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Collusive Investments in Technological Compatibility: Lessons from U.S. Railroads in the Late 19th Century

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Abstract. Collusion is widely condemned for its negative effects on consumer welfare and market efficiency. In this paper, I show that collusion may also in some cases facilitate the creation of unexpected new sources of value. I bring this possibility into focus through the lens of a historical episode from the 19th century, when colluding railroads in the U.S. South converted 13,000 miles of railroad track to standard gauge over the course of two days in 1886, integrating the South into the national transportation network. Route-level freight traffic data reveal that the gauge change caused a large shift in market share from steamships to railroads, but did not affect total shipments or prices on these routes. Guided by these results, I develop a model of compatibility choice in a collusive market and argue that collusion may have enabled the gauge change to take place as it did, while also tempering the effects on prices and total shipments.

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In the early morning hours of Monday, May 31, 1886, railroads across the U.S. South simultaneously stopped running their trains, and over the next 36 hours teams of workers manually narrowed 13,000 miles of railroad track from a 5 foot, 0 inch to a 4 foot, 9 inch gauge (track width) to be compatible with the standard being used throughout most of the rest of the country. Today, the gauge change is celebrated as a remarkable feat of engineering and coordination and is referenced in research and popular press as an example of standardization (e.g., Shapiro and Varian 1999). However, when the story is told, a typically forgotten detail is that these railroads were also running a cartel.

Collusion has been illegal in the United States since the Sherman Act of 1890, out of concern for consumer welfare and market efficiency—and railroads were one of its original targets. But often overlooked is the possibility that in some settings, collusion may also contribute to the creation of unexpected new sources of value, such as standardization. This value creation might in principle even change predictions for the effects of market power on total surplus. In this paper, I bring these issues into focus by way of this historical example: the gauge change instantly integrated the South into the national transportation network, making it possible for goods and passengers to move effortlessly into and out of the region without costs and delays of interchange.

Using historical data from the Southern railroad and steamship cartel, this paper first chronicles the gauge change and shows that it triggered a redistribution of freight traffic into the South from steamships to railroads but did not affect total shipments on sampled routes through 1890. Over the 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. Guided by this evidence, I then develop a simplified model of the market for North-South freight shipment and show that the cartel may have both facilitated the conversion to standard gauge, by providing a venue for coordination and a means of recouping the investment, and concurrently softened its effects on prices and total shipments, by limiting pass-through of carriers' resultant cost savings. Complementing the evidence from cartel data, evidence from railroads' stock returns around the time of the event indicates that investors perceived large financial returns to standardization. The effects of the gauge change were thus large, yet potentially defined by the industry's collusive conduct.

The earliest U.S. railroads were constructed as local and regional enterprises to serve local needs. At the time, opinion over the optimal gauge varied, and without the vision of a national network, distinct gauges were adopted around the country. As the national network began to emerge, these incompatibilities became increasingly costly, and railroads gradually converged on a common gauge via conversion and new construction, such that by the 1880s, nearly all U.S. railroads were on a 4 foot, 8.5 inch standard gauge—except for those in the South. Data from the *Poor's Manual of Railroads* (Poor 1868) confirm that whereas other regions had 95% or more of their track in standard gauge, 75% of that in the South was on an incompatible, 5 foot, 0 inch Southern gauge (even more if excluding Virginia and North Carolina), and accounts indicate that the available adapter technologies were a substantial and costly second-best to a fully integrated network. In early 1886, 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 a standard-compatible 4 foot, 9 inch gauge en masse over the two days of May 31 and June 1, 1886, with traffic halting on May 30 and resuming by the evening of June 1, effortlessly traversing the former breaks in gauge. The conversion was carefully planned, seamlessly executed, and well-documented by contemporaries.

The cartel's primary purpose was to support noncompetitive pricing by Southern carriers through the creation and administration of a traffic pool. To implement the pooling arrangement, the SRSA compiled monthly records of freight traffic borne by individual carriers to and from Southern cities where two or more members operated, which were later reported to cartel members for key routes. I use these data to estimate the effects of the gauge change on merchandise shipments from the North into the South. In a variant on a triple-differences design, I compare within-route traffic borne by rail versus steamship, before and after the gauge change, allowing the effects to vary with route length. Because breaks in gauge imposed a fixed cost of interchange on through shipments, the unit costs on each route will vary with distance. Steamships are a natural comparison group for all-rail traffic, as seaborne freight circumvented the breaks in gauge and was therefore operationally unaffected by the conversion to a standard-compatible gauge.

The cartel records yield a balanced panel of 52 routes with inbound merchandise shipments data pre- and post-standardization. Within this sample, I find that the gauge change caused a sharp increase in all-rail traffic relative to steamship traffic, with the effect strongest on shorter routes and dissipating after roughly 700 to 750 miles. When split across the two all-rail pathways into the South, I find relatively larger increases for the less-trafficked routing. The results are robust to a variety of fixed effects, as well as within assorted subsamples.

Market share models return similar results, indicating a redistribution of traffic from steamships to railroads, with effects dissipating at similar distances. However, I find no differential growth in total shipments on shorter versus longer routes through 1890; the effects are limited to substitution across modes. One possible explanation is that adjustment on the aggregate margin took several years, and the panel is too short for these effects to appear in the data; another is that the choice of mode was more sensitive to breaks in gauge than shipment overall. However, the presence of the cartel is a distinctive feature of the setting, and its potential importance is accentuated by evidence that cartel prices did not decline following the gauge change.

To evaluate the cartel's role in facilitating the gauge change and whether collusive pricing might have constrained total shipments, I turn to theory. I develop a simplified model of the market for freight transport on a North-South route, first using it to show how the existence of the cartel may have facilitated standardization by providing incentives for undertaking the costly investment and a venue for coordinating the regional shift to a different common-gauge equilibrium, and then demonstrating how collusion could have shaped the effects on prices, quantities, and market shares. Although traffic will shift from steamships to all-rail in any market structure, collusion reduces the pass-through of railroads' cost savings to prices and in turn the growth in total shipments, relative to a counterfactual in which railroads and steamships set prices competitively—and if cartel price adjustments are even moderately costly (e.g., due to internal renegotiation costs), prices and total shipments may not change at all. As it were, stock returns to U.S. railroads at the time of the conversion indicate that investors believed it would generate a windfall for Southern railroads, particularly those where the gauge breaks were once located.

This episode offers an example of an unconventional dividend from collusion: the standardization of Southern railway gauge.[1] The enabling role of the cartel was to make it possible for firms to internalize the externalities of their technology choices, and to provide an opportunity to coordinate on decentralized changes such as the conversion of 13,000 miles of railroad track and recover the fixed cost of conversion. This paper thus contributes to the literature on compatibility in interconnecting networks by pointing out the ways in which collusion supported standardization, whereas previous research has largely focused on how market competition shapes compatibility choices and compared markets to standards-setting committees.[2] The results also suggest a regulatory tension in settings with large strategic complementarities (such as from technological compatibility), as collusion (or consolidation) can enable value creation but also harm consumers.

The historical example is also striking because it reverses the direction of the conventional relationship between standards and collusion. Standards-setting organizations (SSOs) have long attracted regulatory scrutiny, especially regarding the market power conveyed to owners of standards-essential patents and the countervailing collective bargaining efforts by the SSO to negotiate licensing terms (e.g., U.S. Department of Justice and Federal Trade Commission 2007). But researchers and policymakers have also voiced concern that SSOs may be a breeding ground for price fixing, as they offer a venue for firms to coordinate their product market decisions with a lower risk of detection, under the cover of standards setting (U.S. Department of Justice and Federal Trade Commission 2007). In the setting of this paper, however, it was instead collusion that facilitated standards adoption.

Finally, the results bring new evidence to bear on the question of how compatibility affects market outcomes. Despite a rich theoretical literature, empirical progress has historically been challenged by the difficulty of linking compatibility to observable outcomes and a lack of standards-adoption events large enough to have measurable effects. This paper contributes to the growing body of work studying the impacts of compatibility and compatibility-dependent technologies directly (e.g., Knittel and Stango 2008, Basker and Simcoe 2019, Li 2019), showing that compatibility can have large effects on market shares of newly integrated firms in settings where traffic is exchanged across connected networks, such as in communications or transportation.

