). The X_{mrt} term includes all other interactions plus fixed effects. In all specifications, I cluster standard errors by route.

As Appendix Table A.2 shows, the sampled routes provide sufficient variation in distance (from 500 to 1,100 miles) to identify the elasticity of all-rail traffic with respect to the distributed (unit) costs of gauge breaks. However, with imperfect competition in the market for freight transport, the gauge change may affect steamship traffic indirectly in general equilibrium, contaminating the control group. In a second set of specifications, I therefore estimate a model on market shares, rather than quantities, which can account for this interdependence. Suppose mode shares are generated by discrete consumer choices, where each mode has latent utility:

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[12] To simplify the exposition, the specifications below are presented as if the ACL and PAL were aggregated into a single observation, but the tables in Section 3 include them as separate observations.

$$\begin{aligned} u_{imrt} = \big[&\beta_0 + \beta_1 Rail_{mrt} + \beta_2 Post_t + \beta_3 Rail_{mrt} Post_t \\ &+ \beta_4 Rail_{mrt} Post_t Dist_r + X_{mrt}\gamma + \xi_{mrt}\big] + \eta_{imrt} \equiv \mu_{mrt} + \eta_{imrt} \ , \end{aligned}$$

where η_{imrt} is an error term distributed type-I extreme value. The market share for each mode is then $s_{mrt} = \frac{\exp(\mu_{mrt})}{\sum_{\ell=1,2}\exp(\mu_{\ell rt})}$, which is jointly determined with that of the other mode. Indexing railroads as $m = 1$ and steamships as $m = 2$, we can write:

$$\begin{aligned} \ln(s_{1rt}) - \ln(s_{2rt}) = &\ \mu_{1rt} - \mu_{2rt} \\ = &\ \tilde{\beta}_0 + \tilde{\beta}_1 Post_t + \tilde{\beta}_2 Post_t Dist_r + \gamma_r + \varepsilon_{rt} \ , \end{aligned} \tag{2}$$

where the γ_r are route fixed effects (which will subsume the $Dist_r$ variable). This model can then be estimated by OLS on a sample of the all-rail observations.

Finally, to evaluate the effects of the gauge change on combined traffic, I collapse the sample to route-years and estimate a specification for total shipments:

$$\ln\left(Q_{rt}\right) = \beta_0 + \beta_1 Post_t + \beta_2 Post_t Dist_r + \gamma_r + \varepsilon_{rt} \tag{3}$$

3 Standardization and Internal Trade

Though adapters like steam hoists were being used across the South by the 1880s, contemporaries nonetheless believed that the gauge change would generate substantial growth in all-rail traffic. As the secretary of the SRSA noted in a U.S. Treasury Department report on Southern transportation, “the [current] movement via all-rail lines is very small, but will in the next few years develop very much, because of the late change of all lines to one uniform gauge” (Sindall 1886, p. 679). Was the conversion to the 4' 9'' gauge a large-enough improvement over the available adapters to affect internal trade between the South and other regions, as predicted?

In this section, I show that the adoption of compatible gauge indeed provoked a large redistribution of freight traffic on North-South routes from steamships to railroads, but it does not appear to have increased shipments in the aggregate. It may be helpful to provide a roadmap to this section in advance. I first contextualize the event within broader trends in trade between the South and other U.S. regions, which was growing rapidly in the 1870s and 1880s. I then estimate the effects of the gauge change on all-rail and steamship traffic, as well as on aggregate shipments. At the end of the section, I consider explanations for these results, focusing on the ways in which collusion may have constrained consumers' gains from standardization.

3.1 North-South Trade

Southern freight traffic grew rapidly over the 1870s and 1880s, during and after Reconstruction. Until the early 1880s, the vast majority of Southern trade was with the North, and this trade was conducted almost entirely by coastal steamship, in connection with interior railroad lines running from those points (Sindall 1886, p. 679). However, with the growth of the Southern rail network (Table 1) and Midwest industry and agriculture, the Southern trade expanded to the west over the decade, to the point where "Western" traffic was incorporated into the cartel in 1887, and all-rail shipping became a viable alternative for "Eastern" routes as well.

Table 3 shows overall trends in merchandise shipments for the sampled routes from 1884 to 1890. Over the six-year interval, total shipments increased by 25%, driven by growth in steamship traffic. The table also demonstrates heterogeneity in all-rail shares across origins – though this variation will be subsumed by route fixed effects in regressions. Given the limited sample of routes, it will nevertheless be important to test robustness across individual origins and destinations in the data. Note that these totals likely understate growth in trade between the South and other regions, as they do not account for the growth in Western traffic and on routes that entered service over the decade as the transportation network expanded.

[Table 3 about here]

3.2 Effects of the Gauge Change

3.2.1 Distributional Effects

Table 4 provides the initial test of the effects of the gauge change, estimating the specification in Equation (1), which regresses log traffic at the route-mode-year level on indicators for the all-rail mode and the post-period, their interaction, and an additional interaction with route length (in units of 100 miles), with the remaining interactions included but not listed for brevity. Column (1) estimates this model as specified, while Columns (2) through (6) add an assortment of fixed effects for routes, modes, years, route-modes, and route-years.

[Table 4 about here]

The table shows the treatment effect and its interaction with distance, suppressing the other parameters. I find that the gauge change caused all-rail traffic to increase by 240-250% relative to steamship traffic on short routes, with the effect diminishing on longer routes, reaching zero after roughly 740 miles. This effect is stable across specifications.

In Table 5, I explore heterogeneity in these effects across the two all-rail paths between the North and South, the ACL and PAL. This exercise is also in part a robustness check to see that both lines were affected by the conversion to the new gauge. The results show that they were, with the less-trafficked line (the ACL) experiencing a larger percentage increase in traffic. I find that the effects dissipate at similar distances for both carriers, roughly 700 miles – statistically comparable to the break-even distance in the previous table at usual significance levels. The effects are again estimated to be larger relative to route-year averages versus other fixed effects.

[Table 5 about here]

As previously discussed, the estimates in Tables 4 and 5 may not be properly identified, due to the interdependence of all-rail and steamship traffic in an imperfectly competitive market.[13] In Table 6, I estimate a model that accounts for this interdependence (Equation 2), in which the outcome variable is the log difference in all-rail and steamship shares. In taking this difference, most fixed effects from the previous table are eliminated, such that Table 6 includes only two variants of the regression: absent and with route fixed effects (Columns 1 and 2, respectively).

[Table 6 about here]

We continue to see positive effects of the gauge change on all-rail shares that decline with distance, significant well beyond the one percent level. The estimates are similar across the two specifications, and the effect of the gauge change is again estimated to dissipate at roughly 730 miles, as in Table 4. In Table 7, I split the effects out for the ACL and PAL. The effects are present for both carriers, continue to be relatively larger for the ACL (the smaller of the two carriers), and again dissipate after roughly 700 miles – much as in Table 5.

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[13] In the language of causal inference, the risk is a violation of the stable unit treatment value assumption (SUTVA): the assumption that untreated observations are unaffected by the treatment. In an imperfectly competitive market, steamships (the control group) may be indirectly affected by the gauge change if they lose traffic to railroads. In this case, a direct comparison would overstate its effects on growth in all-rail traffic.

[Table 7 about here]

I also examine variation in the effects of the gauge change over time. *A priori* it is not obvious whether the effects would be immediate or would phase in: on the one hand, the change was immediate and comprehensive, and improved service available from the first day after the conversion; on the other hand, it may have taken time for information to spread, and for shippers to adjust. To evaluate this question, as well as to test for pre-trends, Table 8 re-estimates the model in Equation (2), allowing the coefficients to vary by year.

[Table 8 about here]

Relative to the omitted year of 1884, the table shows that all-rail and steamship shares did not change in a statistically significant way over the next two years leading up to the gauge change (if anything, the signs of the estimates suggest all-rail shares were declining). Beginning in the first year post-gauge change, we see a significant jump in all-rail shares that grows each year through the end of the panel, and it appears to level out around 1890.

In Appendix C, I test the sensitivity of these results to dropping individual origins, destinations, and years from the cartel sample. Given the limited number of routes (52) and the somewhat short panel (3 years pre-gauge change, 4 years post), these checks are necessary to establish that the results are not driven by outliers or subsamples (for example, by routes originating in Baltimore, the origin nearest to the South). I find consistent results throughout. I also run similar regressions for revenue, which is provided alongside the traffic statistics in the SRSA tables, and find identical effects of the gauge change in sign and magnitude. This result is a natural consequence of the high correlation ($\rho = 0.99$) between traffic and revenue in the data.

3.2.2 Aggregate Effects

The previous results established that the gauge change caused growth in all-rail freight shipments relative to steamship traffic, but leave ambiguous to what degree this effect reflects displacement of existing traffic versus the generation of new traffic. Table 9 answers this question, collapsing the data to the route level and looking at the effects of the gauge change on total route traffic and revenue (Equation 3). The even-numbered columns include route fixed effects. Across all specifications, the change in traffic and revenue is not significantly different from zero. In particular, we see no increase in traffic on shorter routes (where previous tables showed the gauge change had the strongest effects on shares) relative to longer routes: the variation in the growth in route traffic and revenue vis-à-vis distance is a precisely-estimated zero.

[Table 9 about here]

3.3 Explaining the Results

That the standardization of railway gauge caused economic activity to shift to the all-rail mode is plausible, albeit not ex-ante obvious, given the widespread use gateway technologies pre-gauge change that reduced the cost of incompatibility. This evidence alone implies welfare gains for the switchers. But the lack of an effect on the extensive margin – the absence of an increase in aggregate shipments – is surprising, and suggests that the consumer welfare gains were in fact constrained to existing traffic. The most likely reason was the cartel itself.

Though the conversion to a compatible gauge increased railroads' capacity and reduced costs by eliminating interchange, cartel freight rates held constant around the conversion, which may have precluded any change in aggregate shipments. The SRSA's Circular Letters include tables with the issued rates for shipments between various cities within and outside of the South, which list prices by class of merchandise and were revised and republished every time rates were adjusted.[14] These tables make it possible to track route-level price changes over time.

Figure 3 show the distribution of rate changes on the routes in these circulars that are also in the sample for this paper (total of 36 routes, out of the 52 routes in the previous tables). Each observation in the figure is a route-class; with 36 routes and 13 classes, there are 468 observations per period. The left panel of the figure shows the change in rates from February 1885 to March 1886 (a few months prior to the gauge change), and the right panel shows the change from March 1886 to July 1887 (over a year after the gauge change).

[Figure 3 about here]

An overwhelming fraction of routes do not update prices over this period. The handful of price adjustments following the gauge change were increases, rather than decreases, and were limited to

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[14] The SRSA classified freight into 13 different categories (classes) and set prices at the route and class level. More irregular, fragile, or valuable goods were classified into higher classes, which were charged the highest rates. Rates on lower classes were generally a fixed proportion of the first-class rate for each route.

two routes: Philadelphia-Montgomery and Philadelphia-Selma.[15]

Theoretical predictions for prices are ambiguous if demand for all-rail service shifted out concurrently with supply. But with the absence of an effect on total shipments, the evidence is puzzling: if demand and supply shift similarly, prices may hold but total traffic should grow. And if demand were insensitive to the gauge change, then prices should decline, with some of the railroads' cost-savings passed through. Gauge-inelastic demand is also inconsistent with the growth in all-rail market share and the motivations for the gauge change itself.

A closer reading of SRSA documents suggests a potential reason why railroads' cost-savings may not have been passed through to prices: the rate-setting process was contentious, and revisions required the unanimous approval of a committee composed of representatives from member carriers. Compounding this obstacle was the fact that the cartel issued uniform rates for all carriers, likely to avoid perceptions that individual members were being favored, and without comparable cost reductions for steamships, it was difficult to get their representatives to consent to rate reductions on the grounds of the gauge change alone. However, in the event of deadlock, proposed rate changes would be evaluated by the cartel's board of arbitration, which would then issue a ruling by simple majority. In practice, many rate changes were enacted this way.

Another interpretation is that the cartel avoided pass-through and in turn suppressed the welfare gains that would have otherwise been realized by the conversion to a compatible gauge. The natural question is then: what would have happened to prices and total traffic had the cartel been broken? The remainder of the paper seeks to answer this question.

4 The Market for Shipping

To evaluate counterfactual prices and traffic under competition, I model the market for North-South freight shipment. The model assumes shippers in a given route and year make a discrete choice between the all-rail and steamship modes to maximize utility, and that railroads and steamships concurrently set prices to maximize joint or individual profits (under collusion or competition, respectively), under the constraint that collusive prices must be the same for railroads and steamships serving a given route – as was the case for the SRSA cartel.

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[15] Cartel prices were not always so steady: until the early 1880s, prices were reduced regularly, under pressures of competition from alternative routing outside the scope of the cartel. Multiple sources have documented this decline, while also observing that price reductions ended in the early- to mid-1880s (e.g., Hudson (1890) documents prices from Boston, New York, Philadelphia, and Baltimore to Atlanta from 1875 onwards, and shows that rate reductions occurred every 1-2 years until 1884, after which rates went unchanged).

In this model, markets are defined as route-years. Though there are 364 ($= 52 \cdot 7$) markets in the full sample, there are only 288 for which I have price data, such that the sample for this exercise will be restricted to $N = 288$ markets. Within each of these markets, I observe the share of traffic supplied by all-rail and steamship modes, but as in other models of demand I must assume a total market size, which I fix to twice the observed traffic.

Each market is characterized by prices $\{P_{1rt}, P_{2rt}\}$, quantities $\{Q_{1rt}, Q_{2rt}\}$, and marginal costs $\{MC_{1rt}, MC_{2rt}\}$ where $m = 1$ denotes the all-rail mode and $m = 2$ denotes the steamship mode. Under the cartel, $P_{1rt} = P_{2rt} = P_{rt}$, whereas under competition mode prices are allowed to differ. Quantities throughout this and the next section are measured in 100-pound units, while prices and marginal costs are in dollars per 100 pounds of freight on the given route.[16] Though the SRSA priced freight according to a complex classification scheme (with more valuable, irregular, or fragile goods charged higher prices, and bulk commodities charged the lowest prices), the SRSA traffic tables aggregate shipments across classes of merchandise. I thus calculate a weighted average price for each route, weighting by the share of route traffic in each class in 1880, and treat freight as being homogeneous in composition and priced at this index.

4.1 Demand

Suppose the latent utility of each mode m for shipper i on route-year rt is u_{imrt}, and shippers make a discrete choice over mode to maximize utility, as follows:

$$\max_{m} u_{imrt} = G_{mrt}\left(\beta_1 + \beta_2 Dist_r\right) - \alpha P_{mrt} + \gamma_m + \xi_{mrt} + \eta_{imrt} \equiv \delta_{mrt} + \eta_{imrt} ,$$

where G_{mrt} indicates that mode m requires transshipment in route-year rt, $Dist_r$ is distance between route r origin and destination, P_{mrt} is the price of mode m in route-year rt (calculated as the weighted average of rates across all classes of merchandise, as before), γ_m represents mode dummies, ξ_{mrt} is a mean-zero, route-mode-year specific unobservable, and ε_{imrt} is an i.i.d. type-I extreme value error. Mean utility of each mode is denoted as δ_{mrt}, and the outside option (withholding shipment) is indexed $m = 0$ and normalized to have $\delta_{0rt} = 0$.

Under this specification, consumers may have an inherent preference for each mode, but choices are also influenced by prices and by the necessity of transshipment. From this specification of utility,

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[16] Marginal costs should be interpreted as the cost of transporting 100 pounds on a given route, via a given mode, in a given year, which is a function of the mode, distance, and transshipment (if required).

we get choice probabilities (market shares) of the following form:

$$s_{mrt}(P_{mrt}) = \frac{\exp(\delta_{mrt}(P_{mrt}))}{1 + \sum_{\ell} \exp(\delta_{\ell rt}(P_{\ell rt}))}$$

As in Equation (2), we can log-difference the outside market share to obtain the following reduced-form equation, which can be used to estimate the demand parameters:

$$\ln(s_{mrt}) - \ln(s_{0rt}) = G_{mrt}\left(\beta_1 + \beta_2 Dist_r\right) - \alpha P_{mrt} + \gamma_m + \xi_{mrt} \tag{4}$$

When this model is taken to the cartel data, P_{mrt} will effectively be reduced to P_r, as prices on the sampled routes are constant within routes across modes and nearly constant over time. I estimate this model by 2SLS, instrumenting for prices with route length, a principal determinant of costs and prices for long-distance freight shipment. The necessary assumption to satisfy the exclusion restriction is that distance only affects demand through prices.

