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

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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.

**JEL Classification:** F14, F15, L15, L41, L92, N71

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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' 0'' to 4' 9'' 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 U.S. 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' 8.5'' "standard" gauge – except for those in the South. Data from the Poor's Manual of Railroads 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' 0'' "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' 9'' 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 re-negotiation 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

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[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 know-how 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 (IEEE 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.

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 it offers a venue for firms to coordinate their product market decisions with a lower risk of detection, under the cover of standards setting (U.S. DOJ and FTC 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, Li 2019, Basker and Simcoe 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 but also tempered its effects on prices and shipments, with a view towards 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), 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 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 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 shows the state of U.S. railroads east of the Mississippi River at this time, identifying lines with 4'8.5'' (“standard” gauge), 5'0'' (“Southern” gauge), and other track widths.

[Figure 1 about here]

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 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 of tipping on curves. The true cost of incompatibility was thus considerably higher than the physical act of interchange alone (McHenry 1875).

After the Civil War (1861-1865), several pressures coincided to induce private efforts towards 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), 4'8.5'' 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

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[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 (4'8.5'') for its speed, stability, and carrying capacity (Puffert 2009).

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.[4]

## 1.1 The Southern Railway & 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 (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. 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) – 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). 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

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[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).

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 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. 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).[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), and the total cost of delays were growing one-for-one with volume. The first cracks in the 5'0'' 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

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[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.

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' 9'', 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'' 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.[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. 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' 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.

[Table 1 about here]

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, regional

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[7] The 4' 9'' 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' 8.5'' standard (Puffert 2009); as Taylor and Neu (1956) write, "such a deviation was not considered a serious obstacle to through shipment."

[8] The execution of the gauge change is covered in greater depth by several other sources (e.g., Hudson 1887, Taylor and Neu 1956, and Puffert 2009). Extrapolating from the costs of converting the Louisville & Nashville (detailed in its 1886 annual report) to all 5' 0'' 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 Cincinnati, New Orleans, & Texas Pacific) 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.

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 non-competitive 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 which 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 Interior 1883).[10] The sample throughout the paper is a balanced panel of 52 North-South routes (4 origins x 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. Appendix Figure A.2 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 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 (= $52 \cdot 3 \cdot 7$) observations at the route-mode-year level.[11]

The analysis begins with a simple comparison of all-rail and steamship traffic within individual

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[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 below, 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.

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:

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

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 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 above specification 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 $\gamma_{mr}$ and $\delta_{rt}$:

$$\begin{aligned}u_{imrt} = \big[&\beta_0 Rail_m + \beta_1 Rail_m Post_t + \beta_2 Rail_m Post_t Dist_r \\ &+ \gamma_{mr} + \delta_{rt} + \xi_{mrt}\big] + \eta_{imrt} \ \equiv \ \mu_{mrt} + \eta_{imrt} \ ,\end{aligned}$$

where $\eta_{imrt}$ 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 reduce to:

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

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:

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

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 one percent 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 below: 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.

[Table 2 about here]

## 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) through (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 to 4), or alternatively, when comparisons are within route-years, the mode difference-in-differences (Columns 5 and 6).[12]

[Table 3 about here]

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).

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[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.

[Table 4 about here]

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.

[Table 5 about here]

The results continue to show positive effects on all-rail shares that decline with distance, significant beyond the one percent 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 ACL and PAL, they are again larger for the less-trafficked ACL, consistent with previous results.

In 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 (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 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 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]

[Table 6 about here]

### 3.2.3 Other Views of the Data

We can also break these regressions out into annual effects, to test for pre-trends 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.

[Figure 2 about here]

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 non-obvious, given contemporary use of adapter technologies. But juxtaposed against this result,

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[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 ($\rho = 0.07$).

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 to 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-Montgomery and Philadelphia-Selma.[14]

[Figure 3 about here]

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.

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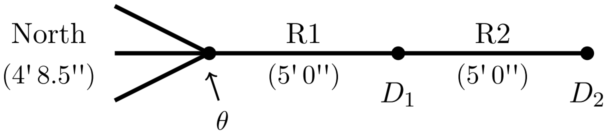
[14] Cartel prices were not always this stable: until the early 1880s, prices were reduced regularly, under pressures of competition from alternative routing outside the scope of the cartel. Multiple sources have documented this decline, while also observing that price reductions ended in the early- 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 1-2 years until 1884, after which rates went 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 Appendix E.

# 4 Compatibility and Collusion

## 4.1 Incentives for standardization

Suppose that to get from a Northern origin on the 4' 8.5'' network to a Southern destination on the 5' 0'' 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 $\theta$ per ton for interchange at the border, as illustrated in the inset below:



Annual shipments (e.g., tonnage) to destination $d$ can be written $Q(P_d) = M_d - aP_d$, 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 $\ell_1$ and R2's is $\ell_2$, 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 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 $c \equiv c_1$ 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. 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 $\Pi_d$ 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 $\theta$). 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 $C$:*

*a. If R1 converts alone:* $\Delta\pi_{R1}^{10} > 0$, $\Delta\pi_{R2}^{10} = 0$

*b. If R2 converts alone:* $\Delta\pi_{R1}^{01} < 0$, $\Delta\pi_{R2}^{01} < 0$

*c. 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 it 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).

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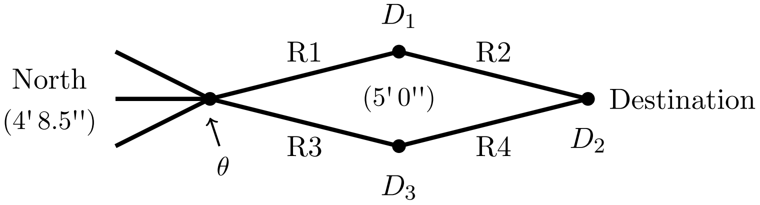
[15] The size of the downstream market ensures that $\Delta\pi_{R1}^{10} < \Delta\pi_{R2}^{11}$ (see Appendix E). The independent conversions of the Illinois Central and the Mobile & Ohio can be explained in this model as a violation of this assumption, where $\Delta\pi_{R1}^{10} > C$ – meaning that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

**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 below:



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:

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

where $B_i$ indicates the presence of a gauge break on $i$, $\lambda$ 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. Chandler 1977, Kolko 1965). If both R1-R2 and R3-R4 standardize, the per-ton cost savings ($\theta$) 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

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[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.

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 above, 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:

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

where $B_i$ indicates the presence of a break on mode $i$ (breaks in gauge for all-rail / intermediate ports requiring transshipment for steamships); $\lambda$ 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 which 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 $\theta$ incurred at breaks, where transshipment or interchange is required. If the two carriers collude, they set a single price $P$ which 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 re-negotiation.

**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 3.1.** ***Conditions under which prices and total quantity may not change***
*(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 4.1.** ***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. 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," 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 1910).

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 collect 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 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, 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 4 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 is published – when it realized a 4 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.

[Figure 4 about here]

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.

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[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.