The paper proceeds as follows. Section 1 reviews U.S. railroad history and the natural experiment at the heart of the paper. Section 2 introduces the data and the empirical strategy. Section 3 estimates the effects of the gauge change on route-level shipments and market shares, identifies the empirical puzzle, and discusses potential explanations, emphasizing the role of the cartel. Section 4 provides the theoretical argument for how the cartel may have both enabled the gauge change to take place and tempered its effects on prices and shipments, with a view toward rationalizing the patterns in the data. Section 5 then shows what happened to stock prices following the gauge change. Section 6 discusses the key lessons, particularly as related to (i) the benefits of interoperability and (ii) the interaction with product market competition, and 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, p. 93), 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 feet, 8.5 inches; 4 feet, 9 inches; 4 feet, 10 inches; and 5 feet, 0 inches), a second wave in the 1840s added three broader gauges to the mix (5 feet, 4 inches; 5 feet, 6 inches; 6 feet, 0 inches), and a "third wave of experimentation" (Puffert 2009, p. 93) in the second half of the century introduced several narrow gauges, the most common of which were 3 feet, 0 inches and 3 feet, 6 inches. Among this set, only 4 feet, 8.5 inches and 4 feet, 9 inches were mutually compatible and allowed for a seamless exchange of traffic.[3]

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 United States during the Civil War, and a tenth in Canada, each predominantly using a different gauge than neighboring regions. Panel (a) of Figure 1 shows the state of U.S. railroads east of the Mississippi River at this time, identifying lines with 4 foot, 8.5 inch (standard gauge), 5 foot, 0 inch (Southern gauge), and other track widths.

In the 1850s, each break in gauge imposed a full-day delay on through shipments and necessitated significant labor and capital for transshipment, which at the time was performed manually, aided by cranes (Poor 1851, Taylor and Neu 1956). Diversity also required railroads to preserve a large fleet of idle rolling stock at each break for transferring freight. By the 1870s, several adapter technologies had been developed to reduce these costs, the most common of which was bogie exchange, whereby each rail car was raised by a steam-powered hoist, and its chassis (bogie or truck) replaced with one of a different gauge. Bogie exchange required not only steam hoists and extra labor for switching trucks, but also rail yards full of empty trucks of both gauges, side tracks, extra buildings, and extra clerical workers, and although changing a single rail car took only a few minutes, a full train could take much longer and might have to wait for exchange facilities to become available. Bogie exchange also yielded a mismatched car and bogie, which damaged tracks, had to run at reduced speeds, and were at risk for tipping on curves. The true cost of incompatibility was thus considerably higher than the physical act of interchange alone (McHenry 1875).

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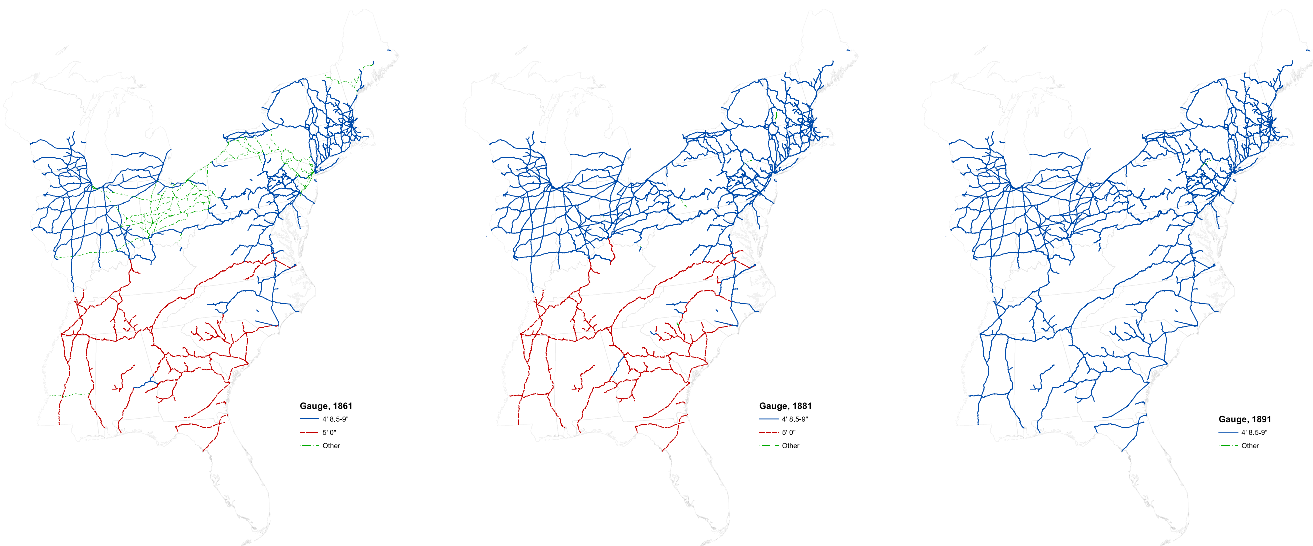
Figure 1. Installed Railroad Gauge East of the Mississippi River, 1861–1891 (Holding Network Fixed)

(a) Baseline: 1861 Railroad Network

(b) Updated Railroad Gauges of the 1861 Network, as of 1881

(c) 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 (blue solid line: 4 feet, 8.5–9 inches; red dashed line: 5 feet, 0 inches; green dotted line: other). Panels (b) and (c) 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 (Poor 1868). Over 99.5% of track miles in the 1861 network shown in the figure were matched to the Poor's data in both 1881 and 1891. State boundary basemap obtained from National Historical Geographic Information System (NHGIS) website (Minnesota Population Center 2011).

After the Civil War (1861–1865), several pressures coincided to induce private efforts toward standardization, including growing demand for interregional shipment, growing trade in time-sensitive perishable goods, competition (within routes), and consolidation (across routes). Despite known technical shortcomings (Puffert 2009), 4 feet, 8.5 inches 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 feet, 10 inches; 5 foot, 6 inches; and 6 feet, 0 inches had all converted to standard gauge, effectively leaving only two gauges in widespread use: 5 foot, 0 inches in the South, and 4 feet, 8.5 inches in the rest of the country.[4]

1.1. The Southern Railway and Steamship Association

Concurrent with (but independent of) these trends, Southern freight carriers had organized into the SRSA cartel in 1875, following a series of price wars. The cartel's express purpose was price maintenance: the cartel agreement states an intention of achieving "a proper correlation of rates," to protect its members and consumers from "irregular and fluctuating" prices (Southern Railway and Steamship Association 1875, vol. 17, p. 1489). 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. Despite a rocky start, and no clear model to follow, by the 1880s the SRSA was sophisticated, successful, and "one of the most powerful and disciplined" traffic pools in the country (White 1993, p. 49)—one documented several times over (e.g., Hudson 1890, Joubert 1949, Argue 1990).[5]

The cartel had its own full-time administration, which had the responsibility of carrying out the terms of the cartel agreement, making new rules as necessary, and settling internal disputes. The mechanism used to ensure that members adhered to the prices set by the cartel's rate committee was apportionment: carriers serving a competed route were allotted a fixed proportion of traffic, determined by "the average amount of freight hauled in past years" (Joubert 1949, p. 45). In the cartel's early years, carriers who exceeded their allotment were required to submit the excess revenue for redistribution to other members, less a one-cent (later half-cent) per-ton mile allowance for the cost 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. For a select set of routes, the cartel also compiled these data into monthly traffic reports, which it then circulated to cartel members and which have since been preserved.

The amended mechanism proved so effective that in 1887, the cartel reported that "since 1877, all balances have been paid and rates thoroughly maintained," excepting one month in 1878 (Hudson 1890, p. 75), 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. The SRSA also demonstrated early on that when competing carriers (members or not) deviated from cartel prices, it would act quickly and decisively by setting destructively low rates until cartel pricing was restored.

The passage of the Interstate Commerce Act (ICA) in February 1887 presented a new threat to the cartel. The ICA prohibited traffic pooling, making the cartel's apportionment mechanism illegal, but the act "by no means put an end to the power of the Association" (Hudson 1890, p. 91).[6] The SRSA responded by transitioning 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. At this point, the cartel stopped circulating traffic data. Though it took several years for the courts to resolve initial ambiguities over whether the SRSA met the statute's definition, by 1897 the cartel had dissolved.

1.2. The Gauge Change

As trade between the South and other regions accelerated after the Civil War, 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, p. 668), and the total cost of delays were growing one-for-one with volume. The first cracks in the 5 foot, 0 inch network developed in 1881 and 1885, when two major lines linking the Midwest to the South (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.

At the cartel's annual convention in July 1885, representatives of member railroads discussed the severity of the compatibility problem and concluded they would convert to standard gauge in the following year, and at a follow-on meeting on February 2–3, 1886, these railroads committed to and began preparing a mass conversion to a 4 foot, 9 inch, standard-compatible gauge on May 31 and June 1 of that year.[7] 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 inches inward, resetting ties, and moving to the next segment. By midday on June 1, 13,000 miles of track had been converted to 4 feet, 9 inches, and traffic had resumed, with freight now moving freely across Southern borders in a physically integrated railroad network.[8]

To verify the scale of the conversion, I collect individual railroads' gauges and mileage from *Poor's Manual of Railroads* (1882–1890), an annual publication listing the universe of railroads in North America (Poor 1868). Table 1 shows the fraction of railroad track in standard-compatible gauge 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 foot, 0 inch gauge. The discrepancy remained until the year of the gauge change: between 1885 and 1887, the total in 5 foot, 0 inch 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.