4.2 Supply

The cartel is assumed to set prices on each route to maximize joint profits, subject to the constraint of a single price for all carriers. Formally, the cartel's problem is:

$$\begin{aligned} \max_{P_{rt}} \Pi_{rt} &= \sum_m (P_{rt} - MC_{mrt}) \cdot Q_{mrt}(P_{rt}) \\ &= M_{rt} \sum_m (P_{rt} - MC_{mrt}) \cdot s_{mrt}(P_{rt}) \end{aligned}$$

with

$$MC_{mrt} = \lambda_m Dist_r + \theta G_{mrt} + \omega_{rt} \ ,$$

where λ_m is the marginal cost of shipping an additional 100 pounds of freight per 100 miles of route length via mode m, θ is the cost of transshipment (if necessary), and ω_{rt} is a mean-zero cost shock shared by both modes on a given route, in a given year.

The cartel's first-order condition for each route-year is then:

$$(s_1 + s_2) + (P - MC_1) \cdot \frac{\partial s_1(P)}{\partial P} + (P - MC_2) \cdot \frac{\partial s_2(P)}{\partial P} = 0$$

which can be rewritten to be linear in the cost parameters, as in Equation (5) below. I invoke this equation to estimate the supply parameters by OLS.

$$\begin{aligned}\left(P + \frac{s_1 + s_2}{{}^{\partial s_1}\!/_{\partial P} + {}^{\partial s_2}\!/_{\partial P}}\right) = {} & \lambda_1 \left(\frac{Dist_r({}^{\partial s_1}\!/_{\partial P})}{{}^{\partial s_1}\!/_{\partial P} + {}^{\partial s_2}\!/_{\partial P}}\right) \\ & + \lambda_2 \left(\frac{Dist_r({}^{\partial s_2}\!/_{\partial P})}{{}^{\partial s_1}\!/_{\partial P} + {}^{\partial s_2}\!/_{\partial P}}\right) + \theta \left(\frac{G_1({}^{\partial s_1}\!/_{P}) + G_2({}^{\partial s_2}\!/_{\partial P})}{{}^{\partial s_1}\!/_{\partial P} + {}^{\partial s_2}\!/_{\partial P}}\right) + \omega \end{aligned} \tag{5}$$

4.3 Estimation

I proceed with estimation via a bootstrap procedure, in five steps:[17]

1. Estimate demand (Equation 4) via 2SLS, with clustered standard errors
2. Draw demand parameters from their joint distribution
3. Use draws to predict market shares and calculate elasticities
4. Estimate supply (Equation 5) via OLS with clustered SEs
5. Bootstrap: Repeat steps 2 through 5 (x2000)

This procedure will return a single set of estimates for demand, with standard errors clustered by route as before, and 2,000 sets of estimates for supply, which account for the parameters' sampling variance as well as the variance of the predicted market shares and elasticities entering the supply equation, which are generated from estimated parameters themselves.

4.4 Parameter Estimates

Table 10 shows the results for both demand and supply. The demand estimates (left panel) show an embedded preference for steamships over the all-rail mode and a negative effect of transshipment on demand, diminishing with route length as in previous results, breaking even around 800 miles. We also see that distance strongly predicts freight tariffs ($F > 200$), validating the choice of instrument, and a negative price coefficient of sensible magnitude ($\alpha = -9$).

[Table 10 about here]

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[17] In concept, the demand and supply parameters could be be jointly estimated via GMM or by a bootstrap, but the GMM estimation is complicated by the different dimensionalities of the demand and pricing equations (specified at the level of route-mode-years and route-years, respectively) and sensitive to starting values. Given its transparency and computational simplicity in this setting, I opt for the bootstrap.

The marginal cost estimates (right panel) show that transshipment imposes a large fixed cost on interregional freight traffic, roughly \$0.17 per 100 pounds (nearly 25% of the median freight tariff for routes in this sample). For comparison, contemporaries (Poor 1851, Dartnell 1858) estimated that breaks in gauge incurred handling costs of \$0.25-0.50 per ton in the 1850s – a cost which would have been largely reduced by steam hoists and other gateway techniques in use by the 1880s – as well as a delay of 24 hours, equal to roughly 300 miles' distance, consistent with the results in the table. We also see similar operating costs per 100 miles of straight-line distance for each mode, at around \$0.04-0.05 per 100 pounds. While steamship costs were in practice lower than all-rail costs per mile traveled, steamships had to travel a longer, less-direct path to interior Southern cities, offsetting this cost advantage in the estimates.

Besides the functional form, recall that the principal assumption of this model is that the total latent market size for each route-year is twice the observed traffic. As in other examples of demand estimation (e.g., Berry et al. 1995), this assumption is necessary to compute outside shares, but is important to note here that the estimates in Table 10 are sensitive to moderate or large deviations from this assumption. The estimates, and the counterfactuals simulated from them, should therefore be interpreted as suggestive rather than incontrovertible evidence; in other words, the usual caution in interpreting structural estimates continues to apply.

5 Standardization with Competition

The question motivating this estimation was whether the gauge change might have generated an increase in trade in a competitive environment. To answer this question, I apply the estimates to simulate a counterfactual in which the two modes compete on prices in a Nash-Bertrand equilibrium. This exercise assumes a single price-setter for each mode, and thus only partially breaks the cartel, since there were two all-rail service providers and multiple steamship lines. Given the limitations of the data (which, as previously described, are provided at the level of paths, which sometimes involved multiple carriers and were not all present in every market), as well as recurrent delineations between all-rail and steamship modes in both the data and the narrative record (in which contemporaries predicted that all-rail traffic would grow relative to steamship traffic under a uniform gauge), reducing the dimensionality of the counterfactual to modes (rather than paths, or carriers) is a natural choice, and sufficient for evaluating the question at hand.

To simulate this counterfactual, we need to solve for the competitive equilibrium. Each mode m

will set prices to maximize profits, with the first-order condition:

$$s_{mrt}(P_{1rt}, P_{2rt}) + (P_{mrt} - MC_{mrt}) \cdot \frac{\partial s_{mrt}}{\partial P_{mrt}} = 0$$

This condition can be rearranged to yield the familiar pricing equation:

$$\begin{bmatrix} P_{1rt} \\ P_{2rt} \end{bmatrix} = \begin{bmatrix} MC_{1rt} \\ MC_{2rt} \end{bmatrix} + \begin{bmatrix} \frac{\partial s_{1rt}}{\partial P_{1rt}} & 0 \\ 0 & \frac{\partial s_{2rt}}{\partial P_{2rt}} \end{bmatrix}^{-1} \begin{bmatrix} s_{1rt}(P_{1rt}, P_{2rt}) \\ s_{2rt}(P_{1rt}, P_{2rt}) \end{bmatrix}$$

into which we can plug the parameter estimates and numerically solve for prices $\{\tilde{P}_{mrt}\}$, which in turn imply quantities $\{Q_{mrt}(\tilde{P}_{1rt}, \tilde{P}_{2rt})\}$ and profits $\{\Pi_{mrt}(\tilde{P}_{1rt}, \tilde{P}_{2rt})\}$.

The results are provided in both tabular and graphical form in Table 11 and Figure 4. The table summarizes prices, traffic, and profits for the all-rail and steamship modes separately for the pre-period (Panel A) and the post-period (Panel B). In the pre-period, competition would drive down the average all-rail tariff by 12% and steamship tariff by 7%. The reduction in prices would generate a 12% increase in total traffic, driven entirely by growth in freight shipments via steamship (which grow in absolute and take share from railroads). Industry profits would fall precipitously, with an 83% decline for all-rail, 37% decline for steamships, and a net 46% reduction in profits for the industry. The decline in profits is driven by both a reduction in revenue and a decline in margins (from 25% to 6% for all-rail, and from 30% to 19% for steamships).

[Table 11 about here]

The results for the pre-period provide a baseline for evaluating the effects of competition on its own, while the post-period results show the effects in the presence of compatibility. Recall that the gauge change reduced all-rail costs by eliminating the fixed cost of interchange at breaks in gauge. In the counterfactual, I find that a competitive market structure would have induced railroads to pass through nearly 70% of their cost-savings from standardization and generated a 27% decline in the average all-rail tariff post-conversion, relative to observed prices, with most (approximately two-thirds) of this reduction attributable directly to compatibility.[18]

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[18] In principle, part of this price reduction is attributable to the effects of competition even in the absence of compatibility, but most of the effect is driven by pass-through of railroads' cost-savings from the gauge change in a competitive market. This can be seen by comparing the effect against that in the pre-period, or against a simulation of a competitive post-period without compatibility, as in Appendix E.

Following this price reduction, post-conversion traffic on the sampled routes would have grown 21%, with the increase driven entirely by growth in all-rail traffic, which would have more than doubled, partly at the expense of steamships and partly by drawing new traffic into the market. As in the pre-period, competition would have driven down profits for all participants, with a net 38% decline in profits for the industry as a whole – although railroad profits would have been insulated by their newly developed advantage in providing a transshipment-free service post-gauge change. Figure 4 provides a visualization of these effects.

[Figure 4 about here]

Results in Context: Standardization in Other Regions

Though data are not available to study earlier conversions in other regions, which anyway occurred piecemeal and at smaller scale, we can look to the historical record for external validation. The most quantitative discussion of the effects of standardized gauge on railroad operations comes from the Erie Railway Company in the early 1870s, when it was considering conversion from 6'0'' to standard gauge. According to Blanchard (1873), the motivation for conversion was that the Erie's broad gauge was costing it substantial traffic, because shippers "demand quick time" and preferred routing that carried freight all the way to its destination "under lock and seal" as opposed to requiring transfers, which "increase the probabilities of loss, damage, and detention." As evidence of the potential returns, he evaluates the most recent example of conversion in North America (the Grand Trunk Railway of Canada, in 1873), and notes that its net income in the subsequent nine weeks (up to the date of publication) had grown 15% over the previous nine weeks and over the same nine weeks in the prior year, due to both lower costs and greater revenue, while its Canadian and American competitors had concurrently lost revenue.

6 Implications for Research and Policy

These results yield lessons for both research and policy. The foremost lesson is that standards are economically important. Despite a large theoretical literature on compatibility, and a recent body of work on standards-setting organizations, there is little evidence explicitly linking compatibility to economic outcomes. In showing that the standardization of railroad gauge in the 1880s materially affected trade, this paper has implications for a wide range of settings where compatibility and standardization are design choices. The most obvious motivating example is Internet and communications technologies, which similarly operate in a heavily networked environment – especially the infrastructure supporting the Internet. For example, early efforts at computer networking led to several networks that developed alongside the Internet, each of which used a proprietary naming system for addressing email traffic; communication across them was enabled by gateways but required users to specify the complete routing, such that "only the most technically skilled" users were capable of sending email (Greenstein 2015), until these networks adopted the domain name system (DNS) as a common standard (Greenstein 2015, Partridge 2008).

The results also yield a deeper lesson on the interaction of standards with product market competition. In many settings, transactions must be executed via intermediaries who provide physical or digital infrastructure for transmission, such as freight carriers (for physical trade), Internet service providers (for communications), and financial exchanges (for asset purchases). These intermediaries often must interconnect with others for delivery. This paper shows that compatibility at connection points can generate large welfare gains – but only if the cost savings are passed through to consumers, which is unlikely to occur if service is not competed. Because these settings experience network effects and are inherently likely to be concentrated, a lack of competition is often a reality, and the results of this paper immediately relevant.

Direct Applications: Modern International Railways

In addition to these contributions, the results have direct bearing on modern-day railway networks. Breaks in gauge are still common around the world, especially in developing regions such as South Asia, Africa, and Latin America. These breaks often occur at national boundaries, though in some cases they are present within them as well – most notably in India, which has recently undertaken a national effort to standardize gauge across a 71,000-mile network. Appendix Figure F.1 illustrates just how pervasive the problem is, showing a world map with countries color-coded by the principal gauge of their railways; developing areas generally have 3 or 4 gauges in use.

The problem has not escaped the attention of policymakers: resolving differences in gauge has been a focal point in repeated international negotiations to integrate domestic railways into transcontinental networks in places like Europe, Asia, and the Middle East. The most recent example of such an agreement was the United Nations-brokered Trans-Asian Railway (TAR) Network Agreement, ratified by 17 Asian countries in 2006 (UNTC 2006). The negotiations behind this agreement date back to the 1950s, when the U.N. Economic Commission for Asia and the Far East (now the U.N. Economic and Social Commission for Asia and the Pacific, or UNESCAP) set out to link Istanbul and Singapore (UNESCAP 1996). The intent was to establish more direct, overland routes between Europe and East Asia to support and promote international trade. Integrating the transportation network became increasingly imperative as trade grew over the following decades, but "this proposal, and the many that followed it, were frustrated ... by the lack of a uniform railway gauge ... and by the presence of gaps, or missing links, in the route" (UNESCAP 1996). Gaps could be filled, but it proved impossible to negotiate a common gauge standard, and when a treaty was finally ratified, it contained no provisions for standardizing the gauge.

As a result, while there are now major lines connecting all parts of the continent, freight moving between Europe and Southeast Asia must cross three breaks in gauge (see Appendix Figure F.2). These breaks remain costly, interrupting the movement of both passengers and cargo and imposing delays. And although more than a century has passed, the same adapters are still being used today: documentation points to transshipment, bogie exchange, and variable gauge as the principal means of interchange. The TAR is also not unique in this regard: a similar agreement in Europe (UNTC 1991) lists the stations where interchange would have to occur and specifies whether it would be conducted by transshipment or bogie exchange (Appendix Table F.2).

In this context, the results of this paper provide direct lessons for present-day treaties and policies governing transport network integration. The main lesson is that eliminating breaks in gauge significantly improves the quality of rail-based freight shipping services, enough to divert traffic from other modes – and if operators' cost-savings are passed through to consumers, enough to increase the total amount of trade conducted. It is important to nevertheless be cautious in extending these results to a different time period, geography, and market structure (many railroads are nationalized), but given the parallels, it seems appropriate to view the evidence in this paper as instructive of the potential benefits of interoperability under a common standard.

7 Conclusion

This paper studies the conversion of 13,000 miles of railroad in the U.S. South to a standard-compatible gauge in 1886 on internal trade between the South and the North. The gauge change integrated the South into the national railroad network and provides a large-scale natural experiment for studying the effects of interoperability standards on economic activity. Using comprehensive records of merchandise shipments on 52 North-to-South routes from a cartel that governed this traffic, I find that the gauge change precipitated a large transfer of market share from steamships to railroads that declines with distance but did not affect total shipments.

To reconcile these results, I turn attention to the cartel itself, which held prices constant around the conversion – likely limiting any response on the extensive margin. The natural question is then whether standardization would have led to lower prices and increased trade in a competitive market. To evaluate this question, I estimate a model of the industry and simulate counterfactuals in which the all-rail and steamship transport modes compete. The results of this exercise suggest that in a competitive industry, the standardization of the gauge would have generated a 27% reduction in all-rail prices and 20% growth in aggregate shipments.

The results offer several lessons, the foremost of which is simply that standards matter. Despite the pervasiveness of compatibility standards across essentially all sectors of the economy, and their importance to industries driving innovation and growth (like ICT), to my knowledge this is the first study that uses experimental variation to connect standards to economic outcomes – and it finds statistically and economically significant effects of railroad gauge standards on trade. The paper also sheds light on the potential benefits to integrating global railroad networks, which continue to suffer from breaks in gauge that necessitate costly interchange.

Finally, the results point to a complex interaction of standards and product market competition in networked environments. While collusion (or consolidation) increases firms' incentives to adopt interoperability standards by internalizing the externality, it also harms consumers and limits the welfare gains from standardization. This tension presents an important tradeoff for antitrust regulators that to my knowledge has not been recognized in the literature on standards or competition but is ripe for attention, given recent antitrust scrutiny on several large Internet and communications firms with products that benefit from interoperability.