# 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 towards 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 datapoint on the effects of compatibility on transactions and has implications for other settings where traffic is exchanged across connecting, incompatible networks, such as the those identified above. 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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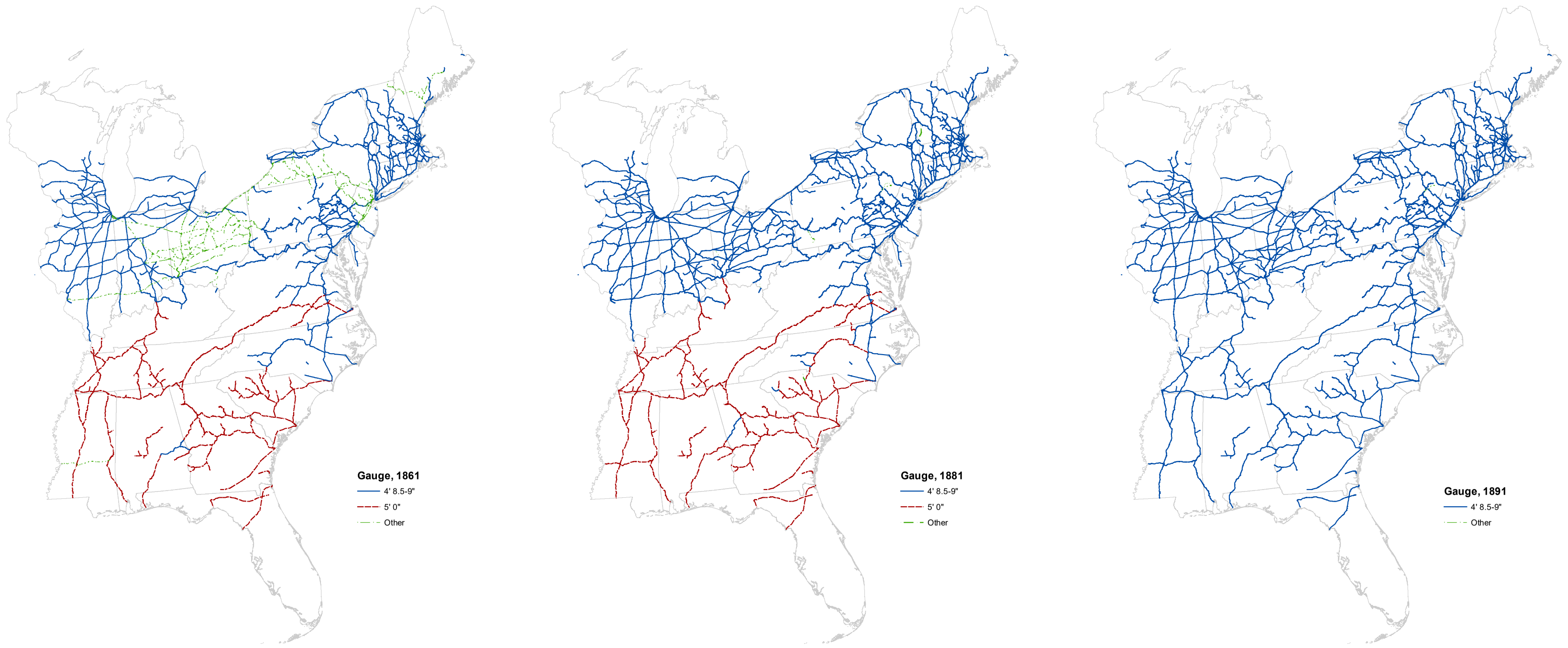
Figure 1: Installed Railroad Gauge East of the Mississippi River, 1861–1891 (holding network fixed)

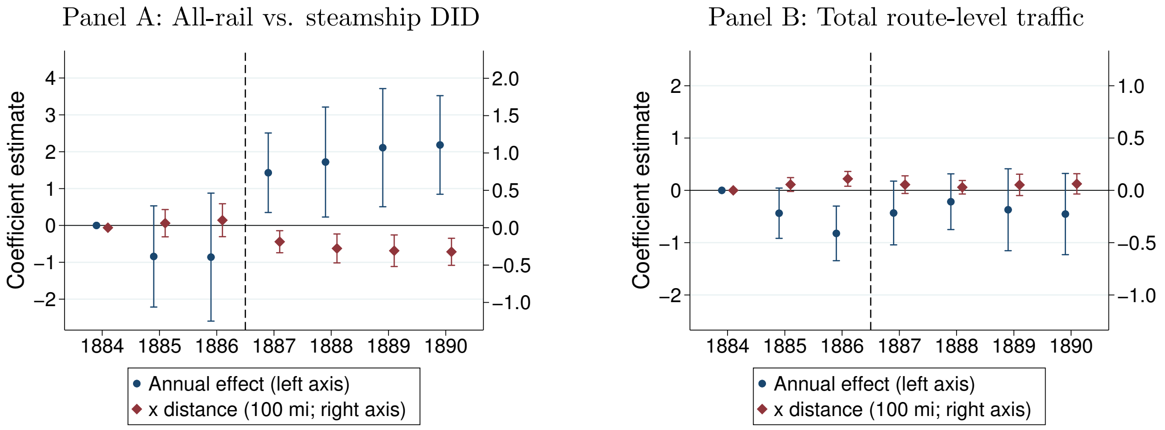

Panel (A)
Baseline: 1861 Railroad Network

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

Panel (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: 4'8.5-9''; red dashed line: 5'0''; 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. 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: Changes in All-rail vs. Steamship Traffic and Total Traffic over Time


Panel A: All-rail vs. steamship DID

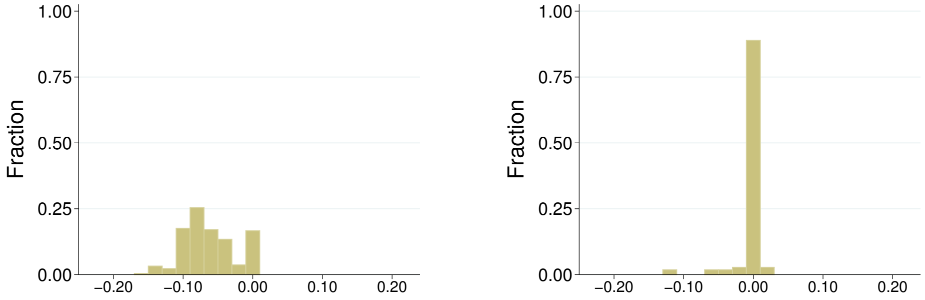
Panel B: Total route-level traffic

Notes: Figure shows the estimated changes in all-rail vs. 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 (in blue), and triple-interacted with route length (in red). 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). SEs clustered by route and 95% confidence intervals provided around each point estimate.