The historical record suggests 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 were higher in a coordinated,

Table 1. Approximate Miles of Railroad in Each Gauge, by Region, 1881–1889

Region	No. of miles (Percent 4 ft, 8.5–9 in.)	Pre-gauge change			Post-gauge change	
		1881	1883	1885	1887	1889
New England	Total miles	6,251.3 (97%)	6,283.8 (97%)	6,418.2 (97%)	6,784.9 (97%)	6,744.1 (98%)
Mid-Atlantic	Total miles	15,845.6 (94%)	18,588.1 (95%)	19,792.2 (96%)	19,420.9 (96%)	20,893.3 (97%)
Midwest	Total miles	37,246.4 (94%)	41,470.0 (93%)	40,495.6 (94%)	43,559.5 (97%)	46,966.7 (98%)
South (focal region)	Total miles	17,257.5 (25%)	19,316.6 (25%)	20,694.3 (29%)	23,596.7 (92%)	26,793.4 (94%)
Western states	Total miles	29,834.8 (88%)	39,575.8 (85%)	41,078.0 (89%)	51,948.4 (92%)	58,318.5 (93%)

Notes. The table shows the approximate miles of railroad in the United States from 1881 to 1889 in two-year intervals and fraction in standard-compatible gauge, confirming the scale of the conversion: 13,000 miles of Southern railroad converted from 5 feet, 0 inches to 4 feet, 9 inches between 1885 and 1887. Data from *Poor's Manual of Railroads* (Poor 1868), which provides a near-complete, annual enumeration of U.S. railroads.

regional conversion. The cartel thus appears to have supported the gauge change in several ways. First, it provided an institutional venue for coordinating on a common gauge and organizing the conversion event itself. But equally importantly, collusion internalized the externalities of compatibility, and noncompetitive pricing ensured that railroads could recoup the cost of the conversion. Without either collusion or consolidation, it is possible the gauge change itself might not have occurred at this time or scale—a question I explore further in Section 4.

2. Data and Empirical Design

I use SRSA records of freight traffic into and out of the South by railroad and steamship to study the effects of the gauge change.[9] I restrict attention to annual merchandise shipments from Northern port cities to cities in the interior South, as merchandise comprised the largest fraction of tonnage in the South at this time and an even greater fraction of value (U.S. Department of the Interior 1883).[10] The sample throughout the paper is a balanced panel of 52 North-South routes (4 origins × 13 destinations) with merchandise shipments apportioned, monitored, and reported by the cartel before and after the gauge change, observed over the 1883–84 to 1889–90 fiscal years. Figure A.2 in Online Appendix A maps the origins and destinations in this sample. The gauge change coincides precisely with the end of the SRSA's 1885–86 fiscal year on May 31.

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 traffic and revenue by routing (see Online Appendix A), 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), 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 (= 52·3·7) observations at the route-mode-year level.[11]

The analysis begins with a simple comparison of all-rail and steamship traffic within individual routes before and after the gauge change. Because they bypassed breaks in gauge, steamships were not directly affected by the gauge change and accordingly provide a comparison group for all-rail shipments. However, breaks in gauge imposed a fixed cost on through shipments, such that they were a larger proportion of total costs on short routes relative to long routes. I therefore relax the effects to vary with distance. With this approach, the longer, less-affected routes then serve as a triple-difference control group against the shorter and more intensively treated ones. These specifications are thus estimated in a triple-difference form:

$$\begin{aligned}\ln(Q_{mrt}) &= \beta_0 + \beta_1 Rail_m + \beta_2 Post_t + \beta_3 Dist_r \\ &\quad + \beta_4 Rail_m Post_t + \beta_5 Rail_m Dist_r + \beta_6 Post_t Dist_r \\ &\quad + \beta_7 Rail_m Post_t Dist_r + X_{mrt}\gamma + \varepsilon_{mrt}, \qquad (1)\end{aligned}$$

where Q_{mrt} is pounds of traffic carried by mode m, on route r, in year t; $Rail_m$ 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 (in hundreds of miles). Throughout the analysis, I measure straight-line distance, rather than traveled distance, which is not observed for either mode and unobservable for seaborne shipments (contemporary sources in Online Appendix A indicate straight-line and rail network distance are in fixed proportion for the sampled routes). The X_{mrt} term includes an assortment of fixed effects. In all specifications, I cluster standard errors by route, though the results are robust to allowing spatial correlation in the error term that declines linearly in the distance between Southern destinations up to 20-, 50-, 100-, and 200-mile cutoffs (Conley 1999).

It is important to note that although the specification in Equation (1) will determine whether all-rail and steamship traffic diverged following the gauge change, and is useful for evaluating the robustness of the results to an assortment of fixed effects or controls, it does not precisely identify the effects of standardization on the *level* of all-rail shipments, as steamships may have simultaneously lost traffic to railroads. For a different view of the data not subject to this qualification, I estimate a simple logit demand model on market shares, rather than quantities, which can account for this interdependence. Suppose mode shares are generated by discrete consumer choices, for which mode m on route r in year t has latent utility that is a function of the mode and period (all-rail versus steamship, before versus after the gauge change), the interaction with distance, and other fixed route-mode and route-year specific characteristics γ_{mr} and δ_{rt}:

$$u_{imrt} = \left[\beta_0 Rail_m + \beta_1 Rail_m Post_t + \beta_2 Rail_m Post_t Dist_r + \gamma_{mr} + \delta_{rt} + \xi_{mrt}\right] + \eta_{imrt} \equiv \mu_{mrt} + \eta_{imrt},$$

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

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

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

$$\ln(Q_{rt}) = \beta_0 + \beta_1 Post_t + \beta_2 Post_t Dist_r + \gamma_r + \varepsilon_{rt}. \quad (3)$$

To the extent that the gauge change differentially impacted shorter versus longer routes, the effects on route-level shipments should emerge in the interaction.

3. Standardization and Freight Shipments

In this section, I examine the first-order effects of the gauge change, showing that the standardization of Southern gauge triggered a redistribution of traffic from steamships to railroads but does not appear to have affected total shipments on these routes. It may be helpful to provide a roadmap to these results in advance. I first present descriptive statistics for the sampled routes, pre- and post-gauge change, which foreshadow the results that follow. I then estimate the effects of the gauge change on all-rail versus steamship traffic, as well as on overall shipments, where the empirical puzzle emerges. At the end of the section, I discuss possible explanations for the results, focusing especially on the ways in which cartel pricing may have limited the growth in total shipments and (implicitly) the consumer welfare gains from standardization.

3.1. Descriptive Statistics

Table 2 provides descriptive statistics for the sampled routes, comparing shorter and longer routes (<25th and >75th percentiles, respectively), pre- versus post-gauge change. The table shows means and standard errors of tonnage, revenue, and all-rail shares. The shorter routes in the sample had less traffic than longer routes throughout the sample period but carried more of this traffic by rail. Total shipments grew at similar rates for the shorter and longer routes over the sample period. However, following the gauge change, the all-rail share of traffic on shorter routes jumped from an average of 40% to an average of 56%, an increase significant beyond the 1% level. In contrast, the all-rail share on longer routes declined from 23% to 19%, not a statistically significant difference. These results provide the first hints of the puzzle that will emerge

Table 2. Descriptive Statistics: Traffic, Revenue, and All-Rail Shares, for Short vs. Long Routes

Statistic	Short routes (<25th pctile) Pre	Short routes (<25th pctile) Post	Long routes (>75th pctile) Pre	Long routes (>75th pctile) Post
Route-years	39	52	39	52
Route distance (mi)	589.01	589.01	977.65	977.65
	(6.90)	(5.95)	(10.54)	(9.09)
Tons (1,000s)	715.88	818.55	1066.39	1161.54
	(130.58)	(134.66)	(210.85)	(221.31)
Revenue ($1,000s)	8.61	8.97	14.59	15.21
	(1.48)	(1.41)	(3.03)	(3.02)
All-rail share, tonnage	0.40	0.56	0.23	0.19
	(0.04)	(0.03)	(0.03)	(0.03)
All-rail share, revenue	0.41	0.57	0.24	0.20
	(0.04)	(0.03)	(0.03)	(0.03)

Notes. Table reports average tonnage, revenue, and all-rail shares of traffic and revenue for shorter versus longer routes (below the 25th percentile and above the 75th percentile of route length, respectively), before versus after the gauge change. Standard error of each mean in parentheses.

later: the gauge change was important enough to prompt substitution across modes, but evidently not enough to increase aggregate shipments in the short to medium run.

3.2. Effects of the Gauge Change

3.2.1. Distributional Effects. Table 3 estimates the specification in Equation (1), with a slight transformation to estimate mode-specific constants instead of shared constants (for purposes of presentation). Column (1) estimates this model as specified, and columns (2)–(6) add an assortment of fixed effects for routes, years, route-modes, and route-years. Only the focal, post-period parameters are shown in the table, which measure within-mode changes over time (columns (1)–(4)), or alternatively, when comparisons are within route-years, the mode difference-in-differences (columns (5) and (6)).[12]

This first cut indicates that after the gauge change, all-rail traffic increased and steamship traffic declined on the (more intensively treated) shorter routes in the data, with these effects diminishing with route length (indeed, in the data, the pattern inverts for the longest routes, with steamship traffic growing and all-rail traffic falling on these routes, which serve as a comparison group; see Table 2). To put the magnitudes in perspective, the estimates imply a 50% increase in all-rail traffic and 30% decrease in steamship traffic on the shortest route in the sample (500 miles), and inverted patterns on routes longer than 700 to 800 miles.