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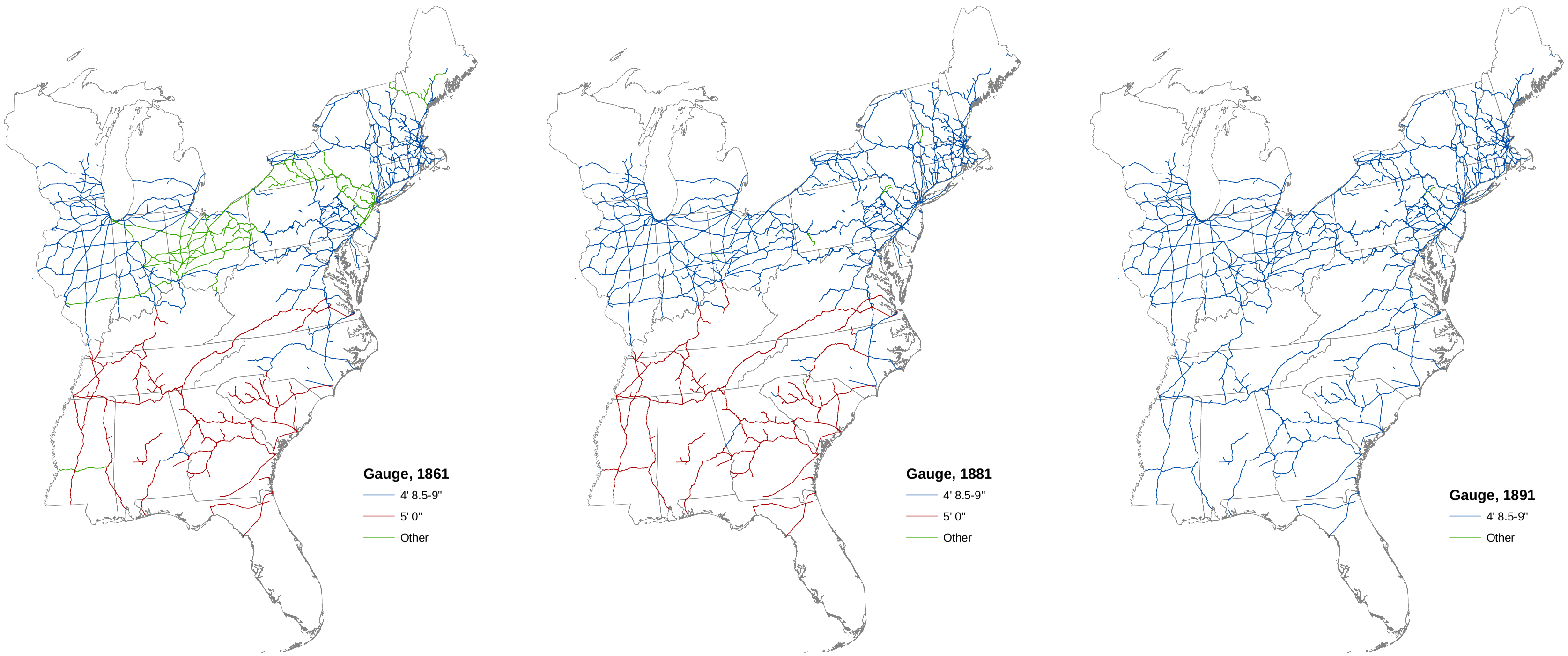
Figure 1: Installed Railroad Gauge East of the Mississippi River, 1861–1891 (holding network fixed)



Baseline: 1861 Railroad Network

Updated Railroad Gauges of the 1861 Network, as of 1881

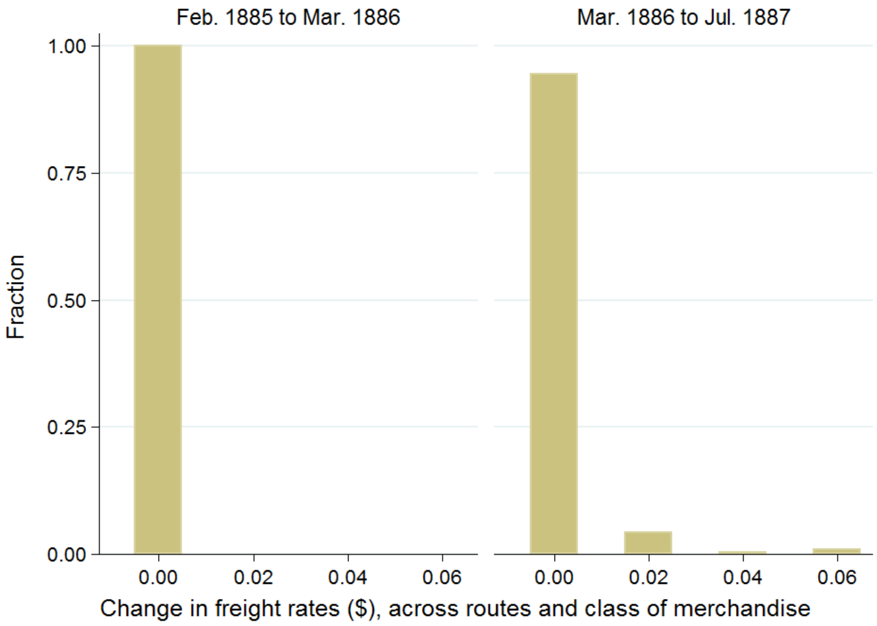
Updated Railroad Gauges of the 1861 Network, as of 1891

Notes: Figure illustrates the United States' transition to a unified, standard-gauge railroad network in the second half of the 19th century. The left-most panel shows the state of the railroad network east of the Mississippi River in 1861, color-coding segments of railroad by their gauge. The middle and right-most panels show the gauge in use in 1881 and 1891, respectively, holding the network fixed (omitting new construction). Network and gauge data for 1861 railroads obtained from the Atack (2015) Historical Transportation Shapefile of Railroads in the United States. Contemporary gauges for these same railroads or their subsequent acquirers in 1881 and 1891 were obtained from Poor's Manual of Railroads volumes for all railroads that could be matched. Over 99.5% of track miles in the 1861 network shown above were matched to the Poor's data in both 1881 and 1891.

Figure 2: Map of Sampled Origins (North) and Destinations (South)

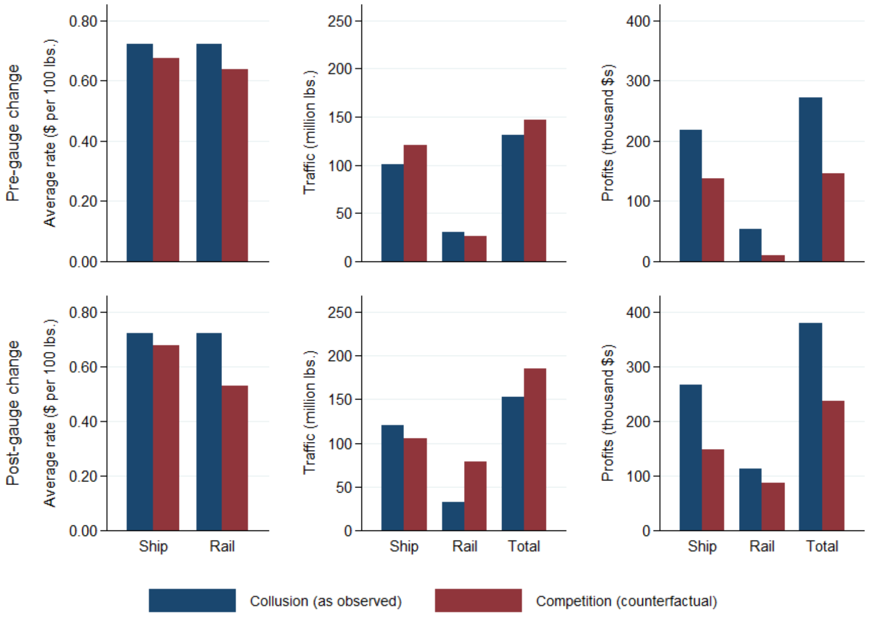
Notes: Figure shows the northern route origins and southern destinations for routes in the sample. These destinations are those for which data was reported by the Southern Railway and Steamship Association both before and after the gauge change. Freight transportation was available by all-rail routes traversing Virginia, Tennessee, and the Carolinas or by a combination of steamship and railroad, via southern port cities such as Charleston, Savannah, Norfolk, and Port Royal.

Figure 3: Distribution of Cartel Price Changes, pre- vs. post-Gauge Change



Notes: Figure shows the distribution of cartel price changes across routes and classes of merchandise from February 1885 to March 1886 (left panel) and March 1886 to July 1887 (right panel), for the subset of routes included in the SRSA rate tables. The handful of rate increases in the latter period come entirely from two routes: Philadelphia to Montgomery, and Philadelphia to Selma. Data from SRSA Circular Letters, Volumes 13-24.

Figure 4: Prices, Quantities, and Profits in Competitive Counterfactual



Notes: Figure shows mean prices, total traffic, and est. profits for railroads and steamships, as observed and in a counterfactual in which they compete. The figure is a visual presentation of the data in Table 11.

Table 1: Approx. Miles of Railroad in each Gauge, by Region, 1881-1889 (Poor's Manual of Railroads)

	Pre-Gauge Change			**Post-Gauge Change**	
New England	**1881**	**1883**	**1885**	**1887**	**1889**
Miles in gauge:					
4' 8.5-9"	6,060.2	6,082.6	6,237.8	6,600.3	6,627.6
5' 0"	0.0	0.0	0.0	0.0	0.0
Other	191.1	201.2	180.4	184.6	116.5
Total Miles	6,251.3	6,283.8	6,418.2	6,784.9	6,744.1
Pct. 4' 8.5-9"	97%	97%	97%	97%	98%
Mid-Atlantic					
Miles in gauge:					
4' 8.5-9"	14,855.0	17,590.3	18,923.4	18,648.6	20,210.7
5' 0"	0.4	0.4	0.5	0.2	0.0
Other	990.2	997.4	868.3	772.0	682.5
Total Miles	15,845.6	18,588.1	19,792.2	19,420.9	20,893.3
Pct. 4' 8.5-9"	94%	95%	96%	96%	97%
Midwest					
Miles in gauge:					
4' 8.5-9"	34,904.3	38,669.2	37,904.4	42,241.2	45,938.1
5' 0"	0.0	0.0	0.0	0.0	0.0
Other	2,342.1	2,800.7	2,591.3	1,318.3	1,028.7
Total Miles	37,246.4	41,470.0	40,495.6	43,559.5	46,966.7
Pct. 4' 8.5-9"	94%	93%	94%	97%	98%
South (focal region)					
Miles in gauge:					
4' 8.5-9"	4,306.8	4,759.6	6,048.6	21,593.6	25,252.7
5' 0"	11,908.1	12,964.5	13,274.2	268.2	19.5
Other	1,042.7	1,592.6	1,371.5	1,734.9	1,521.2
Total Miles	17,257.5	19,316.6	20,694.3	23,596.7	26,793.4
Pct. 4' 8.5-9"	25%	25%	29%	92%	94%
Western States					
Miles in gauge:					
4' 8.5-9"	26,272.5	33,817.6	36,435.9	47,694.8	54,352.6
5' 0"	135.0	135.0	0.0	0.0	0.0
Other	3,427.4	5,623.2	4,642.0	4,253.6	3,965.9
Total Miles	29,834.8	39,575.8	41,078.0	51,948.4	58,318.5
Pct. 4' 8.5-9"	88%	85%	89%	92%	93%

Notes: Table shows the approximate miles of railroad in the U.S. from 1881 to 1889 in two-year intervals, by region and gauge, confirming the scale of the conversion: 13,000 miles of Southern railroad converted from 5'0" to 4' 9" between 1885 and 1887. Data from Poor's Manual of Railroads, which provides a near-complete, annual enumeration of U.S. railroads. The data are subject to regional classification errors which tend to over-attribute mileage to the Midwest, pulling from the Mid-Atlantic and West, as a result of railroads with principal operations in the Midwest extending into these regions. The table uses the regional definitions of the Poor's Manual; the southern states are Virginia, West Virginia, Kentucky, Tennessee, Mississippi, Alabama, Georgia, Florida, the Carolinas, and Louisiana.

Table 2: Origins and Destinations for Sampled Routes

Destinations (south)		**Origins (north)**	
Albany	GA	Boston	MA
Athens	GA	New York	NY
Atlanta	GA	Philadelphia	PA
Augusta	GA	Baltimore	MD
Macon	GA		
Milledgeville	GA		
Newnan	GA		
Rome	GA		
Montgomery	AL		
Opelika	AL		
Selma	AL		
A. & W. Pt. stations (GA)			
W. & A. stations (GA)			

Notes: Table lists the origin and terminus of routes in the sample of Northern merchandise shipments used in the remainder of this paper. These 52 routes (4 origins x 13 destinations) are those for which data was reported by the Southern Railway and Steamship Association both before and after the gauge change. “A. & W. Pt. Stations” refers to stations on the Atlanta and West Point Railroad between East Point and West Point, GA (70 mi), whose traffic was reported collectively; “W. & A. Stations” refers to stations on the Western and Atlantic Railroad between Chattanooga, TN and Marietta, GA (87 mi). These destinations are geotagged to the centroid of their respective endpoints.

Table 3: Trends in Southern Freight Traffic, by Mode and Route Length (sampled routes only)

	Pre-Gauge Change			**Post-Gauge Change**			
	1883-84	**1884-85**	**1885-86**	**1886-87**	**1887-88**	**1888-89**	**1889-90**
Panel A. Mean across routes <25th percentile distance							
Total traffic (million lbs.)	0.75	0.69	0.70	0.74	0.83	0.87	0.83
	(0.26)	(0.24)	(0.26)	(0.27)	(0.31)	(0.32)	(0.29)
via rail	0.70	0.51	0.64	0.88	0.94	0.84	0.93
	(0.26)	(0.21)	(0.30)	(0.33)	(0.38)	(0.33)	(0.34)
via steamship	0.80	0.88	0.76	0.60	0.72	0.91	0.72
	(0.26)	(0.26)	(0.22)	(0.19)	(0.24)	(0.33)	(0.24)
Panel B. Mean across routes >75th percentile distance							
Total traffic (million lbs.)	0.97	0.94	1.28	0.96	1.13	1.13	1.43
	(0.47)	(0.42)	(0.56)	(0.44)	(0.55)	(0.55)	(0.73)
via rail	0.28	0.38	0.58	0.53	0.44	0.25	0.35
	(0.17)	(0.24)	(0.36)	(0.41)	(0.34)	(0.17)	(0.23)
via steamship	1.67	1.50	1.99	1.39	1.83	2.01	2.50
	(0.59)	(0.51)	(0.67)	(0.46)	(0.67)	(0.69)	(0.93)

Notes: Table reports average merchandise shipments by year on shorter routes (<25th percentile) versus longer routes (>75th percentile), breaking out the totals by mode. The table illustrates the rapid growth in Southern freight traffic over the 1880s on a set of routes that were serviced throughout the decade. Southern trade growth would be even higher when considering routes that entered service over the decade, as the rail network expanded (Table 1 shows the growth in mileage). Standard errors of the mean shown in parentheses.