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

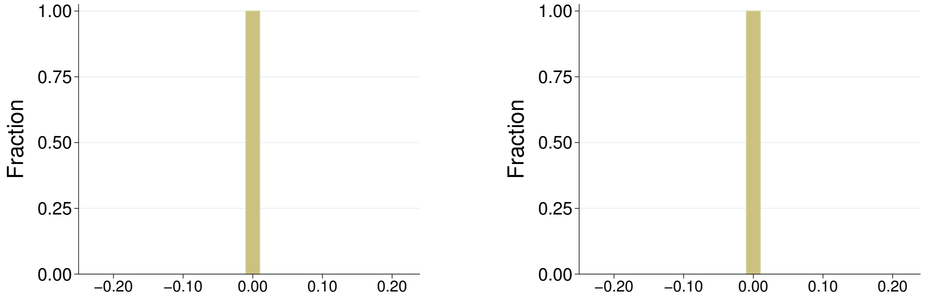
Panel A:
Jul. 1883 to Apr. 1884

Panel B:
Apr. 1884 to Feb. 1885

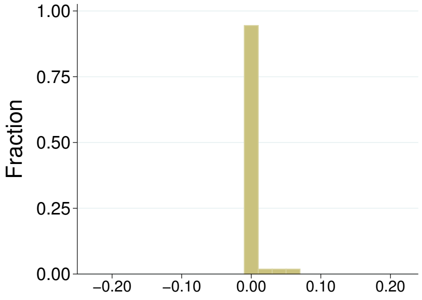


Panel C:
Feb. 1885 to Jul. 1885

Panel D:
Jul. 1885 to Mar. 1886



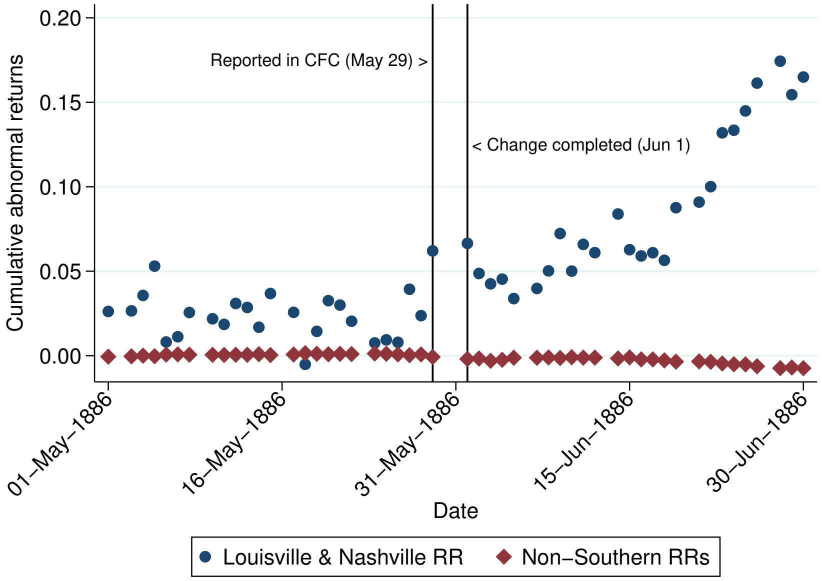
Panel E:
Mar. 1886 (pre-gauge change) to Jul. 1887 (post-change)



Pct. change in freight rates, across routes and class of merchandise

Notes: 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 SRSA Circular Letters, Volumes 13-24.

Figure 4: Cumulative Abnormal Returns to L&N Stock, May 1 to June 30, 1886



Notes: Figure shows cumulative abnormal returns to the stock of the Louisville & Nashville 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.

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

| | | **Pre-Gauge Change** | | | **Post-Gauge Change** | |
|---|---|---|---|---|---|---|
| | | **1881** | **1883** | **1885** | **1887** | **1889** |
| **New England** | 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** | 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** | 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)** | 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** | 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 and fraction in standard-compatible 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.

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

| | **Short Routes (<25th pctile)** | | **Long Routes (>75th pctile)** | |
|---|---|---|---|---|
| | **Pre** | **Post** | **Pre** | **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.

Table 3: Change in All-Rail Traffic

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| All-rail x 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 x 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 | 1036 | 1036 | 1036 | 1036 | 1036 | 1036 |
| $R^2$ | 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-yr 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) to (4) should be interpreted as mode-specific changes relative to the pre-period; those in Columns (5) and (6) as differences-in-differences due to the route-year FEs. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

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

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| A.C.L. x 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) |
| P.A.L. x 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 x 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 | 1036 | 1036 | 1036 | 1036 | 1036 | 1036 |
| $R^2$ | 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-yr 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) to (4) should be interpreted as mode-specific changes relative to the pre-period; those in Columns (5) and (6) as differences-in-differences due to the route-year FEs. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

Table 5: 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) |
| 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 on shorter versus longer routes. 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 6: 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 quantities; in Columns (3) to (4), log revenue. *, **, *** represent significance at the 0.1, 0.05, and 0.01 levels, respectively. SEs clustered by route in parentheses.

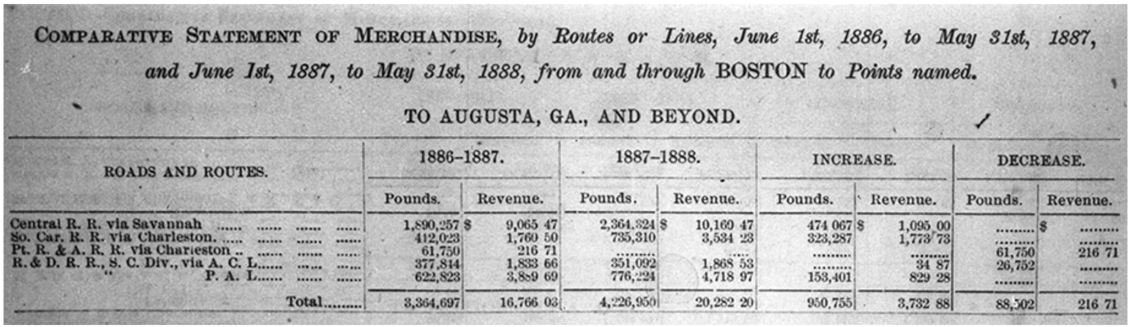
# Web Appendix

# A Data Appendix

This paper draws on several sources of data, most importantly the SRSA records of freight traffic on the set of routes apportioned, monitored, and reported to cartel members. As the paper explains, the SRSA collected daily data on the traffic and revenue of carriers on any route where at least one member requested apportionment, compiled these data into monthly and annual totals, and then circulated the data for select routes to cartel members. These tables, as well as other SRSA circulars, were organized 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 other destinations, origins, and years, although in most cases a table shows 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

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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.

1884 (3). I then impute June 1883 to May 1884 traffic as (2)-(1)+(3).

The primary sample in the paper contains 52 routes, with 4 Northern origins and 13 Southern destinations. Table A.1 lists the origins and destinations in this sample (also mapped in Figure A.2). To make clear how all-rail freight reached Southern interior cities, Figure A.3 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 are 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.

Table A.1: Origins and Destinations for Sampled Routes

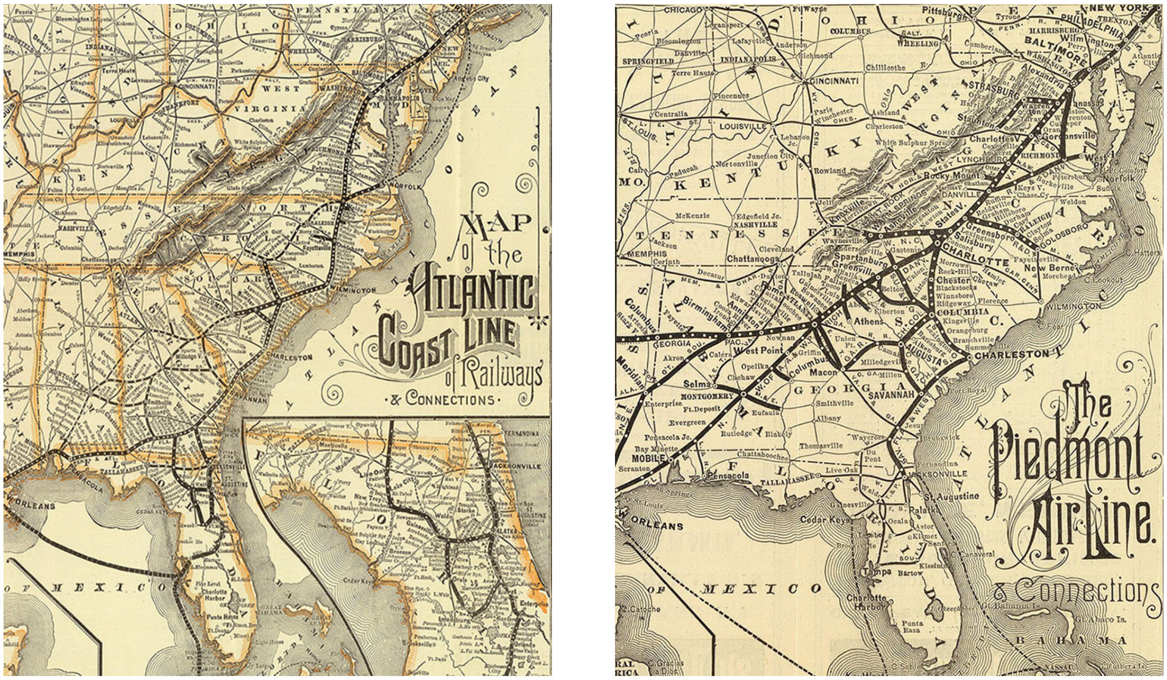
| **Destinations (south)** | | **Origins (north)** | |
|---|---|---|---|
| Albany | GA | Boston | MA |
| Athens | GA | New York | NY |
| Atlanta | GA | Philadelphia | PA |
| Augusta | GA | Baltimore | MD |
| Macon | GA | | |
| Milledgeville | GA | | |
| Newnan | GA | | |
| Rome | GA | | |
| Montgomery | 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.