In Table 4, I split the all-rail estimates by carrier, to both (i) confirm that effects are present for each of the two all-rail paths into South (the ACL and PAL) and (ii) explore any heterogeneity in their magnitude. We see effects for both paths, with the initially less-trafficked one (the ACL) seeing a larger percent increase in traffic (off of its lower base). I also find that the effects dissipate to zero at similar distances for the two routings (roughly 700 miles).

As previously discussed, a specification in quantities can establish whether all-rail and steamship traffic diverged following the gauge change, and whether the results are robust to controls. However, steamships are a problematic control group, due to the interdependence of all-rail and steamship traffic with imperfect competition. Steamships may have also been affected by the gauge change if they lost traffic to railroads, and as a result, they do not provide a clean counterfactual to the railroads. For an alternative approach, in Table 5 I estimate a simple logit demand model that accounts for this interdependence (Equation (2)), in which the outcome variable is the log difference in all-rail and steamship shares of traffic in the given route-year. In taking this difference, most of the fixed effects from the previous table are eliminated, such that Table 5 contains only two variants of the regression: without and with route fixed effects.

The results continue to show positive effects on all-rail shares that decline with distance, significant beyond the 1% level. The estimates are similar across the two specifications, and the effect of the gauge change is estimated to dissipate at roughly 720 miles, statistically and economically comparable to the previous tables. When these effects are split out for the

Table 3. Change in All-Rail Traffic

Variable	(1)	(2)	(3)	(4)	(5)	(6)
All-rail × *post-change*	1.658***	1.672***	1.663***	1.721***	2.466***	2.541***
	(0.316)	(0.298)	(0.307)	(0.316)	(0.559)	(0.582)
× *distance* (100 mi)	−0.227***	−0.239***	−0.238***	−0.244***	−0.331***	−0.341***
	(0.042)	(0.041)	(0.041)	(0.042)	(0.073)	(0.075)
Steamship × *post-change*	−0.779**	−0.756**	−0.761**	−0.763**		
	(0.319)	(0.306)	(0.320)	(0.312)		
× *distance* (100 mi)	0.096**	0.089**	0.090**	0.090**		
	(0.040)	(0.037)	(0.037)	(0.038)		
N	1,036	1,036	1,036	1,036	1,036	1,036
R^2	0.32	0.67	0.67	0.73	0.70	0.75
Route FE		X	X			
Year FE			X			
Route-mode FE				X		X
Route-year FE					X	X

Notes. The table estimates effect of the gauge change on merchandise shipments for shorter versus longer routes. Observations are route-mode-years. The dependent variable in all columns is log pounds of traffic. Estimates in columns (1)–(4) should be interpreted as mode-specific changes relative to the preperiod. Those in columns (5) and (6) as differences-in-differences due to the route-year FEs. Standard errors clustered by route in parentheses.

$^{**}p < 0.05$; $^{***}p < 0.01$.

Table 4. Change in All-Rail Traffic, ACL, and PAL

Variable	(1)	(2)	(3)	(4)	(5)	(6)
ACL × post-change	2.061***	2.082***	2.074***	2.064***	2.848***	2.809***
	(0.443)	(0.472)	(0.477)	(0.477)	(0.686)	(0.671)
× *distance* (100 mi)	−0.302***	−0.310***	−0.309***	−0.306***	−0.403***	−0.396***
	(0.059)	(0.064)	(0.064)	(0.064)	(0.094)	(0.090)
PAL × post-change	1.030***	0.973**	0.956**	1.045**	1.748**	1.829**
	(0.356)	(0.435)	(0.438)	(0.432)	(0.754)	(0.754)
× *distance* (100 mi)	−0.143***	−0.151**	−0.150**	−0.158**	−0.247**	−0.253**
	(0.050)	(0.062)	(0.061)	(0.062)	(0.100)	(0.101)
Steamship × post-change	−0.779**	−0.770**	−0.776**	−0.763**		
	(0.320)	(0.311)	(0.326)	(0.313)		
× *distance* (100 mi)	0.096**	0.092**	0.093**	0.090**		
	(0.040)	(0.038)	(0.038)	(0.038)		
N	1,036	1,036	1,036	1,036	1,036	1,036
R^2	0.48	0.83	0.84	0.89	0.86	0.91
Route FE		X	X			
Year FE			X			
Route-mode FE				X		X
Route-year FE					X	X

Notes. Table estimates effect of the gauge change on merchandise shipments for shorter versus longer routes. Observations are route-mode-years. The dependent variable in all columns is log pounds of traffic. Estimates in columns (1)–(4) should be interpreted as mode-specific changes relative to the preperiod. Those in columns (5) and (6) as differences-in-differences due to the route-year FEs. Standard errors clustered by route in parentheses.
$^{**}p < 0.05$; $^{***}p < 0.01$.

ACL and PAL, they are again larger for the less-trafficked ACL, consistent with previous results.

In Online Appendix D, 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 (three years pre-gauge change, four 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 between quantities and revenues in the data ($\rho = 0.99$).

3.2.2. Aggregate Effects. The results thus far show that the gauge change caused growth in all-rail market share, but leave ambiguous to what degree this effect is strictly substitution across modes versus new activity in the market. Table 6 addresses this question, collapsing the data to the route level and examining the effects on total traffic and revenue (Equation (3)). The even-numbered columns include route fixed effects. Across all specifications, we see no evidence that shorter routes (where previous tables showed the gauge change had the strongest effects

Table 5. Effects on Traffic Shares

Variable	(1)	(2)
All-rail × post-change	2.281***	2.400***
	(0.428)	(0.450)
× *distance* (100 mi)	−0.315***	−0.327***
	(0.056)	(0.058)
N	676	676
R^2	0.12	0.45
Route FE		X

Notes. The table estimates effect of the gauge change on all-rail traffic shares on shorter versus longer routes. The dependent variable is the log difference in all-rail and steamship shares within route-years. Standard errors clustered by route in parentheses.
$^{***}p < 0.01$.

Table 6. Change in Total Traffic/Revenue

Variable	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. The table estimates the effect of the gauge change on total shipments. Observations are route-years. The dependent variable in columns (1) and (2) is log quantities and in columns (3) and (4), log revenue. Standard errors clustered by route in parentheses.

on market shares) grew more quickly than longer routes following the gauge change. The variation in the post-gauge change growth in traffic for routes of different length is a true, and precisely estimated, zero.[13]

3.2.3. Other Views of the Data. We can also break these regressions out into annual effects, to test for pretrends and to explore how the response to the gauge change varied over time. A priori it is unclear 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, or for shippers to adjust. I estimate Equations (1) and (3) with route fixed effects for (i) all-rail versus steamship traffic and (ii) combined traffic, allowing the coefficients to vary by year. The estimates are plotted in Figure 2.

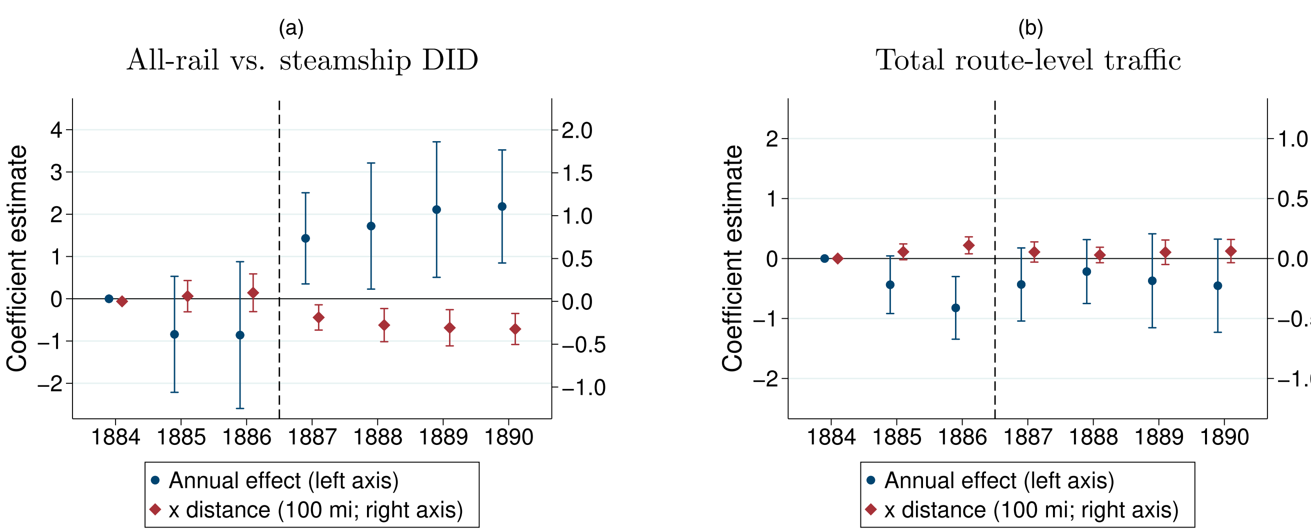
Relative to the omitted year of 1884, differences between all-rail and steamship traffic did not vary in a statistically significant way in the years leading up to the gauge change (panel (a)). However, beginning in 1887 (the first year post-gauge change), we see a growing divergence through the end of the panel, leveling out by around 1890. As in the regression tables, these effects are strongest for short routes and tempered by distance. Total shipments, however, are relatively stable throughout the period for both short and long routes (panel (b)).