Table 4: Change in All-Rail Traffic

	(1)	(2)	(3)	(4)	(5)	(6)
All-rail x post-change	2.437***	2.429***	2.425***	2.484***	2.466***	2.541***
	(0.460)	(0.455)	(0.455)	(0.466)	(0.559)	(0.582)
* distance (100 mi)	-0.322***	-0.328***	-0.328***	-0.334***	-0.331***	-0.341***
	(0.059)	(0.059)	(0.059)	(0.060)	(0.073)	(0.075)
Breakeven distance	756.5	740.5	740.1	742.8	744.1	745.6
	(34.9)	(32.7)	(32.7)	(32.7)	(39.8)	(39.7)
N	1036	1036	1036	1036	1036	1036
R^2	0.32	0.67	0.67	0.73	0.70	0.75
Route FE		X	X			
Mode FE			X			
Year FE			X			
Route-mode FE				X		X
Route-yr FE					X	X

Notes: Table estimates effect of the gauge change on merchandise shipments from North to South. Observations are route-mode-years. The treated group consists of the all-rail mode; the control group, the steamship mode. The "breakeven distance" at which the effects of standardization dissipate to zero is provided below the regression estimates. The dependent variable in all columns is log pounds of traffic. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table 5: Change in All-Rail Traffic, ACL and PAL

	(1)	(2)	(3)	(4)	(5)	(6)
A.C.L. x post-change	2.840***	2.852***	2.851***	2.826***	2.848***	2.809***
	(0.527)	(0.559)	(0.560)	(0.552)	(0.686)	(0.671)
* distance (100 mi)	-0.398***	-0.402***	-0.402***	-0.396***	-0.403***	-0.396***
	(0.071)	(0.076)	(0.076)	(0.074)	(0.094)	(0.090)
P.A.L. x post-change	1.809***	1.743***	1.733***	1.808***	1.748**	1.829**
	(0.555)	(0.610)	(0.609)	(0.607)	(0.754)	(0.754)
* distance (100 mi)	-0.238***	-0.244***	-0.243***	-0.248***	-0.247**	-0.253**
	(0.071)	(0.080)	(0.079)	(0.080)	(0.100)	(0.101)
Breakeven distance (A.C.L.)	713.6	709.6	709.7	713.4	705.9	709.8
	(32.5)	(32.7)	(32.8)	(34.5)	(39.0)	(41.5)
Breakeven distance (P.A.L.)	759.0	715.7	713.5	728.3	707.3	723.9
	(53.2)	(58.6)	(58.8)	(55.6)	(70.4)	(66.5)
N	1036	1036	1036	1036	1036	1036
R^2	0.48	0.83	0.84	0.89	0.86	0.91
Route FE		X	X			
Mode FE			X			
Year FE			X			
Route-mode FE				X		X
Route-yr FE					X	X

Notes: Table estimates effect of the gauge change on merchandise shipments from North to South. Observations are route-mode-years. The treatment group consists of these carriers. The control group remains the steamship mode. The "breakeven distance" at which the effects of standardization dissipate to zero is provided below the regression estimates. The dependent variable in all columns is log pounds of traffic. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table 6: Effects on Traffic Shares

	(1)	(2)
All-rail x post-change	2.281***	2.400***
	(0.428)	(0.450)
* distance (100 mi)	-0.315***	-0.327***
	(0.056)	(0.058)
Breakeven distance	724.6	734.4
	(32.3)	(32.6)
N	676	676
R^2	0.12	0.45
Route FE		X

Notes: Table estimates effect of the gauge change on all-rail traffic shares. The dependent variable is the log difference in all-rail and steamship shares within route-years. The "breakeven distance" at which the effects of standardization dissipate to zero is provided below the regression estimates. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table 7: Effects on Traffic Shares, ACL and PAL

	(1)	(2)
A.C.L. x post-change	2.848***	2.809***
	(0.554)	(0.542)
* distance (100 mi)	-0.403***	-0.396***
	(0.076)	(0.073)
P.A.L. x post-change	1.461**	1.647***
	(0.593)	(0.576)
* distance (100 mi)	-0.216***	-0.232***
	(0.076)	(0.076)
Breakeven distance (A.C.L.)	705.9	709.8
	(31.5)	(33.5)
Breakeven distance (P.A.L.)	676.8	708.8
	(73.1)	(57.3)
N	676	676
R^2	0.45	0.77
Route FE		X

Notes: Table estimates effect of the gauge change on all-rail traffic shares. The dependent variable is the log difference in all-rail and steamship shares within route-years. The "breakeven distance" at which the effects of standardization dissipate to zero is provided below the regression estimates. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table 8: Increasing Effect on Shares over Time

	(1)	(2)
All-rail x 1885	-0.914	-0.914
	(0.701)	(0.729)
* distance (100 mi)	0.071	0.071
	(0.093)	(0.097)
All-rail x 1886	-0.711	-0.630
	(0.863)	(0.813)
* distance (100 mi)	0.079	0.073
	(0.111)	(0.105)
All-rail x 1887	1.343**	1.500**
	(0.543)	(0.576)
* distance (100 mi)	-0.183**	-0.199**
	(0.074)	(0.078)
All-rail x 1888	1.622**	1.753**
	(0.751)	(0.790)
* distance (100 mi)	-0.271***	-0.282***
	(0.098)	(0.103)
All-rail x 1889	1.938**	2.069**
	(0.777)	(0.819)
* distance (100 mi)	-0.290***	-0.300***
	(0.102)	(0.107)
All-rail x 1890	2.040***	2.197***
	(0.678)	(0.720)
* distance (100 mi)	-0.314***	-0.331***
	(0.093)	(0.098)
N	676	676
R^2	0.12	0.45
Route FE		X

Notes: Table estimates the effect of the gauge change on all-rail traffic shares by year, relative to the omitted year of 1884. The dependent variable is the log difference in all-rail and steamship shares within route-years. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table 9: Change in Total Traffic/Revenue

	Ln(Freight traffic)		Ln(Revenue)	
	(1)	(2)	(3)	(4)
Post-change	0.039	0.051	-0.114	-0.091
	(0.230)	(0.222)	(0.183)	(0.186)
* distance (100 mi)	-0.000	-0.006	0.009	0.003
	(0.031)	(0.028)	(0.023)	(0.022)
N	360	360	360	360
R^2	0.01	0.96	0.01	0.97
Route FE		X		X

Notes: Table estimates the effect of the gauge change on total shipments. Observations are route-years. The dependent variable in Columns (1) to (2) is log pounds of traffic; in Columns (3) to (4), log dollars of revenue. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table 10: Supply and Demand Estimates

Demand Parameters		*Marginal Costs ($ per 100 lbs.)*	
Break in gauge	-3.42***	Break in gauge	0.171***
	(0.71)		(0.056)
* distance (100 mi)	0.43***	Distance, rail	0.052***
	(0.09)		(0.014)
Rail dummy	4.54***	Distance, steam	0.045***
	(1.11)		(0.007)
Steam dummy	6.41***	N	244
	(1.13)	Mean R^2	0.78
Price ($ per 100 lbs.)	-8.98***		
	(1.54)		
Breakeven distance	792.7		
	(95.7)		
N	488		
R^2	0.62		
1st-stage F-stat	222.5		
Instrument	Distance		

Notes: Table shows estimates from the joint estimation of demand and supply for freight traffic on the subsample of routes for which prices are available. Demand is estimated over a dataset at the route-mode-year level, with N=244 route-years and J=2 modes. Because cartel policy constrained railroads and steamships serving a given route to the same prices, there are only as many pricing FOCs as there are route-years, hence the halved sample for estimating costs. The price variable is computed as a weighted average of published class rates for the given route, weighting by the share of route traffic in each class in 1880. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. Bootstrapped SEs are provided in parentheses.

Table 11: Prices, Quantities, Profits, and Margins in Competitive Counterfactual

	Average price ($ per 100 lbs.)		**Freight Traffic (million lbs.)**			**Carrier Profits (thousand $s)**			**Gross Margins**	
	Rail	**Steam**	**Rail**	**Steam**	**Total**	**Rail**	**Steam**	**Total**	**Rail**	**Steam**
Panel A: Pre-period (1884-1886)										
Collusion (observed)	0.72	0.72	30.6	100.8	131.4	$54.0	$217.9	$271.8	25%	30%
Competition	0.64	0.67	25.8	120.8	146.6	9.4	136.8	146.1	6%	19%
Percent change	-12%	-7%	-16%	20%	12%	-83%	-37%	-46%		
Panel B: Post-period (1887-1890)										
Collusion (observed)	0.72	0.72	32.9	119.9	152.8	$112.7	$266.8	$379.5	49%	30%
Competition	0.53	0.68	79.3	105.3	184.5	88.1	148.4	236.5	24%	22%
Percent change	-27%	-6%	141%	-12%	21%	-22%	-44%	-38%		

Notes: Table provides a summary of prices, quantities, profits, and margins under collusion (i.e., as observed) and in a counterfactual in which the all-rail and steamship modes compete on prices.

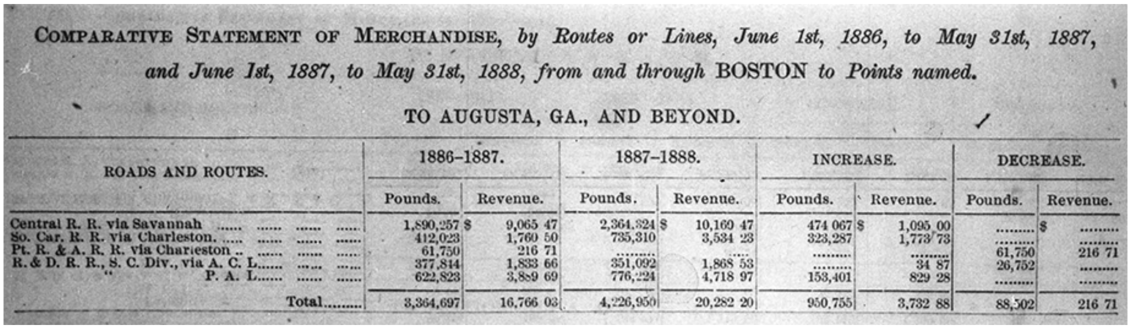
Appendix for Online Publication

A Data Appendix

This paper draws on several sources of data, most importantly the SRSA records of freight traffic on apportioned routes. As the paper describes, the SRSA collected daily data on the traffic and revenue of carriers on competed routes, compiled these data into monthly tables, and circulated these tables, as well as annual totals, to cartel members. These tables, as well as other SRSA circulars, were collected into semiannual volumes and have been preserved in original hard copy at the New York Public Library and Yale University archives.[1]

Figure A.1 provides an example table from these records. The table shows pounds and revenue of merchandise shipments from Boston to Augusta, GA for the 1886-87 and 1887-88 fiscal years. The table lists five different paths that freight traveled for this route: three by steamship plus rail, and two entirely by rail. All-rail shipments can be identified as "via A.C.L." or "via P.A.L.", while the steamship line items indicate the intermediate ports where freight was transshipped (here, Savannah and Charleston). Similar tables are available for the remaining destinations, origins, and years, though in most cases a table provides data for one period only.

Figure A.1: Example of Table from SRSA Traffic Reports



Comparative Statement of Merchandise, *by Routes or Lines, June 1st, 1886, to May 31st, 1887, and June 1st, 1887, to May 31st, 1888, from and through* BOSTON *to Points named.*

TO AUGUSTA, GA., AND BEYOND.

ROADS AND ROUTES.	1886–1887.		1887–1888.		INCREASE.		DECREASE.	
	Pounds.	Revenue.	Pounds.	Revenue.	Pounds.	Revenue.	Pounds.	Revenue.
Central R. R. via Savannah	1,890,257	$ 9,065 47	2,364,324	$ 10,169 47	474 067	$ 1,095 00	....	$ ....
So. Car. R. R. via Charleston.	412,023	1,760 50	735,310	3,534 23	323,287	1,773 73	....	....
Pt. R. & A. R. R. via Charleston	61,750	216 71	....	.....	....	....	61,750	216 71
R. & D. R. R., S. C. Div., via A. C. L......	377,814	1,833 66	351,092	1,868 53	....	34 87	26,752	....
" P. A. L......	622,823	3,889 69	776,224	4,718 97	153,401	829 28	....	....
Total.........	3,364,697	16,766 03	4,226,950	20,282 20	950,755	3,732 88	88,502	216 71

Notes: Figure shows an extracted table from the source data. The table lists total pounds of traffic and revenue from merchandise shipments from Boston to Augusta, GA by carrier, for June 1 to May 31, 1886 and for the same period in 1887. All-rail paths (termed "routes" in the table) can be identified as either A.C.L. or P.A.L.

For the second half of the sample, the cartel operated on a June to May fiscal year and reported annual data accordingly. This accounting period is ideally suited to the purposes of this paper, as the gauge change occurred over May 31 and June 1, 1886 – such that the cartel's annual data provide the cleanest possible comparison. However, until 1886, the cartel operated on a September to August fiscal year. For this earlier period, I therefore collected year-to-date (YTD) traffic in May and August, in order to back out shipments for the June to May period. Concretely: The 1884 fiscal year spanned September 1883 to August 1884, but this paper requires totals from June to May. To obtain them, I transcribed data from three YTD tables in the cartel traffic reports: September 1882 to May 1883 (1), September 1882 to August 1883 (2), and September 1883 to May 1884 (3). I then impute June 1883 to May 1884 traffic as (2)-(1)+(3).

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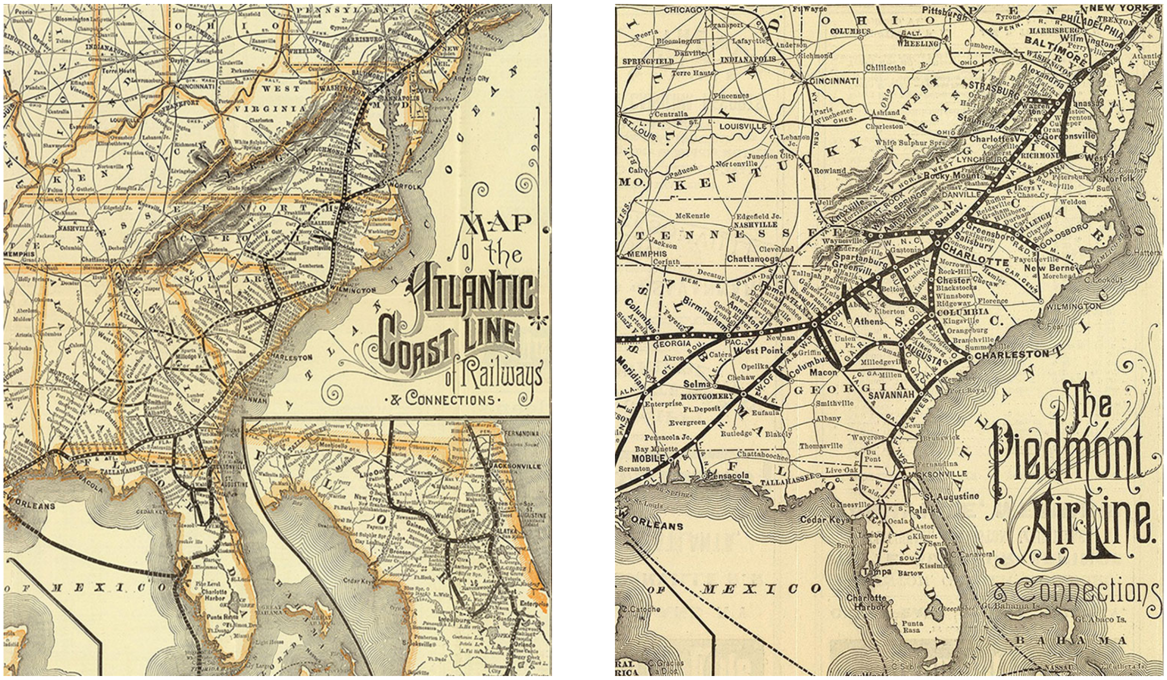
[1] A subset of the content in these circular letters are also available on microfilm from HBS Baker Library, though the microfilm omits the monthly traffic reports which yield the data in this paper.

To make clear how all-rail freight reached Southern interior cities, Figure A.2 shows maps of the A.C.L. and P.A.L. circa 1885. Both served nearly every route in nearly every year, with a few exceptions: the P.A.L. did not deliver freight to Macon in 1884-86, Athens in 1886, or Albany in any year, and the A.C.L. did not deliver to Albany in 1890 (as inferred from their absence from the respective traffic tables). Additionally, no data is available for Albany in 1887. As a result, the sample reported in tables is reduced from 1,092 ($= 52 \cdot 3 \cdot 7$) to 1,036.