Figure A.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. Not shown are two additional destinations in the data, "A. & W. Pt. Stations" (stations on the Atlanta and West Point Railroad between East Point and West Point, GA, 70 mi., whose traffic was reported collectively), and "W. & A. Stations" (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. 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 A.3: All-Rail Paths connecting North and South ca. 1885



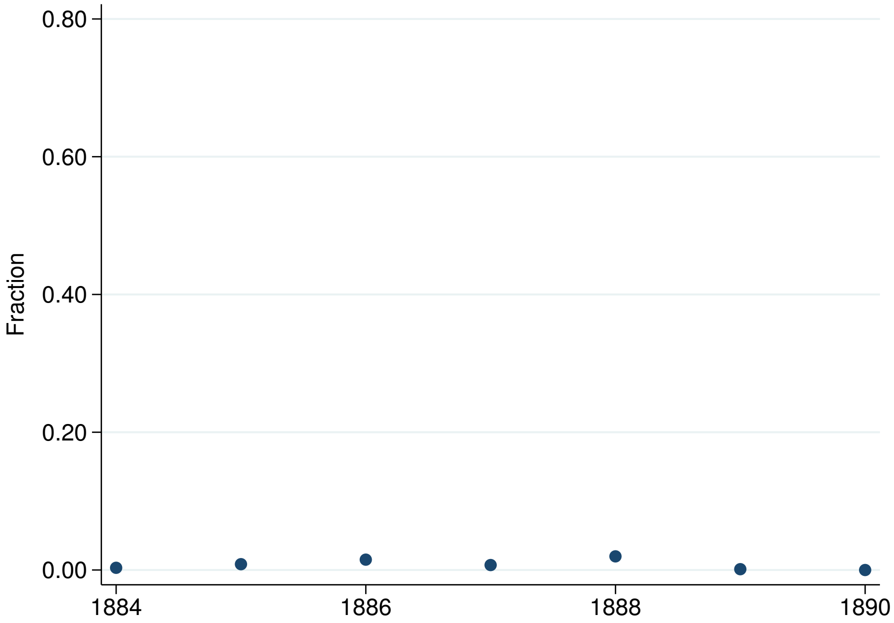
Panel A: Atlantic Coast Line (A.C.L.)

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.4 shows, little is lost: the omitted shipments on average comprise 0.8% of traffic in any given year.

Figure A.4: 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.2 shows, straight-line distance is a roughly fixed proportion (85%) of the point-to-point track length between origin and destination.

Table A.2: 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.3 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.3: 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 A.1 for a list of origins and destinations, and Figure A.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, 1884, 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 extend 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.

To perform the stock price event study in Section 5, I have also collected daily stock prices from the *New York Times* for stocks traded on the New York Stock Exchange between January 1 and October 31, 1886. The stock quote tables in the *New York Times* report opening, closing, high, and low prices and estimated trading volume for stocks traded each trading day. Stocks that did not trade on a given day are not reported in the daily stock quote table, and I treat their price as unchanged from their previous trading day.

## 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, although there were exceptions in the form of "arbitrary divisions", which often applied to the use of bridges or terminals, compensated carriers for a shipment's fixed costs such as loading and unloading, and were allocated before the remaining revenue was prorated (Haines 1905). It is unclear whether arbitraries were used to compensate carriers for the cost of breaks in gauge – and because joint rates came into use around the same time that the gauge was being standardized, no contemporary references to the precise question could be located.

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]

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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).

### 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 (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.

Information on the SRSA's vertical contracting arrangements is thin, but a few key details are available from the cartel's records. What is clear from these 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 yield no insight into what role Northern railroads played in price-setting. My understanding from cartel documents and later accounts is that the SRSA fundamentally controlled prices on shipments into and out of the South – in part due to its outsize influence over these routes, and in part because Southern traffic was relatively unimportant to Northern carriers in volume and value – and it is thus appropriate to model the SRSA as a price-setter.[5] The cartel's records also make clear that revenue division was negotiated outside of the cartel, and typically *pro rata*, following industry norms – such that revenue division is orthogonal to price-setting 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.

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[5] Total railroad tonnage in the New England, Mid-Atlantic, and Great Lakes regions was over 10x that in the South in 1880, and the difference in ton-miles even greater (U.S. Department of Interior 1883).

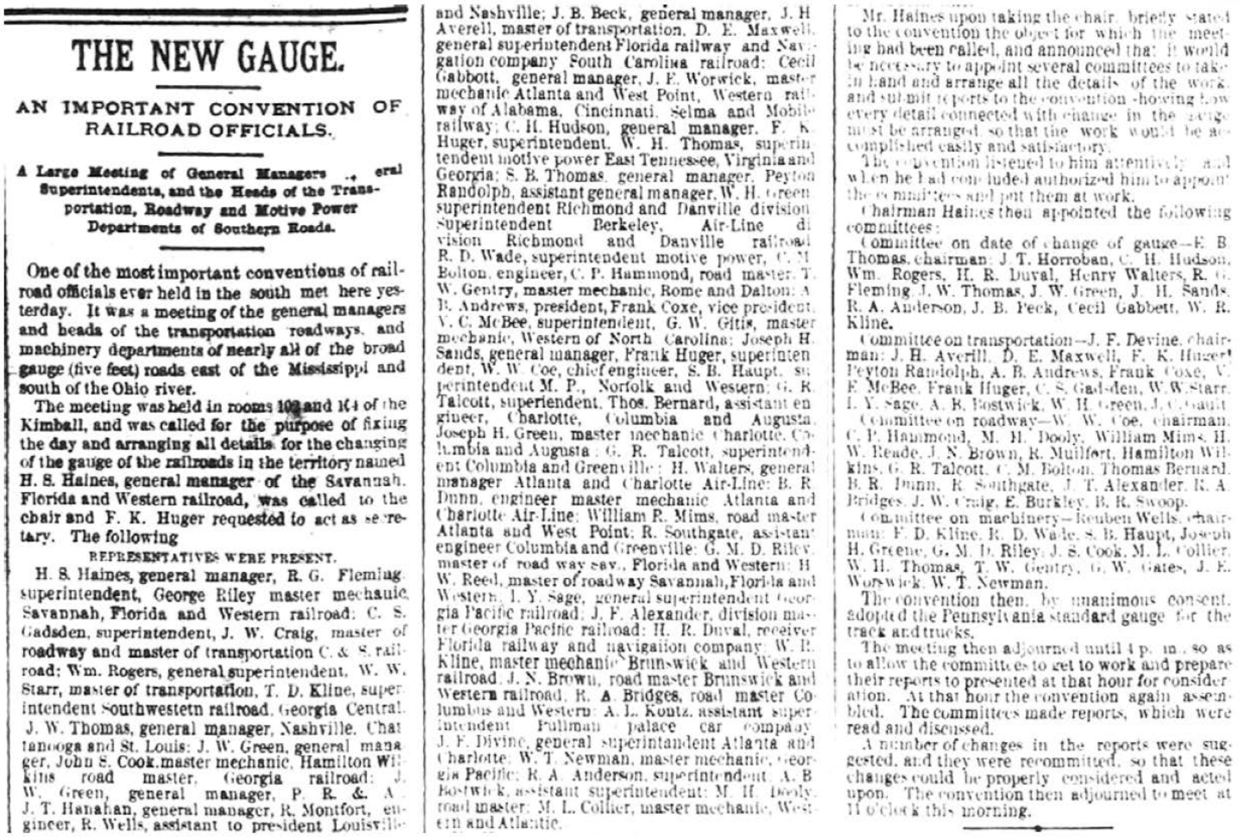
# C Contemporary Accounts of the Gauge Change