3.3. Explaining the Results

The evidence that the gauge change shifted traffic from steamships to railroads is sensible, albeit nonobvious, given contemporary use of adapter technologies. But juxtaposed against this result, the lack of an effect on total shipments poses an empirical puzzle. An additional piece of evidence to be considered is what happened to cartel prices. The SRSA's Circular Letters periodically include rate tables, which list current cartel freight rates on different routes, by class of merchandise. These tables show the prices that all carriers on the given route were committed to charging shippers, and they make it possible to track route-level price changes over time.

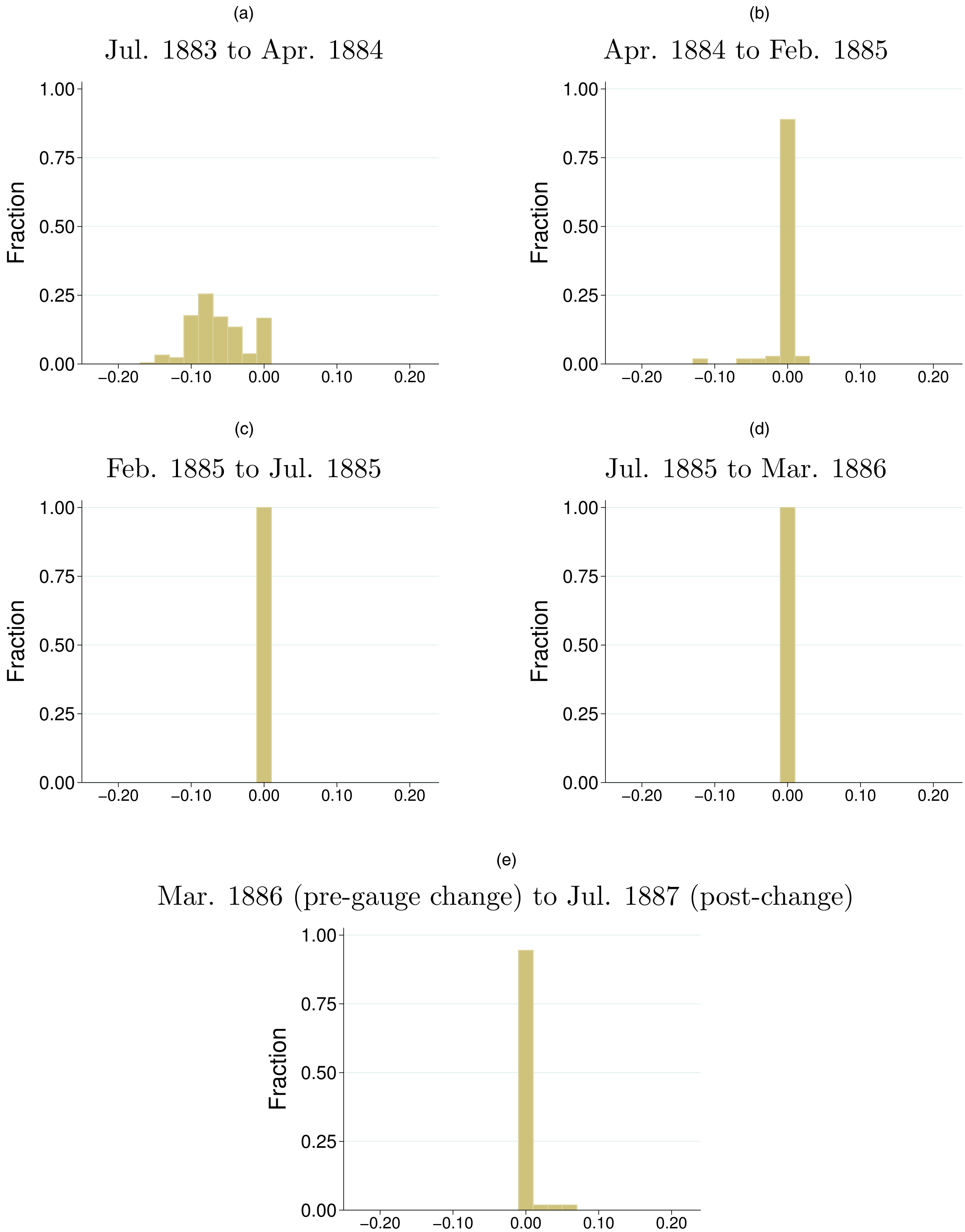
Figure 3 shows the distribution of rate changes on the routes in these circulars that are also in the sample for this paper (total of 36 routes, out of the 52 routes with traffic data). Panels (a)–(d) show a histogram of changes in class-level freight rates between July 1883, April 1884, February 1885, July 1885, and March 1886, a few months prior to the gauge change. Panel (e) shows the equivalent histogram for March 1886 to July 1887, one year after the gauge change. Each observation is a route-class, and with 36 routes and 13 freight rate classes, there are 468 observations per panel. An overwhelming fraction of routes do not see any price changes after April 1884, and the handful of price changes after the gauge change were (small) increases, rather than decreases, and limited to two routes: Philadelphia to Montgomery and Philadelphia to Selma.[14]

Figure 2. (Color online) Changes in All-Rail vs. Steamship Traffic and Total Traffic over Time



Notes. The figure shows the estimated changes in all-rail versus steamship traffic (panel (a)) and in total route-level traffic (panel (b)) on the sampled routes by year, relative to 1884. Panel (a) plots coefficients from a regression in which log quantities are regressed on an indicator for the all-rail mode, interacted with indicators for year (denoted with circles), and triple-interacted with route length (denoted with diamonds). Panel (b) plots coefficients from a regression of log quantities at the route-year level on indicators for year (in blue), interacted with route length (in red). Standard errors clustered by route and 95% confidence intervals provided around each point estimate.

Figure 3. (Color online) Distribution of Cartel Price Changes, Pre- vs. Post-Gauge Change



Notes. The figure shows the distribution of cartel price changes across routes and classes of merchandise throughout the sample period for the subset of routes appearing in both the SRSA freight traffic tables and the rate tables. The handful of rate increases in panel (e) come entirely from two routes: Philadelphia to Montgomery, and Philadelphia to Selma. Data from Southern Railway and Steamship Association (1875, volumes 13–24).

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Theoretical predictions for prices are ambiguous, as the quality of all-rail service increased at the same time as the cost of providing that service declined. For example, if the gauge change caused all-rail demand to shift out and marginal costs to decline on short routes, equilibrium prices could in principle be unchanged, although in a classical supply-and-demand framework, total quantities would then necessarily increase, so the puzzle remains. But there are other reasons why prices may have been rigid. For example, cartel freight rates applied uniformly to all carriers on a route to avoid perceptions that individual members were favored, and steamship companies in the cartel were unlikely to agree to rate reductions, as were interior railroads—neither of which saw direct cost savings as a result of the gauge change. A closer reading of SRSA documents reveals that the rate-setting process was contentious, and in the event of disagreement, rate-setting escalated to the cartel's board of arbitrators, which in practice was often the rate-setting body. Given the absence of price changes, either the matter was never raised for discussion or the board of arbitrators did not view a rate reduction as the appropriate action. In effect, it appears that the cartel believed prices were sufficiently close to profit-maximizing to leave them unchanged.

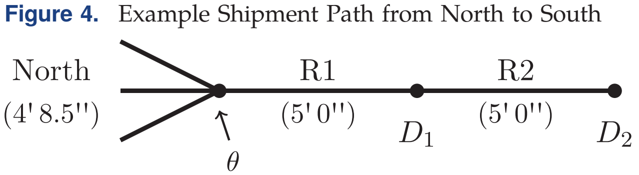
That this price rigidity explains the empirical puzzle is merely one possibility. Another possibility is that the market for final goods needed more time to adjust, and the panel is too short to see the aggregate effects materialize. It might also be that on the demand side, the choice over mode was simply more elastic to the gauge change than the decision to ship at all. However, the presence of a well-functioning cartel is a conspicuous feature of the setting, which likely contributed to these outcomes. In the next section, I use theory to explore how the gauge change and its observed effects might relate to collusion. Proofs are provided in Online Appendix E.

4. Compatibility and Collusion

4.1. Incentives for Standardization

Suppose that to get from a Northern origin on the 4 foot, 8.5 inch network to a Southern destination on the 5 foot, 0 inch network, a shipment may traverse up to two connecting Southern railroads, R1 and R2. Shipments from the North to D_1 (at the endpoint of R1) and D_2 (at the endpoint of R2) incur a fixed cost of θ per ton for interchange at the border, as illustrated in Figure 4.