Figure A.2: All-Rail Paths connecting North and South ca. 1885



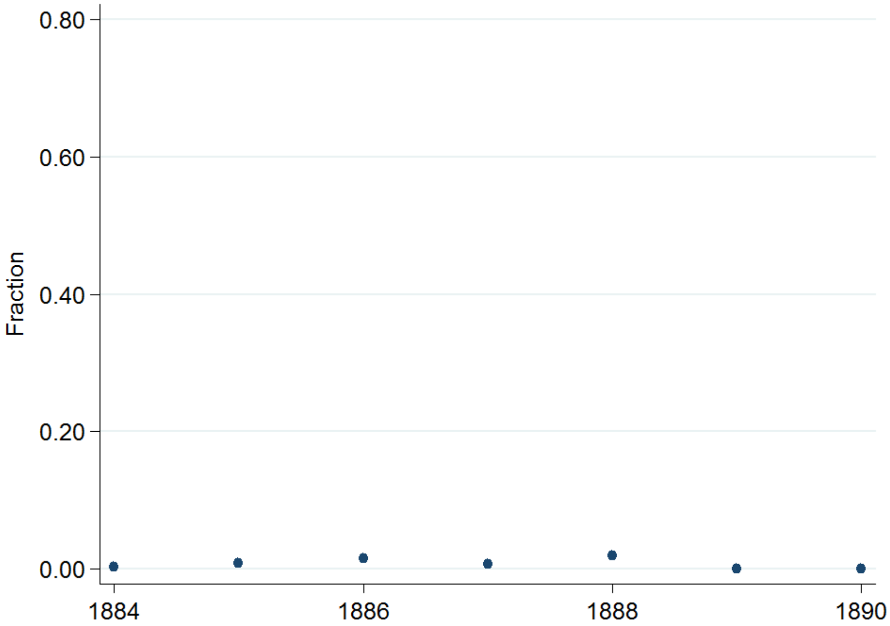
Panel A: Atlantic Coast Line (A.C.L.)

Panel B: Piedmont Air Line (P.A.L.)

Notes: Figure provides maps of the two all-rail paths between the North and South, as of 1885: the Atlantic Coast Line and Piedmont Air Line. Each was established by mutual agreement among the traversed railroads to facilitate interregional traffic. Maps acquired from the David Rumsey Historical Map Collection.

On a few routes, merchandise shipments between Northern and Southern cities are occasionally indicated to have entered the South from the West, via the Louisville and Nashville or the Cincinnati Southern – crossing the Ohio River at Louisville and Cincinnati, respectively. In these cases, it remains ambiguous whether the active mode was all-rail versus river steamer plus connecting railroad. I thus omit these shipments from the analysis. As Figure A.3 shows, little is lost: the omitted shipments on average comprise 0.8% of traffic in any given year.

Figure A.3: Western paths' share of North-South traffic



Notes: Figure shows the annual proportion of total traffic on the sampled routes reported to have been by the L. & N. and the C.S. Railroads, ostensibly after having crossed the Ohio River. Due to ambiguity over the mode of westward travel, this traffic is omitted from all analysis.

To estimate effects that vary with route length, I must measure distances between origin and destination. Throughout the paper, I measure distance as "straight-line" (geodesic) distance, rather than traveled distance, which is not observed. Though traveled distance can in concept be computed for all-rail routes using maps and mapping software, the same cannot be done for steamships, and it is unclear what additional information is generated. Indeed, one early-twentieth century source (Ripley 1913) lists all-rail shipping distances from Boston, New York, Philadelphia, and Baltimore to Atlanta, and as Table A.1 shows, straight-line distance is a roughly fixed proportion (85%) of the point-to-point track length between origin and destination.

Table A.1: Comparison of Straight-line and Track Distances

Origin	**Destination**	**Straight-line (mi.)**	**All-rail (mi.)**	**Ratio**
Boston	Atlanta	937	1089	0.86
New York	Atlanta	747	876	0.85
Philadelphia	Atlanta	666	786	0.85
Baltimore	Atlanta	577	690	0.84

Notes: Table compares straight-line (geodesic) distances and all-rail shipping distances between the points shown. Shipping distances from Ripley (1913).

With a limited sample of routes – and particularly, with origins all in the northeast and destinations in Georgia and Alabama – one might be concerned that the sample does not exhibit sufficient variation in distance to identify this source of heterogeneity. Table A.2 lays this concern to rest, showing that across the 52 routes in the sample, distance varies from 500 to 1,100 miles, with a 25th-75th percentile spread of over 300 miles.

Table A.2: Descriptive Statistics: Distribution of Route Distances

	N	**Min**	**p10**	**p25**	**p50**	**p75**	**p90**	**Max**
Route Distance (mi.)	52	501.0	585.8	661.1	749.5	889.0	971.7	1111.8

Notes: Table summarizes the distribution of routes in the sample by straight-line (geodesic) distance between northern origins and southern destinations. See Table 2 for a list of origins and destinations, and Figure 2 for a map.

Other Data

I also collect data from annual volumes of Poor's Manual of Railroads (1868) to confirm the scale of the gauge change. The Poor's Manual was an annual compendium of railroads in the U.S. and Canada that provides railroads' location, mileage, information on their financial performance (when available) – and conveniently, their gauge. These volumes allow me to calculate annual mileage by region and gauge for the universe of U.S. railroads, and thereby observe both the growth of the network and the standardization of gauge across the country.

To do so, I recorded the name, total mileage, and principal gauge of every railroad in five Poor's Manual volumes: 1882, 1883, 1886, 1888, and 1890 (which provide data from 1881, 1883, 1885, 1887, and 1889).[2] I also recorded the region in which each railroad had principal operations: New England (ME, NH, VT, MA, RI, CT); Middle Atlantic (NY, NJ, PA, DE, MD); Central Northern (OH, IN, IL, MI, WI); South Atlantic (VA, WV, NC, SC, GA, FL); Gulf and Mississippi Valley (KY, TN, AL, MS, LA); Southwestern (MO, AR, TX, KS, CO, NM); Northwestern (WY, NE, IA, MN, Dakota Territory); and Pacific (CA, OR, WA, NV, AZ, UT). In two of the sampled volumes, railroads are sorted alphabetically by these regions; in two other volumes, by state; and in one volume, at the national level. Where available, I use the Poor's Manual-designated region or state as a railroad's location. For the volume with national sorting, I infer each railroad's location from previous or later volumes, or from the address of its principal office (if not otherwise available). There was of course a great deal of new construction and consolidation over this period, but all of it is accounted for in these volumes – indeed, each volume concludes with a table listing all mergers and acquisitions since the first volume in the series was published in 1868.

The collection of the Poor's Manual data proved to be a painstaking process that required significant attention to detail, as many railroads owned subsidiary lines that were listed twice (alone and under the owner), and many railroads leased lines that were listed twice (alone and under the owner). All subsidiary and leased lines were therefore cross-checked against the entered to data to ensure they were not double-counted. The volumes also included railroads under construction, and every

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[2] Please contact the author at dgross@hbs.edu if you would like to make use of these data. I extended a hearty thanks to the Historical Collections team at HBS Baker Library for providing access to the Poor's Manual volumes, and to Mary Vasile for her help in compiling the data.

effort was made to count only completed mileage – though this count includes railroads which were complete but not yet (or no longer) in operation. In a few cases, a gauge was not provided – when this occurred, I inferred the gauge from previous or later volumes, from separately-listed parents or subsidiaries, or from information obtained through Internet searches. There were also a few railroads which listed multiple gauges, and I count these railroads as standard-gauge roads of one of the listed gauges is standard gauge. Finally, in each volume there are a handful of railroads for which the gauge could not be determined, and these railroads are omitted from all analysis, as the cumulative mileage with unknown gauge in any given year is less than 0.1% of the network. In Table 1, I sum railroad mileage by year, region, and gauge, consolidating the Poor's regions into five super-regions: New England, Mid-Atlantic, Midwest, South, and West.

I also make use of mapping data from two sources. I use the NHGIS state boundary shapefiles to sketch states east of the Mississippi River, and Atack's (2015) Historical Transportation Shapefiles to map the railroad network. The Atack (2015) railroad shapefile includes railroads constructed between 1826 and 1911; within this file, individual segments are identified by owner and gauge through the Civil War, but this identifying information is not available for later periods. Given the importance of this information to mapping the network by gauge, I restrict attention to set of railroads in operation by 1861. I use these data to illustrate the diversity of gauge in 1861 and then the standardization that took place through 1881 and 1891, leveraging the Poor's Manual data to identify later gauges of railroads in the Atack (2015) shapefile.

Appendix references not in paper:

Ripley, William Z. *Railway Problems*, Boston: Ginn and Company, 1913.

B Vertical Structure of Freight Shipping

Long-distance freight shipment in the 19th century had an inherent vertical character: to get from origin to destination, traffic had to traverse the tracks of multiple, separately-owned connecting lines. Frictions in the vertical transactions required for through shipment were the source of decades of holdup, and led to the formation of numerous innovative contractual relationships, which could be the subject of an entire separate paper – and indeed are the focus of a large contemporary and historical academic literature. For the purposes of this paper, a better understanding of vertical contracting arrangements is both useful context and important to evaluating the model used to estimate demand and supply and simulate competitive conduct.

B.1 How were long-distance shipments priced?

To fix terms, freight shipments borne by multiple, connecting carriers were known as "through" shipments, typically traveling long distances. Shipments which could be delivered by the originating carrier were "local" shipments. There were two approaches to pricing through shipments: the most primitive method was a combination of local rates, whereby a shipment from point A to point C would be charged the first carrier's local rate from A to B plus the second carrier's local rate from B to C, which were independently determined. Given the number of local rates that had to be considered on routes with many connections, and the frequency of rate changes, predicting the cost of shipping under combination rates was a formidable challenge for shippers.

To simplify pricing, railroads began to set joint rates (also/more often termed as "through rates"), which were point-to-point freight rates set jointly by carriers involved in the route, with a negotiated division of revenue. By the dawn of the regulatory era, through rates were by far the most common means of pricing through traffic. However, while there's abundant discussion of the definition and applications of through rates in historical records, there's unfortunately remarkably little coverage of how through rates were set, and how revenue was divided among carriers.

With effort, it was possible to unearth some contemporary references to the issue, which consistently point to prorating of through revenue according to the distance of each carrier's leg in the journey. Proportions were determined by the "constructive mileage" of each leg, which is derived from true distances but allows adjustments (Haney 1924). For example, in Congressional testimony in 1874, the P.A.L. general manager claimed to prorate through revenue with the water lines with which it connects (U.S. Congress 1874, p. 401), with ocean steamships prorating 3 miles for every 1 railroad mile. In the same Congressional record, a representative of the Green Line (a fast freight line, see next subsection) stated that all railroads in the organization received the same rate per mile from through revenue (p. 786). Division *pro rata* thus appears to have been the norm.

Joint pricing was not the only means of contracting around vertical transfers of shipments. Trackage rights were also common, which gave an originating carrier rights to travel freely over a connecting carrier's tracks. An alternative was vertical integration via merger or acquisition, which was also occurring at a rapid pace during and after the Reconstruction era.

B.2 Who owned/controlled the rolling stock?

Vertical transfers of rolling stock were an entirely different contracting problem that was resolved in a distinct way. While not as important to the paper as the process determining rates, it is useful to understand how rolling stock was transferred across railroads, and who maintained ownership and control, as freight traveled the tracks of multiple carriers along its route.

The root of the problem is that, to send shipments over long distances on the same car, originating railroads had to (i) send their rolling stock across connecting lines, and (ii) get it back. Conversely, intermediate railroads had to host the rolling stock of their connections. The moral hazard problems arise in several places: not only does the originating carrier have to relinquish control over its rolling stock, but it also retains liability for damage or loss of its shipments on connections. Moreover, different railroads might have different quality cars and different maintenance practices, and a low-quality or poorly-maintained car could damage the tracks it traveled. As a result, until the 1860s, freight had to be unloaded, unregistered, reregistered, and reloaded every time one line ended and another began, imposing enormous costs and delays on through traffic.

To address these issues, railroads around the country formed "fast freight lines" in the 1860s and 1870s, which were joint ventures between connecting railroads which pooled their freight cars into a shared rolling stock. The largest of these in the South was the Green Line fast-freight company, established in 1868. Under the agreement, members of the Green Line submitted rolling stock to the common pool in proportion to their total track mileage, and members were paid 1.5 cents per car-mile when other carriers used their cars. Ordinary maintenance was performed by the railroad operating the car and charged to its owner, but if a railroad damaged another carrier's car, it would be responsible for repairing or replacing it – though enforcement of this latter provision was inherently challenged by the difficulty of determining the party at fault.[3,4]

B.3 What was the vertical structure in the South?

Though these contracting innovations were being developed around the country during Reconstruction, the key question for this paper is ultimately what vertical contracting arrangements were in place in the South around the time of the gauge change, to evaluate whether the model of industry conduct is appropriate. The fundamental issues are (i) whether SRSA freight rates were for end-to-end North-South freight traffic, (ii) whether they applied to both railroads and steamships, and

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[3] When asked by Congress "How do you know whether it is the fault of the road or ... the car?" a Green Line agent responded that the issue was an ongoing source of contention (U.S. Congress 1874, p. 788).

[4] For more information on the Green Line, see the following sources: Sindall (1886, pp. 680-861), Joubert (1949, pp. 31-40), Taylor and Neu (1956, pp. 67-76), and Puffert (2009, p. 134).

(iii) whether they were determined in coordination with Northern carriers (which comprised half of each all-rail route) and how revenue from each shipment was divided. If the answer to any of these questions is in the negative, or if revenue division was endogenous, the model of the market could require nonstandard features such as bargaining or a vertical dimension.

Details of the SRSA's vertical contracting arrangements are thin at best. What is clear from SRSA records is that the cartel rates were through rates, from origin to destination, and that these rates applied to all lines in the cartel. However, the records say nothing about how through revenue was divided among carriers down the line, nor about what role Northern railroads played in price-setting, and other sources have not yielded any insight. My best understanding from cartel operations and later accounts is that the SRSA fundamentally controlled prices on shipments into and out of the South – perhaps due to its outsize influence over these routes – and it is thus appropriate to model the SRSA as a price-setter. Revenue from each shipment was most likely distributed *pro rata*, following pre-cartel precedent, such that revenue division is orthogonal to prices and would not enter or affect the cartel's profit-maximization problem.

Appendix references not in paper:

Haney, Lewis H. *The Business of Railway Transportation*, New York: Ronald Press Company, 1924.

U.S. Congress. *Reports of the Select Committee on Transportation Routes to the Seaboard*, Washington: Government Printing Office, 1874.

C Sensitivity Checks

C.1 Sensitivity Checks: Dropping Origins

The tables in this section evaluate the sensitivity of the main results in Tables 4 and 6 to dropping observations with a given origin.