The gauge change received broad coverage in contemporary railroad periodicals and Southern newspapers. The *Atlanta Constitution* reported on the SRSA's gauge change convention as it was underway (Figure C.1), and the *Louisville Courier-Journal* reported several weeks later on the planning, preparations, and procedure for converting 13,000 miles of track in one day (Figure C.2). Though not widely covered in the North, the impending gauge change was nevertheless reported in a lengthy article in the *Commercial and Financial Chronicle* on May 29, where the paper acknowledges that "the matter is hardly attracting the attention it deserves," and the *New York Times* reported on May 31 that the Louisville and Nashville – the only Southern railroad of real importance to Northern shippers and investors – had completed its changeover that day, with no mention of the other railroads simultaneously converting to standard gauge (Figures C.3 and C.4).

Contemporary accounts were not limited to reporting on the mechanics of the gauge change: some newspapers speculated on the effects it might have, or was already having, on the Southern economy. For example, the *Wilmington Morning Star* wrote in April 1886 that to date, "very little lumber [goes] North by rail, for the reason that Southern roads [have] a different gauge from the Northern roads," and that "Southern lumber ports are bound to suffer a considerable loss of business" following the gauge change (Figure C.5) – a prediction consistent with this paper's results.

A year after the gauge change, in July 1887, *The Railroad Gazette* and other railroad journals published a detailed postmortem analysis (Figure C.6) – covering the history of Southern gauge and its "burden [on] both railroads and shippers," the SRSA's gauge change convention in February 1886 and the decision to convert to a 4′ 9′′ gauge on June 1, the plans and procedures for the day of the conversion and the months leading up to it, the engineering challenges, and even estimates of the aggregate expense of converting the rails and the rolling stock. For those interested, this article is the best source for understanding how 13,000 miles of railroad track could be converted to standard gauge in just 36 hours, and confirmation that it was.

Figure C.1: Report of the Gauge Change Convention (*Atlanta Constitution*, February 3, 1886)



# THE NEW GAUGE.

## AN IMPORTANT CONVENTION OF RAILROAD OFFICIALS.

### A Large Meeting of General Managers ., eral Superintendents, and the Heads of the Transportation, Roadway and Motive Power Departments of Southern Roads.

One of the most important conventions of railroad officials ever held in the south met here yesterday. It was a meeting of the general managers and heads of the transportation roadways, and machinery departments of nearly all of the broad gauge (five feet) roads east of the Mississippi and south of the Ohio river.

The meeting was held in rooms 102 and 104 of the Kimball, and was called for the purpose of fixing the day and arranging all details for the changing of the gauge of the railroads in the territory named H. S. Haines, general manager of the Savannah, Florida and Western railroad, was called to the chair and F. K. Huger requested to act as secretary. The following

REPRESENTATIVES WERE PRESENT.

H. S. Haines, general manager, R. G. Fleming superintendent, George Riley master mechanic, Savannah, Florida and Western railroad: C. S. Gadsden, superintendent, J. W. Craig, master of roadway and master of transportation C. & S. railroad; Wm. Rogers, general superintendent, W. W. Starr, master of transportation, T. D. Kline, superintendent Southwestern railroad, Georgia Central. J. W. Thomas, general manager, Nashville, Chattanooga and St. Louis: J. W. Green, general manager, John S. Cook, master mechanic, Hamilton Wilkins road master, Georgia railroad: J. W. Green, general manager, P. R. & A. J. T. Hanahan, general manager, R. Montfort, engineer, R. Wells, assistant to president Louisville and Nashville; J. B. Beck, general manager, J. H. Averell, master of transportation, D. E. Maxwell, general superintendent Florida railway and Navigation company South Carolina railroad: Cecil Gabbott, general manager, J. F. Worwick, master mechanic Atlanta and West Point, Western railway of Alabama, Cincinnati, Selma and Mobile railway; C. H. Hudson, general manager, F. K. Huger, superintendent, W. H. Thomas, superintendent motive power East Tennessee, Virginia and Georgia; S. B. Thomas, general manager, Peyton Randolph, assistant general manager, W. H. Green superintendent Richmond and Danville division Superintendent Berkeley, Air-Line division Richmond and Danville railroad R. D. Wade, superintendent motive power, C. M. Bolton, engineer, C. P. Hammond, road master, T. W. Gentry, master mechanic, Rome and Dalton: A. B. Andrews, president, Frank Coxe, vice president, V. C. McBee, superintendent, G. W. Gitis, master mechanic, Western of North Carolina; Joseph H. Sands, general manager, Frank Huger, superintendent, W. W. Coe, chief engineer, S. B. Haupt, superintendent M. P., Norfolk and Western; G. R. Talcott, superiendent, Thos. Bernard, assistant engineer, Charlotte, Columbia and Augusta. Joseph H. Green, master mechanic Charlotte, Columbia and Augusta; G. R. Talcott, superintendent Columbia and Greenville; H. Walters, general manager Atlanta and Charlotte Air-Line; B. R. Dunn, engineer master mechanic Atlanta and Charlotte Air-Line; William R. Mims, road master Atlanta and West Point; R. Southgate, assistant engineer Columbia and Greenville; G. M. D. Riley, master of road way Sav., Florida and Western; H. W. Reed, master of roadway Savannah, Florida and Western; I. Y. Sage, general superintendent Georgia Pacific railroad; J. F. Alexander, division master Georgia Pacific railroad; H. R. Duval, receiver Florida railway and navigation company; W. R. Kline, master mechanic Brunswick and Western railroad; J. N. Brown, road master Brunswick and Western railroad; R. A. Bridges, road master Columbus and Western; A. L. Koutz, assistant superintendent Pullman palace car company. J. F. Divine, general superintandent Atlanta and Charlotte; W. T. Newman, master mechanic, Georgia Pacific; R. A. Anderson, superintendent; A. B. Bostwick, assistant superintendent; M. H. Dooly, road master; M. L. Collier, master mechanic, Western and Atlantic.