Figure 4. Example Shipment Path from North to South



Annual shipments (e.g., tonnage) to destination d can be written as $Q(P_d) = M_d - aP_d$, where M_d is the market size, P_d is the freight tariff (per ton), and $a > 0$ (to simplify the task of illustrating basic principles, I invoke linear demand throughout this section). We will assume D_1 is a waypoint and D_2 is a larger market (or collection of markets) further downstream, with $M_2 > 2M_1$, which is broadly consistent with the historical setting. Suppose R1's segment is length ℓ_1 and R2's is ℓ_2, and let c_d denote the per-ton shipment cost to d incurred independent of any breaks in gauge (the cost of carriage), which is proportional to route length. Shipment revenue and costs are in turn divided among the carriers involved, as they appear to have been historically (for example, for shipments to D_1, R1 retains all revenue but also bears all of the costs, whereas for shipments to D_2, R1 and R2 divide costs and revenues proportionally; see Online Appendix B). Let the railroads' cost of converting to standard gauge be C_1 and C_2, also proportional to route length.

To simplify the exposition, I will further assume that R1 and R2 are equal length, and that breaks in gauge create an interchange cost but do not directly enter demand, though these assumptions are not essential to the results and can be relaxed, as the latter will be in the next section. Because $\ell_1 = \ell_2$, we can define $c \equiv c_1$ to be the cost of carriage to D_1, such that $2c$ is the cost to D_2, and let $C \equiv C_1 = C_2$ be each railroad's cost of standardizing its gauge.

In this setting, each firm's returns to standardization depends on the other's choice. If R1 converts alone, a gauge break is eliminated for shipments to D_1 but remains for those to D_2, as the break moves down the line. If R2 converts alone, a second break would be introduced for shipments to D_2. And if R1 and R2 both adopt standard gauge, breaks are removed entirely, eliminating the cost of interchange. Prices may decline as well, insofar as the cost savings are passed through to prices. To allow for this possibility, we must specify the railroads' profit maximization problem. Railroads R1 and R2 thus set prices $\{P_d\}$ to each destination d to maximize

$$\Pi_d(P_d) = (P_d - c_d)Q_d - \theta(B_d Q_d),$$

where Π_d are the profits on shipments to destination d, and B_d denotes the number of gauge breaks en route to destination d (each incurring a cost of θ). Taking into account the division of profits by R1 and R2, firm-specific profits are $\pi_{R1} = \Pi_1 + \frac{1}{2}\Pi_2$ and $\pi_{R2} = \frac{1}{2}\Pi_2$, respectively. This construction leads to the following lemma characterizing the payoffs to standardization, where the superscripts in the notation indicate the choices of R1 and R2, respectively.

Lemma 1. *Standardization can generate the following payoffs to R1 and R2 relative to the status quo, before accounting for the fixed cost of conversion C:*

i. *If R1 converts alone:* $\Delta\pi_{R1}^{10} > 0$, $\Delta\pi_{R2}^{10} = 0$.
ii. *If R2 converts alone:* $\Delta\pi_{R1}^{01} < 0$, $\Delta\pi_{R2}^{01} < 0$.
iii. *If R1 and R2 convert jointly:* $\Delta\pi_{R1}^{11} > \Delta\pi_{R1}^{10}$, $\Delta\pi_{R2}^{11} > 0$.

In view of this lemma, we will make one more assumption: Suppose $\Delta\pi_{R1}^{10} < C < \Delta\pi_{R2}^{11}$, such that this cost is at least as large as the direct savings that R1 would realize if it converted to standard gauge alone (otherwise R1 would have already done so), but not so large that R2 would never find it profitable to standardize its gauge.[15] As long as this is the case, the following proposition establishes that there are two equilibria of the simultaneous-move game in the adoption of standard gauge: joint conversion and the status quo (no change).

Proposition 1. *In the absence of competition, provided* $\Delta\pi_{R1}^{10} < C < \Delta\pi_{R2}^{11}$, *there are two equilibria for standardization: either both firms convert to standard gauge, or neither firm converts (the status quo). Unilateral conversion to standard gauge is never an equilibrium.*

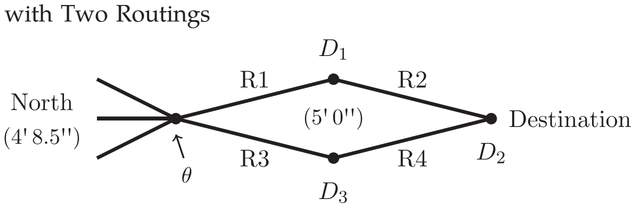
Standardization is thus an equilibrium (and the Pareto-efficient) outcome in this model, but given that the status quo is also an equilibrium, conversion requires coordinated decision-making. This coordinated effort was supported by the existence of the cartel, beginning with the discussion at the cartel's annual convention in July 1885 where members agreed to convert their tracks, and the meeting half a year later where they finalized the date of the conversion, selected the new gauge, and planned the technical details of how to execute the change.[16]

To see the importance of collusive pricing to standardization, now suppose service is competed. We can add symmetric railroads R3 and R4, which compete against R1 and R2 to provide service to D_2, through a different intermediate point D_3 as illustrated in Figure 5.

Consider shipments to D_2 (the only route on which the carriers compete), and let $Q_{R_{12}}$ and $Q_{R_{34}}$ be the quantity (in tons) carried by R1-R2 and R3-R4, but now let

$$Q_i(P, B) = M - \lambda B_i - aP_i \qquad \text{for} \quad i, j \in \{R_{12}, R_{34}\}$$

Figure 5. Example Shipment Paths from North to South with Two Routings



where B_i indicates the presence of a gauge break on i, λ is the direct effect of breaks on demand, and the other parameters are defined as before. As long as they are on the same gauge, shipment to via R1-R2 and R3-R4 is undifferentiated, demand will go to the lower-priced routing, and prices will be competed to marginal cost (as they often were throughout this era in the absence of collusion, e.g., Kolko 1965, Chandler 1977). If both R1-R2 and R3-R4 standardize, the per-ton cost savings (θ) will be passed through, leaving the firms with no means of recovering the fixed cost of changing the gauge (C). As a result, collective standardization is not an equilibrium outcome. If instead the carriers collude and set prices jointly, the Proposition 2 establishes that collective standardization can be an equilibrium outcome with mild regularity conditions.

Proposition 2. *Collective standardization is only an equilibrium outcome with collusion.*

4.2. Effects of Standardization Under Collusion

The results thus far have demonstrated two ways in which collusion may have facilitated the gauge change, via coordination and incentives. However, collusion may have also tempered the effects on prices and total shipments if it limited pass-through, relative to what the effects would have been in a competitive environment. Even if the gauge change would have been less likely in a competitive market, this counterfactual offers a comparative benchmark. Can we explain the absence of a significant effect on prices or total quantities in the data with collusion?

To explore this question, we can continue to focus on a single route between an arbitrary Northern origin and Southern destination, as earlier, but enrich the model and now assume that rather than being served by two railroads, it is served by a railroad and a steamship (these can be interpreted as vertically integrated all-rail versus steamship-to-rail, and are differentiated). Let Q_R and Q_S represent the quantity carried by railroad and by steamship, with

$$Q_i(\mathbf{P}, \mathbf{B}) = M - \lambda B_i + \lambda B_j - aP_i + bP_j \qquad \text{for } i, j \in \{R, S\},\ i \neq j,$$

where B_i indicates the presence of a break on mode i (breaks in gauge for all-rail/intermediate ports requiring transshipment for steamships); λ is the direct effect of these breaks on demand, and can be interpreted as a quality parameter; a and b are own- and cross-price effects on demand, with $a > b > 0$; and M is the market size, which henceforth will be normalized to $M = 1$. Each mode's demand is thus a function of own price and quality and the other mode's price and quality. As written, breaks in gauge have offsetting direct effects on demand ($\pm\lambda$), such that market shares are sensitive to service quality, but total shipments are not—a feature that is necessary but not sufficient in explaining the earlier empirical patterns, as prices will also be endogenous to breaks in gauge and can shift aggregate demand independently of quality.