Table C.1: Change in All-Rail Traffic, omitting Boston

	(1)	(2)	(3)	(4)	(5)	(6)
All-rail x post-change	3.342***	3.362***	3.363***	3.412***	3.368***	3.455***
	(0.827)	(0.780)	(0.782)	(0.801)	(0.955)	(0.983)
* distance (100 mi)	-0.460***	-0.470***	-0.470***	-0.474***	-0.469***	-0.478***
	(0.122)	(0.115)	(0.115)	(0.118)	(0.141)	(0.144)
Breakeven distance	727.1	715.7	715.8	720.3	717.7	722.9
	(31.3)	(27.3)	(27.4)	(28.9)	(33.4)	(35.5)
N	777	777	777	777	777	777
R^2	0.34	0.69	0.69	0.72	0.71	0.75
Route FE		X	X			
Mode FE			X			
Year FE			X			
Route-mode FE				X		X
Route-yr FE					X	X

Notes: This table is a robustness check on the results in Table 4, omitting observations with an origin of Boston. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.2: Share of Traffic, omitting Boston

	(1)	(2)
All-rail x post-change	3.369***	3.471***
	(0.691)	(0.734)
* distance (100 mi)	-0.481***	-0.487***
	(0.102)	(0.107)
Breakeven distance	701.0	712.1
	(23.4)	(26.0)
N	507	507
R^2	0.29	0.48
Route FE		X

Notes: This table is a robustness check on the results in Table 6, omitting observations with an origin of Boston. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.3: Change in All-Rail Traffic, omitting New York

	(1)	(2)	(3)	(4)	(5)	(6)
All-rail x post-change	2.314***	2.313***	2.310***	2.367***	2.358***	2.430***
	(0.460)	(0.449)	(0.449)	(0.469)	(0.548)	(0.590)
* distance (100 mi)	-0.301***	-0.308***	-0.307***	-0.314***	-0.313***	-0.321***
	(0.057)	(0.057)	(0.057)	(0.060)	(0.070)	(0.075)
Breakeven distance	767.7	752.0	751.5	754.5	754.0	755.8
	(41.0)	(39.1)	(39.1)	(39.5)	(46.7)	(47.9)
N	777	777	777	777	777	777
R^2	0.28	0.67	0.67	0.71	0.70	0.73
Route FE		X	X			
Mode FE			X			
Year FE			X			
Route-mode FE				X		X
Route-yr FE					X	X

Notes: This table is a robustness check on the results in Table 4, omitting observations with an origin of New York. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.4: Share of Traffic, omitting New York

	(1)	(2)
All-rail x post-change	2.155***	2.275***
	(0.424)	(0.452)
* distance (100 mi)	-0.293***	-0.305***
	(0.055)	(0.057)
Breakeven distance	735.6	746.8
	(38.7)	(39.8)
N	507	507
R^2	0.14	0.37
Route FE		X

Notes: This table is a robustness check on the results in Table 6, omitting observations with an origin of New York. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.5: Change in All-Rail Traffic, omitting Philadelphia

	(1)	(2)	(3)	(4)	(5)	(6)
All-rail x post-change	2.487***	2.466***	2.458***	2.502***	2.472***	2.519***
	(0.489)	(0.485)	(0.484)	(0.495)	(0.585)	(0.606)
* distance (100 mi)	-0.323***	-0.327***	-0.327***	-0.332***	-0.327***	-0.334***
	(0.060)	(0.061)	(0.061)	(0.062)	(0.074)	(0.076)
Breakeven distance	770.6	753.6	752.7	754.0	755.9	754.8
	(37.3)	(35.4)	(35.4)	(35.0)	(43.3)	(42.3)
N	777	777	777	777	777	777
R^2	0.34	0.68	0.68	0.74	0.70	0.77
Route FE		X	X			
Mode FE			X			
Year FE			X			
Route-mode FE				X		X
Route-yr FE					X	X

Notes: This table is a robustness check on the results in Table 4, omitting observations with an origin of Philadelphia. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.6: Share of Traffic, omitting Philadelphia

	(1)	(2)
All-rail x post-change	2.320***	2.396***
	(0.455)	(0.472)
* distance (100 mi)	-0.313***	-0.321***
	(0.057)	(0.059)
Breakeven distance	740.3	746.2
	(35.2)	(34.7)
N	507	507
R^2	0.13	0.50
Route FE		X

Notes: This table is a robustness check on the results in Table 6, omitting observations with an origin of Philadelphia. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.7: Change in All-Rail Traffic, omitting Baltimore

	(1)	(2)	(3)	(4)	(5)	(6)
All-rail x post-change	2.133***	2.108***	2.102***	2.196***	2.203***	2.325**
	(0.653)	(0.644)	(0.645)	(0.676)	(0.807)	(0.870)
* distance (100 mi)	-0.289***	-0.293***	-0.292***	-0.304***	-0.302***	-0.318***
	(0.075)	(0.076)	(0.076)	(0.079)	(0.095)	(0.101)
Breakeven distance	737.9	719.5	718.8	723.3	728.6	731.9
	(55.3)	(54.0)	(54.2)	(53.4)	(63.6)	(63.1)
N	777	777	777	777	777	777
R^2	0.34	0.68	0.68	0.73	0.71	0.76
Route FE		X	X			
Mode FE			X			
Year FE			X			
Route-mode FE				X		X
Route-yr FE					X	X

Notes: This table is a robustness check on the results in Table 4, omitting observations with an origin of Baltimore. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.8: Share of Traffic, omitting Baltimore

	(1)	(2)
All-rail x post-change	1.905***	2.088***
	(0.611)	(0.658)
* distance (100 mi)	-0.273***	-0.293***
	(0.071)	(0.076)
Breakeven distance	697.7	712.5
	(58.2)	(55.8)
N	507	507
R^2	0.03	0.36
Route FE		X

Notes: This table is a robustness check on the results in Table 6, omitting observations with an origin of Baltimore. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

C.2 Sensitivity Checks: Dropping Destinations

The tables in this section evaluate the sensitivity of the main results in Tables 4 and 6 to dropping observations with a given destination.

Table C.9: Change in All-Rail Traffic, omitting Albany

	(1)	(2)	(3)	(4)	(5)	(6)
All-rail x post-change	2.298***	2.288***	2.281***	2.328***	2.348***	2.405***
	(0.458)	(0.449)	(0.448)	(0.462)	(0.542)	(0.569)
* distance (100 mi)	-0.311***	-0.316***	-0.316***	-0.319***	-0.322***	-0.327***
	(0.058)	(0.058)	(0.058)	(0.059)	(0.070)	(0.072)
Breakeven distance	738.8	723.5	722.8	728.9	728.7	735.8
	(34.9)	(33.0)	(33.0)	(34.1)	(39.1)	(41.3)
N	992	992	992	992	992	992
R^2	0.32	0.66	0.66	0.72	0.69	0.74
Route FE		X	X			
Mode FE			X			
Year FE			X			
Route-mode FE				X		X
Route-yr FE					X	X

Notes: This table is a robustness check on the results in Table 4, omitting observations with a destination of Albany. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.10: Share of Traffic, omitting Albany

	(1)	(2)
All-rail x post-change	2.200***	2.306***
	(0.427)	(0.449)
* distance (100 mi)	-0.309***	-0.317***
	(0.055)	(0.057)
Breakeven distance	712.5	726.8
	(32.7)	(34.0)
N	656	656
R^2	0.11	0.44
Route FE		X

Notes: This table is a robustness check on the results in Table 6, omitting observations with a destination of Albany. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.11: Change in All-Rail Traffic, omitting Athens

	(1)	(2)	(3)	(4)	(5)	(6)
All-rail x post-change	2.199***	2.178***	2.179***	2.247***	2.210***	2.304***
	(0.461)	(0.450)	(0.452)	(0.468)	(0.555)	(0.589)
* distance (100 mi)	-0.301***	-0.305***	-0.306***	-0.313***	-0.308***	-0.319***
	(0.058)	(0.058)	(0.058)	(0.060)	(0.072)	(0.075)
Breakeven distance	731.0	713.2	713.1	717.9	716.6	721.4
	(38.3)	(36.1)	(36.1)	(36.4)	(43.6)	(44.3)
N	956	956	956	956	956	956
R^2	0.33	0.69	0.69	0.74	0.71	0.77
Route FE		X	X			
Mode FE			X			
Year FE			X			
Route-mode FE				X		X
Route-yr FE					X	X

Notes: This table is a robustness check on the results in Table 4, omitting observations with a destination of Athens. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.12: Share of Traffic, omitting Athens

	(1)	(2)
All-rail x post-change	2.034***	2.193***
	(0.426)	(0.464)
* distance (100 mi)	-0.293***	-0.308***
	(0.055)	(0.059)
Breakeven distance	695.3	711.9
	(36.4)	(36.9)
N	624	624
R^2	0.11	0.46
Route FE		X

Notes: This table is a robustness check on the results in Table 6, omitting observations with a destination of Athens. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.13: Change in All-Rail Traffic, omitting Atlanta

	(1)	(2)	(3)	(4)	(5)	(6)
All-rail x post-change	2.637***	2.587***	2.583***	2.646***	2.632***	2.712***
	(0.475)	(0.467)	(0.468)	(0.478)	(0.574)	(0.597)
* distance (100 mi)	-0.339***	-0.342***	-0.342***	-0.349***	-0.346***	-0.356***
	(0.061)	(0.061)	(0.061)	(0.062)	(0.076)	(0.077)
Breakeven distance	776.8	756.2	755.8	758.3	760.2	761.6
	(35.3)	(33.1)	(33.1)	(33.0)	(40.3)	(40.0)
N	952	952	952	952	952	952
R^2	0.35	0.65	0.65	0.72	0.68	0.75
Route FE		X	X			
Mode FE			X			
Year FE			X			
Route-mode FE				X		X
Route-yr FE					X	X

Notes: This table is a robustness check on the results in Table 4, omitting observations with a destination of Atlanta. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.14: Share of Traffic, omitting Atlanta

	(1)	(2)
All-rail x post-change	2.429***	2.562***
	(0.438)	(0.462)
* distance (100 mi)	-0.328***	-0.341***
	(0.057)	(0.059)
Breakeven distance	741.2	751.0
	(32.4)	(32.8)
N	620	620
R^2	0.12	0.47
Route FE		X

Notes: This table is a robustness check on the results in Table 6, omitting observations with a destination of Atlanta. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.15: Change in All-Rail Traffic, omitting Augusta

	(1)	(2)	(3)	(4)	(5)	(6)
All-rail x post-change	2.634***	2.532***	2.527***	2.594***	2.576***	2.658***
	(0.529)	(0.513)	(0.514)	(0.528)	(0.631)	(0.659)
* distance (100 mi)	-0.341***	-0.337***	-0.337***	-0.344***	-0.341***	-0.352***
	(0.066)	(0.065)	(0.065)	(0.066)	(0.080)	(0.082)
Breakeven distance	772.1	750.8	750.3	753.0	754.6	756.1
	(35.8)	(34.6)	(34.6)	(34.6)	(41.9)	(41.8)
N	952	952	952	952	952	952
R^2	0.33	0.64	0.64	0.70	0.66	0.72
Route FE		X	X			
Mode FE			X			
Year FE			X			
Route-mode FE				X		X
Route-yr FE					X	X

Notes: This table is a robustness check on the results in Table 4, omitting observations with a destination of Augusta. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.16: Share of Traffic, omitting Augusta

	(1)	(2)
All-rail x post-change	2.358***	2.490***
	(0.485)	(0.514)
* distance (100 mi)	-0.321***	-0.334***
	(0.061)	(0.064)
Breakeven distance	734.5	744.3
	(34.7)	(35.0)
N	620	620
R^2	0.10	0.42
Route FE		X

Notes: This table is a robustness check on the results in Table 6, omitting observations with a destination of Augusta. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.17: Change in All-Rail Traffic, omitting Macon

	(1)	(2)	(3)	(4)	(5)	(6)
All-rail x post-change	2.353***	2.354***	2.351***	2.362***	2.340***	2.348***
	(0.471)	(0.481)	(0.482)	(0.487)	(0.588)	(0.598)
* distance (100 mi)	-0.318***	-0.319***	-0.319***	-0.322***	-0.317***	-0.321***
	(0.060)	(0.062)	(0.062)	(0.063)	(0.077)	(0.077)
Breakeven distance	740.2	738.5	737.9	734.0	739.1	731.5
	(36.3)	(36.3)	(36.3)	(35.8)	(44.8)	(43.6)
N	964	964	964	964	964	964
R^2	0.30	0.66	0.66	0.71	0.68	0.74
Route FE		X	X			
Mode FE			X			
Year FE			X			
Route-mode FE				X		X
Route-yr FE					X	X

Notes: This table is a robustness check on the results in Table 4, omitting observations with a destination of Macon. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.18: Share of Traffic, omitting Macon

	(1)	(2)
All-rail x post-change	2.253***	2.244***
	(0.454)	(0.462)
* distance (100 mi)	-0.309***	-0.311***
	(0.059)	(0.059)
Breakeven distance	729.8	721.8
	(35.5)	(35.6)
N	632	632
R^2	0.12	0.43
Route FE		X

Notes: This table is a robustness check on the results in Table 6, omitting observations with a destination of Macon. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.19: Change in All-Rail Traffic, omitting Milledgeville

	(1)	(2)	(3)	(4)	(5)	(6)
All-rail x post-change	2.218***	2.231***	2.228***	2.296***	2.271***	2.358***
	(0.478)	(0.479)	(0.480)	(0.493)	(0.590)	(0.617)
* distance (100 mi)	-0.297***	-0.305***	-0.305***	-0.313***	-0.309***	-0.320***
	(0.061)	(0.062)	(0.062)	(0.063)	(0.076)	(0.078)
Breakeven distance	745.9	730.4	730.1	733.6	734.6	736.9
	(39.9)	(37.7)	(37.7)	(37.6)	(45.6)	(45.6)
N	952	952	952	952	952	952
R^2	0.32	0.66	0.66	0.72	0.69	0.74
Route FE		X	X			
Mode FE			X			
Year FE			X			
Route-mode FE				X		X
Route-yr FE					X	X

Notes: This table is a robustness check on the results in Table 4, omitting observations with a destination of Milledgeville. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.20: Share of Traffic, omitting Milledgeville

	(1)	(2)
All-rail x post-change	2.047***	2.193***
	(0.444)	(0.473)
* distance (100 mi)	-0.289***	-0.303***
	(0.057)	(0.060)
Breakeven distance	709.2	722.6
	(37.5)	(37.9)
N	620	620
R^2	0.12	0.45
Route FE		X

Notes: This table is a robustness check on the results in Table 6, omitting observations with a destination of Milledgeville. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.21: Change in All-Rail Traffic, omitting Montgomery

	(1)	(2)	(3)	(4)	(5)	(6)
All-rail x post-change	2.343***	2.366***	2.362***	2.428***	2.407***	2.496***
	(0.489)	(0.481)	(0.482)	(0.493)	(0.596)	(0.619)
* distance (100 mi)	-0.303***	-0.314***	-0.314***	-0.321***	-0.318***	-0.329***
	(0.064)	(0.064)	(0.064)	(0.064)	(0.079)	(0.081)
Breakeven distance	774.1	753.8	753.4	755.8	757.2	757.8
	(39.2)	(35.7)	(35.7)	(35.4)	(43.6)	(42.7)
N	952	952	952	952	952	952
R^2	0.30	0.68	0.68	0.73	0.70	0.76
Route FE		X	X			
Mode FE			X			
Year FE			X			
Route-mode FE				X		X
Route-yr FE					X	X

Notes: This table is a robustness check on the results in Table 4, omitting observations with a destination of Montgomery. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.22: Share of Traffic, omitting Montgomery

	(1)	(2)
All-rail x post-change	2.230***	2.350***
	(0.455)	(0.475)
* distance (100 mi)	-0.303***	-0.315***
	(0.060)	(0.062)
Breakeven distance	736.2	746.7
	(34.6)	(34.9)
N	620	620
R^2	0.10	0.45
Route FE		X

Notes: This table is a robustness check on the results in Table 6, omitting observations with a destination of Montgomery. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.23: Change in All-Rail Traffic, omitting Newnan

	(1)	(2)	(3)	(4)	(5)	(6)
All-rail x post-change	2.590***	2.598***	2.595***	2.655***	2.640***	2.718***
	(0.469)	(0.467)	(0.468)	(0.479)	(0.576)	(0.600)
* distance (100 mi)	-0.346***	-0.353***	-0.353***	-0.360***	-0.357***	-0.367***
	(0.059)	(0.060)	(0.060)	(0.060)	(0.074)	(0.076)
Breakeven distance	748.9	735.3	735.0	737.6	739.0	740.6
	(34.4)	(32.5)	(32.5)	(32.5)	(39.4)	(39.4)
N	952	952	952	952	952	952
R^2	0.33	0.67	0.67	0.73	0.69	0.76
Route FE		X	X			
Mode FE			X			
Year FE			X			
Route-mode FE				X		X
Route-yr FE					X	X

Notes: This table is a robustness check on the results in Table 4, omitting observations with a destination of Newnan. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.24: Share of Traffic, omitting Newnan

	(1)	(2)
All-rail x post-change	2.448***	2.572***
	(0.440)	(0.464)
* distance (100 mi)	-0.340***	-0.353***
	(0.056)	(0.058)
Breakeven distance	719.2	728.8
	(32.0)	(32.5)
N	620	620
R^2	0.12	0.47
Route FE		X

Notes: This table is a robustness check on the results in Table 6, omitting observations with a destination of Newnan. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.25: Change in All-Rail Traffic, omitting Opelika