Mr. Haines upon taking the chair, briefly stated to the convention the object for which the meeting had been called, and announced that it would be necessary to appoint several committees to take in hand and arrange all the details of the work, and submit reports to the convention showing how every detail connected with change in the gauge must be arranged, so that the work would be accomplished easily and satisfactory.

The convention listened to him attentively and when he had concluded authorized him to appoint the committees and put them at work.

Chairman Haines then appointed the following committees:

Committee on date of change of gauge—E. B. Thomas, chairman; J. T. Horroban, C. H. Hudson, Wm. Rogers, H. R. Duval, Henry Walters, R. G. Fleming, J. W. Thomas, J. W. Green, J. H. Sands, R. A. Anderson, J. B. Peck, Cecil Gabbett, W. R. Kline.

Committee on transportation—J. F. Devine, chairman; J. H. Averill, D. E. Maxwell, F. K. Huger, Peyton Randolph, A. B. Andrews, Frank Coxe, V. E. McBee, Frank Huger, C. S. Gadsden, W. W. Starr, I. Y. Sage, A. B. Bostwick, W. H. Green, J. C. Gault.

Committee on roadway—W. W. Coe, chairman, C. P. Hammond, M. H. Dooly, William Mims, H. W. Reade, J. N. Brown, R. Muilfort, Hamilton Wilkins, G. R. Talcott, C. M. Bolton, Thomas Bernard, B. R. Dunn, R. Southgate, J. T. Alexander, R. A. Bridges, J. W. Craig, E. Burkley, B. R. Swoop.

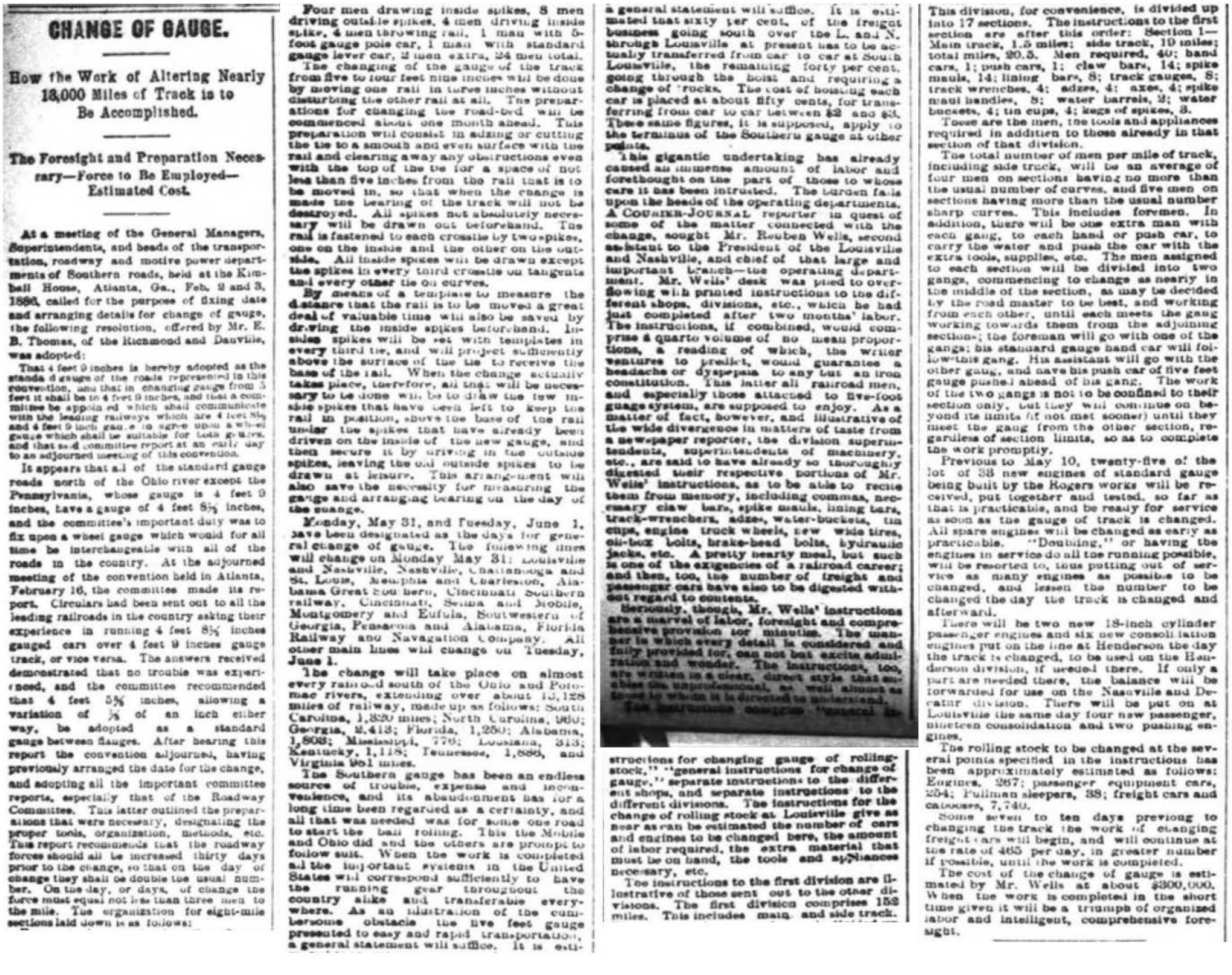
Committee on machinery—Reuben Wells, chairman; F. D. Kline, R. D. Wade, S. B. Haupt, Joseph H. Greene, G. M. D. Riley, J. S. Cook, M. L. Collier, W. H. Thomas, T. W. Gentry, G. W. Gates, J. E. Worswick, W. T. Newman.

The convention then, by unanimous consent, adopted the Pennsylvania standard gauge for the track and trucks.

The meeting then adjourned until 4 p. m., so as to allow the committees to get to work and prepare their reports to presented at that hour for consideration. At that hour the convention again assembled. The committees made reports, which were read and discussed.

A number of changes in the reports were suggested, and they were recommitted, so that these changes could be properly considered and acted upon. The convention then adjourned to meet at 11 o'clock this morning.

Figure C.2: Preparations and Procedures for Conversion (*Louisville Courier-Journal*, March 23, 1886)



# CHANGE OF GAUGE.

## How the Work of Altering Nearly 13,000 Miles of Track is to Be Accomplished.

### The Foresight and Preparation Necessary—Force to Be Employed—Estimated Cost.

At a meeting of the General Managers, Superintendents, and heads of the transportation, roadway and motive power departments of Southern roads, held at the Kimball House, Atlanta, Ga., Feb. 2 and 3, 1886, called for the purpose of fixing date and arranging details for change of gauge, the following resolution, offered by Mr. E. B. Thomas, of the Richmond and Danville, was adopted:

> That 4 feet 9 inches is hereby adopted as the standard gauge of the roads represented in this convention, and that in changing gauge from 5 feet it shall be to 4 feet 9 inches, and that a committee be appointed which shall communicate with the leading railways which are 4 feet 8½ and 4 feet 9 inch gauge to agree upon a wheel gauge which shall be suitable for both gauges, and that said committee report at an early day to an adjourned meeting of this convention.