Suppose both modes have common per-ton marginal costs c, and an incremental per-ton cost of θ incurred at breaks, where transshipment or interchange is required. If the two carriers collude, they set a single price P that applies to both carriers to maximize joint profits, whereas if they compete, they set prices P_R and P_S to maximize individual profits. With this simple model, we can explore the potential effects of the gauge change on prices and shipments with competition versus collusion. We begin by comparing collusive prices and quantities pre-gauge change ($B_R = B_S = 1$) versus post-gauge change ($B_R = 0,\ B_S = 1$). Joint profits under collusion are

$$\Pi(\mathbf{P}, \mathbf{B}) = (P - c)(Q_R + Q_S) - \theta(B_R Q_R + B_S Q_S).$$

Proposition 3 establishes that in this setting, standardization should generate a reduction in the collusive price of a relatively low (but nonzero) fraction of the cost savings, modestly increase total shipments, and shift market share to the all-rail carrier. An immediate corollary is that there are two conditions under which prices and total shipments may not be affected by the gauge change, even as market share shifts across the two modes: (i) if $\theta = 0$, such that transshipment and interchange were actually costless, or (ii) if there is a transaction cost to cartel price changes, and this cost exceeds the incremental profits that the carriers would realize by adjusting prices after standardizing the gauge. In the first case, breaks in gauge enter demand but not supply costs. The elimination of the gauge break will increase demand for all-rail shipping and generate an offsetting reduction in demand for steamships, and these effects in turn offset in the price-setting problem, such that the profit-maximizing cartel price is unchanged. In the latter case, small price adjustments may be too costly to justify, due to uncertainty or disagreement among cartel members over such changes and the previously discussed difficulty of renegotiation.

Proposition 3 (Effects of Standardization on Collusive Price and Quantities). *Eliminating the break in gauge reduces the collusive price by $\frac{1}{4}\theta$, redistributes market share from steamships to all-rail, and increases total shipments by $\frac{1}{2}\theta(a - b)$.*

Corollary 1. *Conditions under which prices and total quantity may not change include:*

i. *If $\theta = 0$, the collusive price and total shipments are unaffected by removing the break in gauge.*

ii. *If $\theta > 0$, and collusive prices and quantities do not adjust after removing the break in gauge, the cost of price adjustments must be greater than the foregone profits, $\frac{1}{8}\theta^2(a - b)$.*

4.3. Effects of Standardization in Differentiated Oligopoly

For comparison, we can evaluate the effects of the gauge change on prices, market shares, and total shipments when the two carriers compete on prices. We will consider the same route, but we now permit that the two carriers set their respective prices P_R and P_S individually and competitively in equilibrium. Each carrier's profits are thus

$$\Pi_i(\mathbf{P}, \mathbf{B}) = (P_i - c)Q_i - \theta B_i Q_i \quad \text{for} \quad i \in \{R, S\}.$$

In this setting, the conversion to standard gauge has an ambiguous effect on the all-rail price, with upward pressure from increased demand and downward pressure from the reduction in costs. Steamship prices, however, unambiguously decline, due to their relative drop in demand. Substitution across modes still takes place, as in the collusive scenario, but more notably, total shipments will increase by more than they do in the collusive environment.

Proposition 4 (Effects of Standardization in a Competitive Market). *Eliminating the break in gauge has an ambiguous effect on the all-rail price, depending on the size of a demand effect, which puts upward pressure on the all-rail price, and the pass-through of cost savings, which puts downward pressure. Steamship prices strictly decline, market share shifts from steamships to all-rail, and total shipments increase by $\frac{a\theta(a-b)}{2a-b}$.*

Corollary 2 (Comparing the Effects by Market Structure). *Standardization generates a larger increase in total shipments under competition than collusion.*

4.4. Discussion

This simple model can explain both the effect of the gauge change on mode shares and the absence of an effect on prices and total shipments, while demonstrating that price competition may have increased pass-through but would have also made the gauge change less likely. However, the two explanations proposed for why cartel prices might not adjust—that adjustments were costly, and that breaks in gauge were not actually costly—warrant further attention.

Ample evidence from cartel records (especially minutes from rate committee meetings) suggests that price changes were relatively difficult. Rate-setting was contentious, requiring unanimous agreement of representatives from cartel members who almost always deadlocked. When rate cases then escalated to the cartel's internal board of arbitrators, which could issue a ruling by simple majority, these arbitrators often declined changes too (see Section 3).

Likewise, the historical evidence suggests that transshipment and interchange were also costly. The most reliable measures of railroads' direct costs from breaks in gauge are accounting costs, which can be obtained from annual reports. For example, the Cincinnati, New Orleans & Texas Pacific (CNO&TP, which was an SRSA member and participated in the gauge change) reported its direct expense for breaks in gauge to be $32,365 in 1884 and $33,355 in 1885, or 350% and 21% of the railroad's net income in each of these years ($9,210 and $159,011, respectively), with roughly half this cost attributed to the operation of steam hoists, and the other half to the payroll of transfer clerks and laborers (Cincinnati, New Orleans & Texas Pacific 1884, 1885, 1886). The CNO&TP's annual reports further note that these figures do not include the indirect costs of "extra switching engines, extra yard crews, and no allowance is made for the loss . . . from delay to business" or for the opportunity cost of "freight thereby diverted" because its tracks are "blocked with loaded cars waiting their turn" (Cincinnati, New Orleans & Texas Pacific 1884, p. 13) nor do they account for the other ancillary costs discussed in Section 1, such that the accounting cost is understated. Transshipment at port was similarly costly. Although data from the 1880s are not available, in 1908, the transfer expense for freight transshipped from coastal steamships to the Georgia Railway (a former SRSA member) at Savannah, Georgia was 8 cents per hundred pounds for merchandise and 5 cents for commodities, which is on the order of 10%–20% of the lowest merchandise and commodity rates for the routes in this paper, and rates for other Southern ports and other Southern railroads connecting to them were "practically the same" (U.S. Department of Commerce and Labor 1910, p. 312).

Collectively, the evidence thus supports attributing the price rigidity seen in Section 3 to a combination of collusion (which dampened pass-through) and costly price adjustment (which impeded any residual changes), rather than to breaks in gauge not actually having been a material cost to carriers, which is further contradicted by their revealed preference for standardizing the gauge. In the absence of prices changes, total shipments were also unaffected.

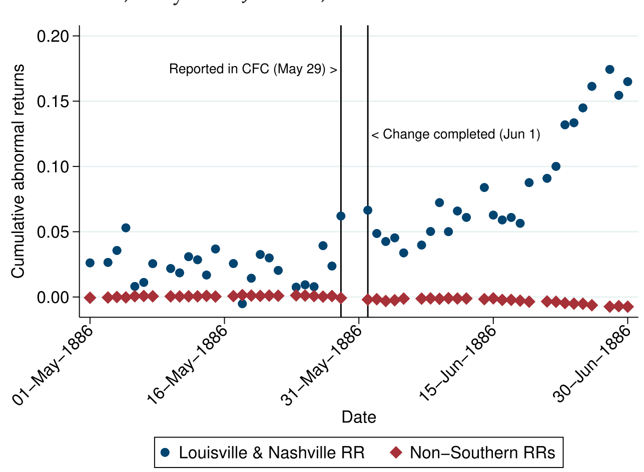
5. The View from Wall Street

Taken together, the results in Sections 3 and 4 suggest the gauge change might have generated a windfall for Southern railroads (which reduced costs and gained share), at the expense of steamship operators (which lost share), with only limited benefits to consumers (as prices and total shipments were evidently unaffected). Although data for studying the impact of the gauge change on consumers is constrained to what is available in cartel records, our understanding of the impact on carriers can be rounded out by studying their stock prices.

To do so, I collected daily New York Stock Exchange (NYSE) closing prices from historical editions of the *New York Times* for January 1 to October 31, 1886. The vast majority of traded securities at this time were issued by railroads (146 of 177, including preferred stock), and a dozen Southern railroads were traded during this period. Using these data, we can perform an event study on railroad stock prices around the gauge change.[17] Although some information about the impending conversion was provided in annual reports, Southern newspapers, and specialized railroad journals (see online Appendix C), the event itself was uncertain until the date drew closer, and its effects could only be known ex post. The gauge change appears to have not been a focus of the financial press until May 29, when the *Commercial and Financial Chronicle* (CFC) published a lengthy article notifying readers of the imminent event and explaining its importance.

I define an event window of two months around the gauge change (May 1, 1886 to June 30), estimate a standard market returns model on the preceding four months of railroad stock returns (through April 30,

Figure 6. (Color online) Cumulative Abnormal Returns to L&N Stock, May 1 to June 30, 1886



Notes. The figure shows cumulative abnormal returns to the stock of the L&N Railroad, the largest railroad in the South by mileage and one of two that directly connected the South to other regions and were listed on the NYSE, in a two-month window around the gauge change. The figure marks two key dates around the gauge change: May 29, when the event was first announced and discussed at length in the *Commercial and Financial Chronicle*; and June 1, when the change was completed. See text for additional discussion. Data from *New York Times* historical stock quote tables.

1886), predict returns through the event window, and compute cumulative abnormal returns for each of the Southern railroads. Throughout the exercise, I restrict the sample to securities with at least 50 trading days in the estimation window and 100 trading days in the full sample to ensure that all estimates and tests are sufficiently powered, although the results are not sensitive to the precise restriction imposed.