	(1)	(2)	(3)	(4)	(5)	(6)
All-rail x post-change	2.440***	2.443***	2.438***	2.498***	2.485***	2.559***
	(0.481)	(0.477)	(0.477)	(0.486)	(0.589)	(0.608)
* distance (100 mi)	-0.328***	-0.336***	-0.335***	-0.342***	-0.340***	-0.349***
	(0.063)	(0.063)	(0.063)	(0.064)	(0.078)	(0.079)
Breakeven distance	743.1	727.1	726.7	729.7	730.8	732.8
	(35.3)	(32.7)	(32.7)	(32.9)	(39.7)	(39.9)
N	952	952	952	952	952	952
R^2	0.32	0.68	0.68	0.74	0.71	0.76
Route FE		X	X			
Mode FE			X			
Year FE			X			
Route-mode FE				X		X
Route-yr FE					X	X

Notes: This table is a robustness check on the results in Table 4, omitting observations with a destination of Opelika. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.26: Share of Traffic, omitting Opelika

	(1)	(2)
All-rail x post-change	2.291***	2.414***
	(0.451)	(0.470)
* distance (100 mi)	-0.323***	-0.335***
	(0.060)	(0.061)
Breakeven distance	709.9	720.1
	(32.0)	(32.5)
N	620	620
R^2	0.13	0.46
Route FE		X

Notes: This table is a robustness check on the results in Table 6, omitting observations with a destination of Opelika. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.27: Change in All-Rail Traffic, omitting Rome

	(1)	(2)	(3)	(4)	(5)	(6)
All-rail x post-change	2.835***	2.828***	2.823***	2.898***	2.863***	2.958***
	(0.438)	(0.426)	(0.427)	(0.436)	(0.524)	(0.548)
* distance (100 mi)	-0.364***	-0.370***	-0.370***	-0.378***	-0.373***	-0.385***
	(0.058)	(0.058)	(0.058)	(0.059)	(0.072)	(0.074)
Breakeven distance	779.2	763.9	763.4	765.9	767.4	768.4
	(30.6)	(27.9)	(27.8)	(27.4)	(34.4)	(33.5)
N	952	952	952	952	952	952
R^2	0.30	0.68	0.68	0.73	0.70	0.75
Route FE		X	X			
Mode FE			X			
Year FE			X			
Route-mode FE				X		X
Route-yr FE					X	X

Notes: This table is a robustness check on the results in Table 4, omitting observations with a destination of Rome. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.28: Share of Traffic, omitting Rome

	(1)	(2)
All-rail x post-change	2.658***	2.817***
	(0.402)	(0.419)
* distance (100 mi)	-0.355***	-0.371***
	(0.055)	(0.056)
Breakeven distance	748.7	759.2
	(27.0)	(26.7)
N	620	620
R^2	0.13	0.43
Route FE		X

Notes: This table is a robustness check on the results in Table 6, omitting observations with a destination of Rome. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.29: Change in All-Rail Traffic, omitting Selma

	(1)	(2)	(3)	(4)	(5)	(6)
All-rail x post-change	2.378***	2.405***	2.403***	2.469***	2.438***	2.529***
	(0.504)	(0.497)	(0.498)	(0.508)	(0.613)	(0.635)
* distance (100 mi)	-0.310***	-0.321***	-0.321***	-0.329***	-0.324***	-0.336***
	(0.067)	(0.067)	(0.067)	(0.067)	(0.082)	(0.084)
Breakeven distance	766.9	748.3	747.8	750.2	752.2	752.9
	(38.7)	(35.2)	(35.2)	(34.9)	(43.1)	(42.3)
N	952	952	952	952	952	952
R^2	0.29	0.67	0.67	0.72	0.69	0.75
Route FE		X	X			
Mode FE			X			
Year FE			X			
Route-mode FE				X		X
Route-yr FE					X	X

Notes: This table is a robustness check on the results in Table 4, omitting observations with a destination of Selma. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.30: Share of Traffic, omitting Selma

	(1)	(2)
All-rail x post-change	2.264***	2.385***
	(0.469)	(0.489)
* distance (100 mi)	-0.310***	-0.322***
	(0.063)	(0.064)
Breakeven distance	731.4	741.7
	(34.1)	(34.4)
N	620	620
R^2	0.09	0.43
Route FE		X

Notes: This table is a robustness check on the results in Table 6, omitting observations with a destination of Selma. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.31: Change in All-Rail Traffic, omitting A. & W. Pt.

	(1)	(2)	(3)	(4)	(5)	(6)
All-rail x post-change	2.442***	2.447***	2.441***	2.500***	2.489***	2.560***
	(0.488)	(0.482)	(0.482)	(0.492)	(0.597)	(0.616)
* distance (100 mi)	-0.319***	-0.326***	-0.326***	-0.332***	-0.331***	-0.340***
	(0.063)	(0.063)	(0.063)	(0.063)	(0.078)	(0.079)
Breakeven distance	766.1	749.4	748.9	751.9	752.3	754.1
	(37.8)	(35.2)	(35.2)	(35.2)	(42.7)	(42.6)
N	952	952	952	952	952	952
R^2	0.33	0.69	0.69	0.74	0.71	0.76
Route FE		X	X			
Mode FE			X			
Year FE			X			
Route-mode FE				X		X
Route-yr FE					X	X

Notes: This table is a robustness check on the results in Table 4, omitting observations with a destination of A. & W. Pt.. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.32: Share of Traffic, omitting A. & W. Pt.

	(1)	(2)
All-rail x post-change	2.287***	2.410***
	(0.453)	(0.476)
* distance (100 mi)	-0.312***	-0.325***
	(0.059)	(0.061)
Breakeven distance	732.7	742.5
	(34.6)	(35.1)
N	620	620
R^2	0.13	0.45
Route FE		X

Notes: This table is a robustness check on the results in Table 6, omitting observations with a destination of A. & W. Pt.. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.33: Change in All-Rail Traffic, omitting W. & A.

	(1)	(2)	(3)	(4)	(5)	(6)
All-rail x post-change	2.298***	2.300***	2.294***	2.354***	2.342***	2.416***
	(0.485)	(0.480)	(0.480)	(0.491)	(0.593)	(0.616)
* distance (100 mi)	-0.307***	-0.314***	-0.314***	-0.321***	-0.318***	-0.328***
	(0.062)	(0.062)	(0.062)	(0.063)	(0.077)	(0.078)
Breakeven distance	748.1	731.8	731.1	734.2	735.8	737.5
	(39.4)	(37.0)	(37.0)	(37.0)	(44.7)	(44.9)
N	952	952	952	952	952	952
R^2	0.33	0.68	0.68	0.74	0.71	0.76
Route FE		X	X			
Mode FE			X			
Year FE			X			
Route-mode FE				X		X
Route-yr FE					X	X

Notes: This table is a robustness check on the results in Table 4, omitting observations with a destination of W. & A.. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.34: Share of Traffic, omitting W. & A.

	(1)	(2)
All-rail x post-change	2.143***	2.253***
	(0.453)	(0.471)
* distance (100 mi)	-0.300***	-0.311***
	(0.059)	(0.060)
Breakeven distance	713.6	723.6
	(36.8)	(37.2)
N	620	620
R^2	0.10	0.44
Route FE		X

Notes: This table is a robustness check on the results in Table 6, omitting observations with a destination of W. & A.. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

C.3 Sensitivity Checks: Dropping Years

The tables in this section evaluate the sensitivity of the main results in Tables 4 and 6 to dropping observations in a given year.

Table C.35: Change in All-Rail Traffic, omitting 1884

	(1)	(2)	(3)	(4)	(5)	(6)
All-rail x post-change	2.730***	2.712***	2.704***	2.777***	2.746***	2.837***
	(0.567)	(0.560)	(0.558)	(0.573)	(0.683)	(0.707)
* distance (100 mi)	-0.350***	-0.355***	-0.354***	-0.363***	-0.357***	-0.368***
	(0.072)	(0.072)	(0.072)	(0.073)	(0.088)	(0.090)
Breakeven distance	780.5	764.2	763.5	765.5	769.7	770.1
	(37.8)	(36.0)	(35.9)	(35.8)	(44.4)	(43.7)
N	888	888	888	888	888	888
R^2	0.32	0.67	0.67	0.73	0.69	0.75
Route FE		X	X			
Mode FE			X			
Year FE			X			
Route-mode FE				X		X
Route-yr FE					X	X

Notes: This table is a robustness check on the results in Table 4, omitting observations in 1884. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.36: Share of Traffic, omitting 1884

	(1)	(2)
All-rail x post-change	2.563***	2.685***
	(0.532)	(0.545)
* distance (100 mi)	-0.341***	-0.354***
	(0.069)	(0.069)
Breakeven distance	751.8	758.9
	(35.9)	(35.6)
N	580	580
R^2	0.12	0.45
Route FE		X

Notes: This table is a robustness check on the results in Table 6, omitting observations in 1884. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.37: Change in All-Rail Traffic, omitting 1885

	(1)	(2)	(3)	(4)	(5)	(6)
All-rail x post-change	2.291***	2.274***	2.272***	2.330***	2.277***	2.354***
	(0.455)	(0.447)	(0.448)	(0.465)	(0.537)	(0.572)
* distance (100 mi)	-0.318***	-0.323***	-0.323***	-0.330***	-0.321***	-0.331***
	(0.056)	(0.056)	(0.057)	(0.058)	(0.068)	(0.071)
Breakeven distance	721.3	704.3	704.0	706.3	710.3	711.8
	(35.6)	(34.0)	(34.0)	(34.2)	(41.6)	(42.1)
N	888	888	888	888	888	888
R^2	0.32	0.67	0.67	0.73	0.70	0.75
Route FE		X	X			
Mode FE			X			
Year FE			X			
Route-mode FE				X		X
Route-yr FE					X	X

Notes: This table is a robustness check on the results in Table 4, omitting observations in 1885. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.38: Share of Traffic, omitting 1885

	(1)	(2)
All-rail x post-change	2.084***	2.182***
	(0.411)	(0.445)
* distance (100 mi)	-0.303***	-0.314***
	(0.052)	(0.055)
Breakeven distance	687.1	694.8
	(35.3)	(36.1)
N	580	580
R^2	0.13	0.47
Route FE		X

Notes: This table is a robustness check on the results in Table 6, omitting observations in 1885. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.39: Change in All-Rail Traffic, omitting 1886

	(1)	(2)	(3)	(4)	(5)	(6)
All-rail x post-change	2.297***	2.286***	2.287***	2.338***	2.375***	2.450***
	(0.484)	(0.494)	(0.495)	(0.508)	(0.621)	(0.651)
* distance (100 mi)	-0.300***	-0.305***	-0.305***	-0.310***	-0.317***	-0.325***
	(0.065)	(0.067)	(0.067)	(0.068)	(0.084)	(0.087)
Breakeven distance	765.9	749.4	749.3	753.5	749.4	753.3
	(39.4)	(37.2)	(37.2)	(37.9)	(43.0)	(44.3)
N	892	892	892	892	892	892
R^2	0.32	0.67	0.67	0.73	0.69	0.75
Route FE		X	X			
Mode FE			X			
Year FE			X			
Route-mode FE				X		X
Route-yr FE					X	X

Notes: This table is a robustness check on the results in Table 4, omitting observations in 1886. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.40: Share of Traffic, omitting 1886

	(1)	(2)
All-rail x post-change	2.197***	2.329***
	(0.480)	(0.512)
* distance (100 mi)	-0.300***	-0.312***
	(0.065)	(0.068)
Breakeven distance	731.4	745.5
	(34.3)	(36.3)
N	584	584
R^2	0.13	0.46
Route FE		X

Notes: This table is a robustness check on the results in Table 6, omitting observations in 1886. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.41: Change in All-Rail Traffic, omitting 1887

	(1)	(2)	(3)	(4)	(5)	(6)
All-rail x post-change	2.561***	2.571***	2.566***	2.623***	2.595***	2.669***
	(0.512)	(0.515)	(0.516)	(0.534)	(0.631)	(0.664)
* distance (100 mi)	-0.346***	-0.356***	-0.356***	-0.361***	-0.358***	-0.366***
	(0.065)	(0.066)	(0.066)	(0.068)	(0.081)	(0.085)
Breakeven distance	740.7	721.9	721.7	726.1	724.8	728.6
	(35.9)	(33.7)	(33.7)	(34.5)	(40.6)	(41.8)
N	892	892	892	892	892	892
R^2	0.32	0.68	0.68	0.73	0.70	0.76
Route FE		X	X			
Mode FE			X			
Year FE			X			
Route-mode FE				X		X
Route-yr FE					X	X

Notes: This table is a robustness check on the results in Table 4, omitting observations in 1887. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.42: Share of Traffic, omitting 1887

	(1)	(2)
All-rail x post-change	2.406***	2.533***
	(0.489)	(0.522)
* distance (100 mi)	-0.341***	-0.353***
	(0.063)	(0.066)
Breakeven distance	705.5	717.0
	(33.9)	(34.7)
N	580	580
R^2	0.12	0.45
Route FE		X

Notes: This table is a robustness check on the results in Table 6, omitting observations in 1887. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.43: Change in All-Rail Traffic, omitting 1888

	(1)	(2)	(3)	(4)	(5)	(6)
All-rail x post-change	2.483***	2.477***	2.473***	2.532***	2.496***	2.567***
	(0.471)	(0.461)	(0.462)	(0.473)	(0.563)	(0.588)
* distance (100 mi)	-0.321***	-0.327***	-0.327***	-0.334***	-0.328***	-0.338***
	(0.062)	(0.062)	(0.063)	(0.063)	(0.076)	(0.078)
Breakeven distance	774.2	757.6	757.1	758.4	761.3	759.8
	(36.8)	(33.7)	(33.7)	(33.6)	(41.7)	(41.2)
N	884	884	884	884	884	884
R^2	0.31	0.67	0.67	0.73	0.70	0.75
Route FE		X	X			
Mode FE			X			
Year FE			X			
Route-mode FE				X		X
Route-yr FE					X	X

Notes: This table is a robustness check on the results in Table 4, omitting observations in 1888. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.44: Share of Traffic, omitting 1888

	(1)	(2)
All-rail x post-change	2.318***	2.440***
	(0.433)	(0.457)
* distance (100 mi)	-0.312***	-0.325***
	(0.059)	(0.061)
Breakeven distance	742.2	749.9
	(32.4)	(33.2)
N	576	576
R^2	0.11	0.43
Route FE		X

Notes: This table is a robustness check on the results in Table 6, omitting observations in 1888. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.45: Change in All-Rail Traffic, omitting 1889

	(1)	(2)	(3)	(4)	(5)	(6)
All-rail x post-change	2.353***	2.352***	2.348***	2.405***	2.389***	2.454***
	(0.423)	(0.423)	(0.422)	(0.434)	(0.520)	(0.541)
* distance (100 mi)	-0.310***	-0.317***	-0.317***	-0.324***	-0.322***	-0.331***
	(0.054)	(0.055)	(0.055)	(0.055)	(0.068)	(0.068)
Breakeven distance	757.7	741.1	740.6	741.7	742.5	740.8
	(34.5)	(32.3)	(32.3)	(32.1)	(38.7)	(38.5)
N	884	884	884	884	884	884
R^2	0.31	0.67	0.67	0.73	0.70	0.76
Route FE		X	X			
Mode FE			X			
Year FE			X			
Route-mode FE				X		X
Route-yr FE					X	X

Notes: This table is a robustness check on the results in Table 4, omitting observations in 1889. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.46: Share of Traffic, omitting 1889

	(1)	(2)
All-rail x post-change	2.214***	2.327***
	(0.397)	(0.417)
* distance (100 mi)	-0.306***	-0.319***
	(0.052)	(0.053)
Breakeven distance	722.5	730.3
	(31.0)	(31.4)
N	576	576
R^2	0.11	0.44
Route FE		X

Notes: This table is a robustness check on the results in Table 6, omitting observations in 1889. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.47: Change in All-Rail Traffic, omitting 1890

	(1)	(2)	(3)	(4)	(5)	(6)
All-rail x post-change	2.351***	2.329***	2.326***	2.387***	2.380***	2.455***
	(0.497)	(0.488)	(0.489)	(0.502)	(0.593)	(0.622)
* distance (100 mi)	-0.311***	-0.312***	-0.312***	-0.319***	-0.317***	-0.326***
	(0.064)	(0.063)	(0.063)	(0.064)	(0.077)	(0.080)
Breakeven distance	755.0	745.7	744.9	748.1	750.2	753.9
	(37.0)	(36.5)	(36.6)	(36.5)	(43.7)	(44.2)
N	888	888	888	888	888	888
R^2	0.32	0.67	0.67	0.73	0.69	0.75
Route FE		X	X			
Mode FE			X			
Year FE			X			
Route-mode FE				X		X
Route-yr FE					X	X

Notes: This table is a robustness check on the results in Table 4, omitting observations in 1890. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table C.48: Share of Traffic, omitting 1890

	(1)	(2)
All-rail x post-change	2.185***	2.310***
	(0.454)	(0.480)
* distance (100 mi)	-0.299***	-0.311***
	(0.059)	(0.061)
Breakeven distance	730.2	743.2
	(36.3)	(36.6)
N	580	580
R^2	0.10	0.45
Route FE		X

Notes: This table is a robustness check on the results in Table 6, omitting observations in 1890. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

D Sensitivity Checks for Supply/Demand Estimation

This appendix provides estimates and simulation results from a model in which consumer utility is linear in log (rather than level) prices, such that the parameter α in Equation (4) measures the elasticity of the ratio of inside to outside good market shares with respect to prices. The adjustment changes the computation of shares as well as the own-price elasticities that determine markups in the counterfactual simulation: while under the linear specification,

$$\frac{\partial s_{mrt}}{\partial P_{mrt}} = -\alpha s_{mrt}(1 - s_{mrt}) \ ,$$

under the log specification, elasticities will vary directly with prices:

$$\frac{\partial s_{mrt}}{\partial P_{mrt}} = -\alpha p_{mrt} s_{mrt}(1 - s_{mrt})$$

Table D.1 shows the demand and supply parameter estimates under this specification, providing the counterpart to Table 10 in the body of the paper, and Table D.2 presents the counterfactual, providing the counterpart to Table 11.