It appears that all of the standard gauge roads north of the Ohio river except the Pennsylvania, whose gauge is 4 feet 9 inches, have a gauge of 4 feet 8½ inches, and the committee's important duty was to fix upon a wheel gauge which would for all time be interchangeable with all of the roads in the country. At the adjourned meeting of the convention held in Atlanta, February 16, the committee made its report. Circulars had been sent out to all the leading railroads in the country asking their experience in running 4 feet 8½ inches gauged cars over 4 feet 9 inches gauge track, or vice versa. The answers received demonstrated that no trouble was experienced, and the committee recommended that 4 feet 5⅜ inches, allowing a variation of ⅛ of an inch either way, be adopted as a standard gauge between flanges. After hearing this report the convention adjourned, having previously arranged the date for the change, and adopting all the important committee reports, especially that of the Roadway Committee. This latter outlined the preparations that were necessary, designating the proper tools, organization, methods, etc. This report recommends that the roadway forces should all be increased thirty days prior to the change, so that on the day of change they shall be double the usual number. On the day, or days, of change the force must equal not less than three men to the mile. The organization for eight-mile sections laid down is as follows:

Four men drawing inside spikes, 8 men driving outside spikes, 4 men driving inside spike, 4 men throwing rail, 1 man with 5-foot gauge pole car, 1 man with standard gauge lever car, 2 men extra, 24 men total.

The changing of the gauge of the track from five to four feet nine inches will be done by moving one rail in three inches without disturbing the other rail at all. The preparations for changing the road-bed will be commenced about one month ahead. This preparation will consist in adzing or cutting the tie to a smooth and even surface with the rail and clearing away any obstructions even with the top of the tie for a space of not less than five inches from the rail that is to be moved in, so that when the change is made the bearing of the track will not be destroyed. All spikes not absolutely necessary will be drawn out beforehand. The rail is fastened to each crosstie by two spikes, one on the inside and the other on the outside. All inside spikes will be drawn except the spikes in every third crosstie on tangents and every other tie on curves.

By means of a template to measure the distance that the rail is to be moved a great deal of valuable time will also be saved by driving the inside spikes beforehand. Inside spikes will be set with templates in every third tie, and will project sufficiently above the surface of the tie to receive the base of the rail. When the change actually takes place, therefore, all that will be necessary to be done will be to draw the few inside spikes that have been left to keep the rail in position, shove the base of the rail under the spikes that have already been driven on the inside of the new gauge, and then secure it by driving in the outside spikes, leaving the old outside spikes to be drawn at leisure. This arrangement will also save the necessity for measuring the gauge and arranging bearing on the day of the change.

Monday, May 31, and Tuesday, June 1, have been designated as the days for general change of gauge. The following lines will change on Monday May 31: Louisville and Nashville, Nashville, Chattanooga and St. Louis, Memphis and Charleston, Alabama Great Southern, Cincinnati Southern railway, Cincinnati, Selma and Mobile, Montgomery and Eufula, Southwestern of Georgia, Pensacola and Alabama, Florida Railway and Navagation Company. All other main lines will change on Tuesday, June 1.

The change will take place on almost every railroad south of the Ohio and Potomac rivers, extending over about 13,128 miles of railway, made up as follows: South Carolina, 1,820 miles; North Carolina, 960; Georgia, 2,413; Florida, 1,250; Alabama, 1,808; Mississippi, 776; Louisiana, 313; Kentucky, 1,118; Tennessee, 1,886, and Virginia 951 miles.

The Southern gauge has been an endless source of trouble, expense and inconvenience, and its abandonment has for a long time been regarded as a certainty, and all that was needed was for some one road to start the ball rolling. This the Mobile and Ohio did and the others are prompt to follow suit. When the work is completed all the important systems in the United States will correspond sufficiently to have the running gear throughout the country alike and transferable everywhere. As an illustration of the cumbersome obstacle the five feet gauge presented to easy and rapid transportation, a general statement will suffice. It is estimated that sixty per cent. of the freight business going south over the L. and N. through Louisville at present has to be actually transferred from car to car at South Louisville, the remaining forty per cent. going through the hoist and requiring a change of trucks. The cost of hoisting each car is placed at about fifty cents, for transferring from car to car between $2 and $3. These same figures, it is supposed, apply to the terminus of the Southern gauge at other points.

a general statement will suffice. It is esti-

This gigantic undertaking has already caused an immense amount of labor and forethought on the part of those to whose care it has been intrusted. The burden falls upon the heads of the operating departments. A COURIER-JOURNAL reporter in quest of some of the matter connected with the change, sought Mr. Reuben Wells, second assistant to the President of the Louisville and Nashville, and chief of that large and important branch—the operating department. Mr. Wells' desk was piled to overflowing with printed instructions to the different shops, divisions, etc., which he had just completed after two months' labor. The instructions, if combined, would comprise a quarto volume of no mean proportions, a reading of which, the writer ventures to predict, would guarantee a headache or dyspepsia to any but an iron constitution. This latter all railroad men, and especially those attached to five-foot guage system, are supposed to enjoy. As a matter of fact, however, and illustrative of the wide divergence in matters of taste from a newspaper reporter, the division superintendents, superintendents of machinery, etc., are said to have already so thoroughly digested their respective portions of Mr. Wells' instructions, as to be able to recite them from memory, including commas, necessary claw bars, spike mauls, lining bars, track-wrenchers, adzes, water-buckets, tin cups, engine truck wheels, new wide tires, oil-box bolts, brake-head bolts, hydraulic jacks, etc. A pretty hearty meal, but such is one of the exigencies of a railroad career; and then, too, the number of freight and passenger cars have also to be digested without regard to contents.

Seriously, though, Mr. Wells' instructions are a marvel of labor, foresight and comprehensive provision for minutiæ. The manner in which every detail is considered and fully provided for, can not but excite admiration and wonder. The instructions, too, are written in a clear, direct style that enables the unprofessional, as well almost as those to whom it is directed to understand.

The instructions comprise "general instructions for changing gauge of rolling-stock," "general instructions for change of gauge," separate instructions to the different shops, and separate instructions to the different divisions. The instructions for the change of rolling stock at Louisville give as near as can be estimated the number of cars and engines to be changed here, the amount of labor required, the extra material that must be on hand, the tools and appliances necessary, etc.

The instructions to the first division are illustrative of those sent out to the other divisions. The first division comprises 152 miles. This includes main and side track. This division, for convenience, is divided up into 17 sections. The instructions to the first section are after this order: Section 1—Main track, 1.5 miles; side track, 19 miles; total miles, 20.5. Men required, 40; hand cars, 1; push cars, 1; claw bars, 14; spike mauls, 14; lining bars, 8; track gauges, 8; track wrenches, 4; adzes, 4; axes, 4; spike maul handles, 8; water barrels, 2; water buckets, 4; tin cups, 4; kegs of spikes, 3.

These are the men, the tools and appliances required in addition to those already in that section of that division.

The total number of men per mile of track, including side track, will be an average of four men on sections having no more than the usual number of curves, and five men on sections having more than the usual number sharp curves. This includes foremen. In addition, there will be one extra man with each gang, to each hand or push car, to carry the water and push the car with the extra tools, supplies, etc. The men assigned to each section will be divided into two gangs, commencing to change as nearly in the middle of the section, as may be decided by the road master to be best, and working from each other, until each meets the gang working towards them from the adjoining sections; the foreman will go with one of the gangs; his standard gauge hand car will follow this gang. His assistant will go with the other gang, and have his push car of five feet gauge pushed ahead of his gang. The work of the two gangs is not to be confined to their section only, but they will continue on beyond its limits (if not met sooner) until they meet the gang from the other section, regardless of section limits, so as to complete the work promptly.