The gauge change coincides with large, positive abnormal returns to the Southern railroads that were most directly affected. Figure 6 shows the cumulative abnormal returns to the Louisville & Nashville (L&N), the largest railroad in the South by mileage and one of two that directly connected the South to other regions and were listed on the NYSE. The L&N's cumulative abnormal returns are near zero and roughly constant until May 29 (the date that the CFC article was published), when it realized a four percentage point positive abnormal return. Between May 29 and the end of the event window, the cumulative abnormal returns grew to 17 percentage points, as the impacts of the gauge change began to materialize. I find similar (albeit slightly higher variance) patterns for the Richmond & Danville, another major system spanning the Southern border, but no such effects for interior Southern railroads, suggesting that investors believed the benefits were mainly realized by the lines where breaks in gauge were once located.

The magnitude of the cumulative abnormal returns to the L&N through the end of June suggests that the gauge change had a substantive financial impact on the affected railroads, and paired with earlier evidence that prices and overall quantities did not change, it suggests most of the benefits of the gauge change were appropriated by these carriers.

6. Implications and Conclusion

In summary, I find that the gauge change generated significant growth in all-rail market share that declines with route distance, but it did not affect prices or total shipments. To explain these results, I use theory to argue that the presence of the cartel may have enabled the gauge change to take place as it did, while likely also tempering the effects on prices and total shipments. The theory indicates that prices and total shipments may not be affected by standardization if either cartel price adjustments are sufficiently costly, or if interchange is in fact costless. Contemporary evidence appears to favor the former, as cartel meeting minutes document contentious debate around price changes, whereas railroads' annual reports demonstrate that the costs of servicing breaks in gauge were large enough to make an otherwise profitable railroad unprofitable, and evidence from stock market returns indicates that investors perceived a windfall.

These results bring into focus a nuanced interaction of interoperability and product market competition. Although antitrust scholars and regulators have traditionally been more concerned with standards-setting efforts by competitors being a bridge to product market collusion, in this paper, it appears that collusion instead contributed to standards adoption—but with some of the classical downstream consequences. The tension between the two (effectively, between value creation and consumer welfare) can arise in any setting with strategic complementarities, but it may be particularly liable to occur in networked settings, where transactions are executed through intermediaries that interconnect for delivery, and the technological complementarities are therefore large, such as freight carriers (for physical trade), Internet service providers (communications), or financial exchanges (asset purchases). This tension is underappreciated in the academic literature but ripe for attention, especially since firms in many network industries not only benefit from interoperability but also have a natural tendency toward concentration.

The results also contribute to the largely theoretical academic literature on technological compatibility. Compatibility standards can be found in nearly every technical product and industry, but to date there is limited evidence directly linking them to firms' or market outcomes. In unveiling the ways in which the Southern gauge change affected the market for freight shipment, this paper provides a historical data point on the effects of compatibility on transactions and has implications for other settings where traffic is exchanged across connecting, incompatible networks, such as those identified earlier. With archival data becoming increasingly accessible, historical settings such as the early U.S. telephone and railroad industries present a growing opportunity for future research on network connection, compatibility, and related themes.

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Endnotes

[1] History offers other such examples. For example, in the 1920s, seven major international light bulb manufacturers colluded to divide national markets and limit the working life of light bulbs, increasing both sales and margins at the expense of consumers. But the so-called "Phoebus cartel" also served as a venue for manufacturers to exchange technical knowhow and implement standards. One by-product of the cartel, for example, was the standardization of screw-in light bulbs and sockets, which persists to this day (Krajewski 2014).

[2] Seminal contributions include Farrell and Saloner (1985, 1986, 1988, 1992), Katz and Shapiro (1985, 1986), Matutes and Regibeau (1988, 1992), and Economides (1989). See David and Greenstein (1990), Katz and Shapiro (1994), and Besen and Farrell (1994) for early reviews. Subsequent research has studied interconnection and compatibility in a wide range of settings, including electric power supply (David and Bunn 1988), U.S. telephone service (e.g., Mueller 1997), ATM networks (e.g., Knittel and Stango 2008), and more.

[3] 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 feet, 8.5 inches) for its speed, stability, and carrying capacity (Puffert 2009).

[4] Over this same period, physical gaps in the network were also being closed by cross-town connections between depots (e.g., Richmond in 1867) and bridges over the major rivers (e.g., the Ohio River at Louisville in 1868 and Cincinnati in 1877), such that differences in gauge were the primary obstacle to a physically integrated network.

[5] The SRSA both preceded and was the model for future railroad cartels, including the Joint Executive Committee, which governed railroads running between the Midwest and East Coast and has been widely studied in the economics literature (e.g., Ulen 1979, Porter 1983, Ellison 1994, and others). Though the SRSA has received less attention, contemporaries claimed that it "came nearer to fulfilling the purposes for which it was intended than any other association ever formed for the regulation of competition in this country" (Haines 1905, p. 215).

[6] The act had little impact in its early years, and if anything may have empowered carriers and helped stabilized prices (Prager 1989, Blonigen and Cristea 2013), consistent with the revisionist interpretation of Kolko (1965), who notes that railroads welcomed the regulation. Other sources suggest that the content of the ICA, and the Interstate Commerce Commission it created, were subject to near-total regulatory capture.

[7] The 4 foot, 9 inch gauge was chosen to match that of the Pennsylvania Railroad, an important connection in the Mid-Atlantic, and because it was thought that the smaller adjustment would reduce the cost of converting rolling stock (Puffert 2009), but it was understood to be compatible with the 4 foot, 8.5 inch standard (Puffert 2009). As Taylor and Neu (1956) write, "such a deviation was not considered a serious obstacle to through shipment" (p. 11).

[8] The execution of the gauge change is covered in greater depth by several other sources (e.g., Hudson 1887, Taylor and Neu 1956, Puffert 2009). Extrapolating from the costs of converting the L&N (detailed in its 1886 annual report (Louisville & Nashville Railroad Co. 1886)) to all 5 foot, 0 inch mileage, the total cost of the gauge change was likely at least \$1.2 million in 1886, equivalent to \$31 million today, but another, smaller Southern railroad (the CNO&TP) spent nearly twice as much per mile. To put the cost in perspective, the L&N's expenditure on the gauge change was 30% of its construction expense in 1886 and 37% of net income, and the CNO&TP's expenditure was roughly 1.6 times the previous annual direct cost of its breaks in gauge.

[9] Route-level traffic data (both freight and passenger) from this period are rare. Data on the routes in this paper are available only because they were compiled into tables, which were circulated to SRSA members, by order of the cartel's commissioner, and later bound and preserved. Despite an extended effort, I have been unable to find comparable data for other routes to supplement those studied here, nor to find data to study earlier conversions, such as those by the Illinois Central or Mobile & Ohio, which were not members of the cartel.

[10] Cotton shipments in the reverse direction comprise a smaller sample, were dwindling over the period due to growth in Southern textile production, and could potentially be influenced by fluctuations in foreign demand, and are thus excluded. Shipments of merchandise and commodities from the Midwest are also excluded, as they grew rapidly over the decade and only became part of the collusive agreement (and thus, had their traffic monitored and recorded) beginning in 1887, subsequent to the gauge change (Hudson 1890).

[11] 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.

[12] In columns (5) and (6), all residual variation is between modes, and the steamship coefficients drop out of the regression (being absorbed by the fixed effects). The all-rail coefficients in these columns are comparable to the difference between all-rail and steamship coefficients in the previous columns.

[13] In unreported analysis, I also verify that the estimates in Table 3 are consistent with on average a net zero effect on total shipments, and one that does not vary with route length. To do so, I begin with the true (observed) log shipments for each route-mode-year in the pre-gauge change sample, apply the estimates from column (1) of Table 3 to calculate (linearly-projected) counterfactual log quantities with standardized gauge, exponentiate to levels, aggregate up to observed and counterfactual total quantities for route-years, and calculate the difference between them, as a measure of the implied "aggregate effect" of the gauge change at the route level. The average difference is 0.5% of observed values (25th percentile –5.4%, 75th percentile 7.0%), and more importantly, consistent with the results in Table 6, this difference is uncorrelated with route length ($\rho = 0.07$).

[14] Cartel prices were not always this stable. 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 onward, and shows that rate reductions occurred every one to two years until 1884, after which rates went unchanged).

[15] The size of the downstream market ensures that $\Delta\pi_{R1}^{10} < \Delta\pi_{R2}^{11}$ (see Online Appendix E). The independent conversions of the Illinois Central and the Mobile & Ohio can be explained in this model as a violation of this assumption, where $\Delta\pi_{R1}^{10} > C$, meaning that it was profitable to convert to standard gauge alone. This can be the case if, for example, the markets that these lines directly served were sufficiently large.

[16] It is worth noting that this proposition is in part a function of the static nature of the game. With multiple periods and sufficiently patient players, one party might be able to standardize at a short-run cost but realize long-run profits if its neighbors are then incentivized to follow. Indeed, the history (of other railroads) in Section 1

suggests that standardization of Southern railroads' gauge might have nevertheless eventually taken place in the absence of collusion, albeit perhaps not as early, as quickly, or at the same scale.

[17] Note that this exercise is limited to railroads, as no steamship companies were traded on the NYSE at the time. The results are also limited to stock price changes and cannot be extended to measure changes in market capitalization (or other measures of value), because the number of outstanding shares is not observed.

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