The parameter estimates are qualitatively similar across specifications. For the demand estimates: the price coefficient remains negative, the steamship mode still has an intrinsic advantage over the all-rail mode, though the fixed effects decrease, such that they carry less weight in determining market shares. The effects of incompatibility are quantitatively identical. The supply estimates are also quite similar across the two specifications, with a slight increase in the estimated cost of breaks in gauge (from \$0.17 to \$0.25 per 100 pounds of freight), a slight increase in the marginal costs of moving 100 pounds of freight per 100 miles of straight-line distance via rail (from \$0.03 to \$0.06), and a slight decrease in the marginal cost via steamship (from \$0.04 to \$0.03), though the differences are not statistically significant at usual levels.

The counterfactual is in general consistent with that in the body, excepting that the pre-period simulation suggests all-rail prices would have increased, rather than decreased, had the cartel's policy of equalizing prices across modes been relaxed. In essence, this result suggests that on the routes sampled for this exercise, the cartel primarily benefited the steamships – indeed, given the higher point estimates on railroad operating costs, the simulation suggests that railroads struggled to break even on these routes prior to the gauge change, even with cartel pricing.[5] Otherwise, the counterfactual reflects the same patterns as in the body of the paper: (i) competition reduces steamship prices, increases total traffic, and reduces industry profits in the pre-period; (ii) competition would have induced railroads to pass through 95% of their cost-savings post-conversion, generating a significant price reduction, doubling all-rail traffic, increasing aggregate trade by roughly 20%, and driving down profits of both modes and of the industry by 38%.

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[5] Given that railroads took the lead in organizing the cartel, this might be an artifact of the model, and would certainly not be uniformly true across all routes over which cartel members colluded.

Table D.1: Supply and Demand Estimates (alt. utility specification)

Demand Parameters		*Marginal Costs ($ per 100 lbs.)*	
Break in gauge	-3.43***	Break in gauge	0.247***
	(0.73)		(0.050)
* distance (100 mi)	0.43***	Distance, rail	0.064***
	(0.09)		(0.010)
Rail dummy	-4.12***	Distance, steam	0.032***
	(0.44)		(0.008)
Steam dummy	-2.25***	N	244
	(0.44)	Mean R^2	0.84
Log Price	-6.50***		
	(1.18)		
Breakeven distance	794.1		
	(98.8)		
N	488		
R^2	0.62		
1st-stage F-stat	203.5		
Instrument	Distance		

Notes: Table provides a specification check on Table 10 from the body of the paper. This table shows estimates from the joint estimation of demand and supply for freight traffic, when utility is specified as linear in log prices instead of level prices. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. Bootstrapped SEs in parentheses.

Table D.2: Competitive Counterfactual (alt. utility specification)

	Average price ($ per 100 lbs.)		**Freight Traffic (million lbs.)**			**Carrier Profits (thousand $s)**			**Gross Margins**	
	Rail	**Steam**	**Rail**	**Steam**	**Total**	**Rail**	**Steam**	**Total**	**Rail**	**Steam**
Panel A: Pre-period (1884-1886)										
Collusion (observed)	0.72	0.72	30.6	100.8	131.4	-$0.8	$237.8	$237.0	0%	33%
Competition	0.83	0.66	4.7	143.4	148.1	4.0	183.0	186.9	11%	21%
Percent change	15%	-8%	-85%	42%	13%	-618%	-23%	-21%		
Panel B: Post-period (1887-1890)										
Collusion (observed)	0.72	0.72	32.9	119.9	152.8	$81.6	$291.2	$372.8	36%	33%
Competition	0.60	0.67	65.8	115.4	181.3	33.5	198.9	232.4	11%	26%
Percent change	-17%	-7%	100%	-4%	19%	-59%	-32%	-38%		

Notes: Table provides a summary of prices, quantities, profits, and margins under collusion (i.e., as observed) and in a counterfactual in which the all-rail and steamship modes compete on prices, calculated using the parameters in Table D.1.

E Additional Counterfactual Tables

As the paper notes, the post-period comparison of collusion and competition in Table 11 does not fully separate the effects of the gauge change in a competitive market structure from the effects of competition alone, independent of compatibility. Specifically, part of the price reduction found in the table is attributable to the effects of competition even in the absence of compatibility, and part is attributable to the interaction of compatibility with competition.

There are two ways to distinguish these two forces. One is to compare the post-period results in the table against the pre-period results – but this risks contemporaneous changes in the market that may distort the comparison. The alternative is to simulate a competitive post-period with and without compatibility. Table E.1 below makes this comparison.

Table E.1: Post-Period Competitive Outcomes: With vs. Without Gauge Change

	Average price ($ per 100 lbs.)		**Freight Traffic (million lbs.)**			**Carrier Profits (thousand $s)**			**Gross Margins**	
	Rail	**Steam**	**Rail**	**Steam**	**Total**	**Rail**	**Steam**	**Total**	**Rail**	**Steam**
No gauge change	0.66	0.69	34.0	122.5	156.5	$19.8	$171.7	$191.5	10%	22%
Gauge change	0.53	0.68	79.3	105.3	184.5	88.1	148.4	236.5	24%	22%
Percent difference	-20%	-2%	133%	-14%	18%	345%	-14%	23%		

Notes: Table provides a summary of counterfactual competitive prices, quantities, profits, and margins in the post-period (1887-1890) without versus with a uniform gauge. The table shows that nearly all of the difference between collusive and competitive post-period traffic in Table 11 is attributable to the pass-through of railroads' cost-savings from standardization to all-rail prices, rather than competitive pricing independent of the gauge change.

Relative to a competitive post-period with no gauge change, the gauge change reduces rail prices by 20% and increases total shipments by 18%. The increase in traffic is again driven entirely by growth in all-rail shipments, which are more than double (albeit off a relatively small base). All-rail profits in turn are more than quadruple, while steamship traffic and profits decline roughly 15%. These results thus buttress the evidence that the majority of the post-period decline in rail prices and increase in total traffic found in Table 11 are the result of compatibility in a competitive market, rather than a result of competitive conduct alone.

F International Railway Agreements

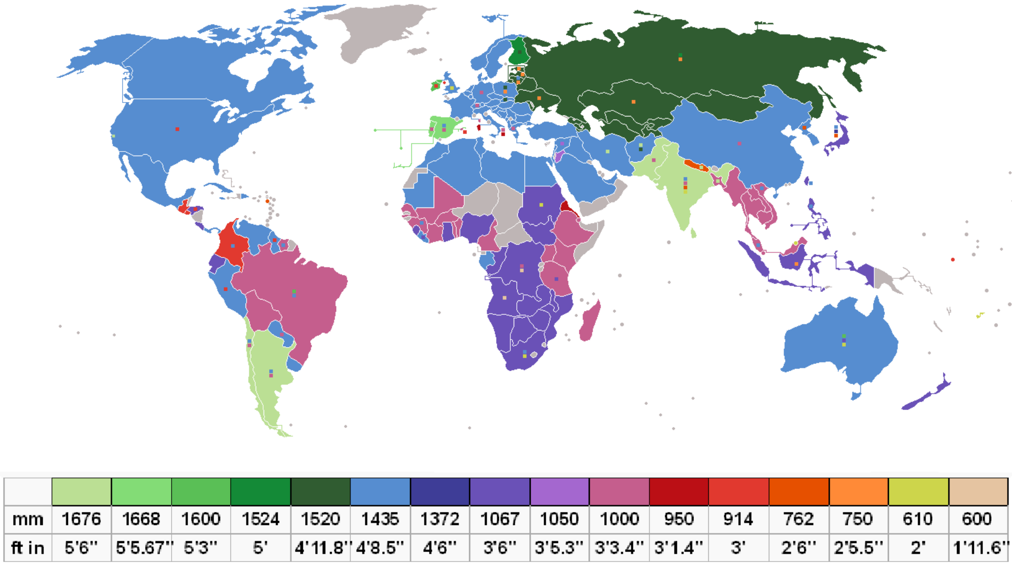
This appendix provides more background on the persistence of breaks in gauge around the world today, accompanying the discussion in Section 6 on what these results might teach us regarding the value of standardizing railway gauge in the present. Though countries in North America and Western Europe have adopted a common standard, gauge breaks are prevalent in underdeveloped regions, including most of Asia, Africa, and South America.

To focus attention, I invoke two examples: Asia and the European periphery. Table F.1 shows the principal gauges currently used in countries in South and Southeast Asia. This diversity precluded an agreement to unify domestic railways into a transcontinental railway network for over 50 years, and the problem of incompatibility was never fully resolved: when the Trans-Asian Railway Network Agreement (UNTC 2006) was ratified in 2006, they skirted the issue, instead opting to continue using adapters at border crossings, which were enumerated in the agreement itself.

Similarly, when European countries agreed to unify their railway networks in 1991, no uniform standard was specified. Though much of Western Europe was on standard gauge, breaks persisted in various places. Table F.2 lists the interchange stations enumerated in the European Agreement on Important International Combined Transport Lines (UNTC 1991, p. 38), as well as the means of interchange at each station – which are (shockingly) the same technologies that were in use 100 years prior. These breaks are present mostly along the eastern periphery, though there are also two junctions where French and Spanish tracks of incompatible gauge meet.

To make the problem more concrete, Figures F.1 and F.2 illustrate the diversity in gauge in Asia and around the world. The former figure is taken from supporting documentation for the Trans-Asian Railway Network Agreement and maps the major lines in Asia, color-coding by gauge. The latter figure is from Wikipedia and shows a map of the world which color-codes countries by their principal gauge. Both figures make it visually obvious just how much of a problem breaks in gauge continue to be in less developed parts of the world: sending a rail car from Europe to Southeast Asia requires at least two interchanges, and from parts of Russia, three.

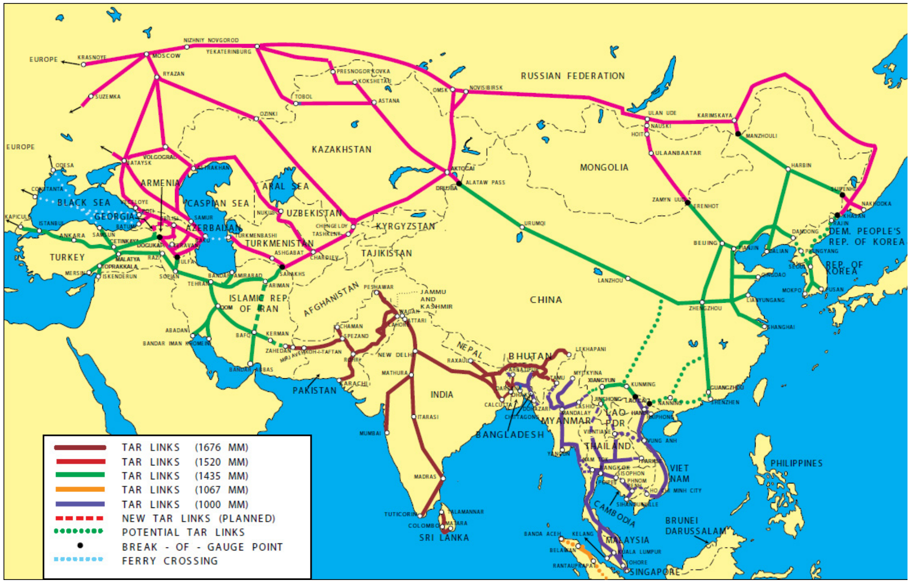
Figure F.1: World Map, Color-coding Countries by Principal Gauge



	🟩	🟩	🟩	🟩	🟩	🟦	🟦	🟪	🟪	🟪	🟥	🟥	🟧	🟧	🟨	🟫
mm	1676	1668	1600	1524	1520	1435	1372	1067	1050	1000	950	914	762	750	610	600
ft in	5'6"	5'5.67"	5'3"	5'	4'11.8"	4'8.5"	4'6"	3'6"	3'5.3"	3'3.4"	3'1.4"	3'	2'6"	2'5.5"	2'	1'11.6"

Notes: Map illustrates the principal gauge of individual countries around the world, color-coding each country by gauge, thereby making the prevalence of breaks visually apparent. Figure obtained from Wikipedia, available at https://upload.wikimedia.org/wikipedia/commons/1/1f/Rail_gauge_world.png.

Figure F.2: Map of Principal Lines in Asia, Color-coded by Gauge (2006)



Notes: Map shows major lines in Asia covered by the Trans-Asian Railway Network Agreement (UNTC 2006), as well as links planned under the agreement, color-coding by gauge. Figure published in 1999 and available as part of the supporting documentation for the TAR.

Table F.1: Railway Gauge of Trans-Asian Railway Members at Time of Agreement (2006)

1,000 mm (3' 3.375")	1,067 mm (3' 6")	1,435 mm (4' 8.5")	1,520 mm (6' 0")	1,676 mm (6' 6")
Bangladesh	Indonesia	China	Armenia	Bangladesh
Laos		North Korea	Azerbaijan	India
Malaysia		South Korea	Georgia	Nepal
Myanmar		Iran	Kazakhstan	Pakistan
Singapore		Turkey	Kyrgyzstan	Sri Lanka
Thailand			Mongolia	
Vietnam			Russia	
			Tajikistan	
			Turkmenistan	
			Uzbekistan	

Notes: Table lists the varying railroad gauge standards of the countries that were party to or affected by the Intergovernmental Agreement on the Trans-Asian Railway Network at the time of ratification (November 21, 2006). Data from text of the agreement (UNTC 2006).

Table F.2: Gauge Interchanges on European Country Borders at Time of Agreement (1991)

		Means of Interchange	
Countries	**Number of Interchanges**	**Change of wagon axles/bogies**	**Transshipment by crane or other equipment**
Hungary-Ukraine	2	X	X
Romania-Moldova	2	X	X
Romania-Ukraine	2	X	X
Spain-France	2	X	X
Poland-Belarus	1	X	X
Poland-Lithuania	1	X	X
Poland-Ukraine	1	X	X
Russia-North Korea	1	X	X
Russia-China	1	X	X
Kazakhstan-China	1	X	X
Slovakia-Ukraine	1		X

Notes: Table counts number of gauge interchange stations on the border between country pairs, and the means of interchange used to transfer freight across gauges, at the time of the European Agreement on Important International Combined Transport Lines and Related Installations (February 1, 1991). Data from text of the agreement (UNTC 1991).