Previous to May 10, twenty-five of the lot of 38 new engines of standard gauge being built by the Rogers works will be received, put together and tested, so far as that is practicable, and be ready for service as soon as the gauge of track is changed. All spare engines will be changed as early as practicable. "Doubling," or having the engines in service do all the running possible, will be resorted to, thus putting out of service as many engines as possible to be changed, and lessen the number to be changed the day the track is changed and afterward.

There will be two new 18-inch cylinder passenger engines and six new consolidation engines put on the line at Henderson the day the track is changed, to be used on the Henderson division, if needed there. If only a part are needed there, the balance will be forwarded for use on the Nashville and Decatur division. There will be put on at Louisville the same day four new passenger, nineteen consolidation and two pushing engines.

The rolling stock to be changed at the several points specified in the instructions has been approximately estimated as follows: Engines, 267; passenger equipment cars, 254; Pullman sleepers, 38; freight cars and cabooses, 7,740.

Some seven to ten days previous to changing the track the work of changing freight cars will begin, and will continue at the rate of 465 per day, in greater number if possible, until the work is completed.

The cost of the change of gauge is estimated by Mr. Wells at about $300,000. When the work is completed in the short time given it will be a triumph of organized labor and intelligent, comprehensive foresight.

Figure C.3: Report on the Conversion (*Commercial and Financial Chronicle*, May 29, 1886)

## *THE UNIFICATION OF OUR RAILROAD GAUGE.*

On Monday and Tuesday next, according to previous arrangement and agreement, an important work will be undertaken and carried through. This is nothing less than the changing of the guage of all Southern roads whose width of track now is 5 feet, to a standard that will bring these lines more closely in conformity with the standard now in use in other parts of the country.

The matter is attracting hardly as much attention as it deserves. It is a task of no little magnitude. Practically it involves the taking up and relaying of one rail over the entire length of all the roads (and in some cases a change in the road bed and of course alteration of the rolling stock) in the territory bounded by the Atlantic Ocean on the one side and the Mississippi and Ohio Rivers on the other, and comprising the States of Virginia, West Virginia, Kentucky, Tennessee, Mississippi, Alabama, Georgia, Florida and North and South Carolina. Some of the newer systems in these States, like the Chesapeake & Ohio and its accessories, and the Louisville New Orleans & Texas, are of the standard Northern gauge, and so is the Southern Line of the Illinois Central, while the Mobile & Ohio was last year also altered to conform to this standard. But the vast bulk of the mileage in the Southern States at the present moment has a track width of five feet, and it is estimated that next week's operations will embrace fully 14,000 to 15,000 miles, from which one can judge of the dimensions of the work. And as already said, not only will the track have to be changed, but the rolling stock—locomotives and cars—will have to be adjusted to the new guage (where it has not previously been done) the latter being really the most difficult part of the undertaking. All the preliminaries, however, have been completed, preparations for the event having been in progress for several months, and much of the equipment having been already altered, so when on the 31st of May and 1st of June the 14,000 or 15,000 miles of track are simultaneously changed (some branches and minor pieces will be changed a day or two earlier), everything will be in readiness, and the business and operations of the roads proceed as if nothing had happened, while the means of intercourse between the different sections of the country will have been improved and our transportation interests benefited.

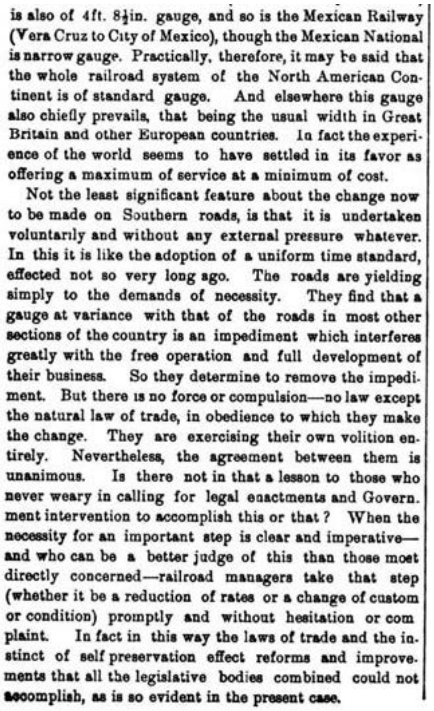
The new gauge will not be precisely the same as the commonly accepted standard, but it will be so nearly so as to be equivalent to the same thing. It will be 4 feet 9 inches, whereas the prevailing width is 4 feet 8½ inches. The Pennsylvania, however, has a gauge of 4 feet 9 inches, and the Southern lines have adopted the same figure. In reality, though, the difference—half an inch—is so small that the rolling stock of the one can and is being freely used upon the track of the other, so that for all practical purposes the two gauges are identical. Moreover, these two gauges embrace together the greater part of the railroad mileage of the country—the Southern roads with their five foot gauge forming the only important exception. According to the Census Report of 1880, of the total track in the country at that time (July 1) 66·3 per cent belonged to the roads with 4 ft. 8½ in. gauge, and 11·4 per cent belonged to those of the 4 ft. 9 in. gauge, making together 77·7 per cent, while of the 5-foot gauge (almost exclusively Southern roads and now to be changed) there was 11·4 per cent more, giving in the aggregate over 89 per cent of the total track in the country. The remaining 10 per cent was distributed chiefly between roads with the 6-foot gauge, some of which have since been changed to the standard, and narrow gauge roads with the 3-foot gauge, the most of which contemplate changing where they have not already changed. It follows, then, that after next week the mileage of the United States will be substantially of one and the same gauge, the exceptions of a wider or narrower gauge being so few as merely to emphasize the rule.

The step which the Southern roads have taken is of course an important one, both in its immediate effects in entailing an exceptional outlay in making the change, and in its ultimate effects in bringing Southern lines in closer communication with Northern and Western systems. In the latter particular the importance of the move can hardly be overestimated. The free interchange of traffic which a common standard will permit, we need hardly say will be of benefit to all interests concerned. The shipper will be saved delays, the railroad will be able to cheapen the cost of handling the traffic, and the mercantile and financial community generally will feel the effects in the increased stimulus that this gives to the development of trade and industry between the different sections. Hitherto the South has been in a measure shut off from the rest of the country by this lack of uniformity. On the north, the Ohio River marked the limit beyond which Southern freight could not go without a transfer of the contents of the car, or at least a change of trucks, and on the West the Mississippi River also formed a dividing line, for Texas and Arkansas roads are of standard gauge. After the change however, this barrier will no longer exist, and traffic can then be moved to the North or West without breaking bulk. Aside from the saving of expense that this will involve, good results may be expected to follow from the fact that the equipment of Northern and Western roads will be placed at the service of Southern roads, which may prove of considerable advantage to these, especially during the months when the cotton movement is most active. And upon the sections themselves the effect of such an interchange in bringing the people closer together, is not to be lightly dismissed. It should even help to attract attention to the South as a field for the profitable employment of capital. That section has been comparatively neglected heretofore. There has of course been growth in recent years—very decided growth indeed,—but as compared with the West and Northwest, the South has not gained as much as the inducements she offers warrant. The flood of immigration especially has passed her by. It is unnecessary to inquire into the causes of this. It is sufficient to know that the change of gauge will make the union between the sections more complete, and in connection with the new industrial development now making such rapid progress, ought to tend to give greater prominence to that section hereafter.

As to the cost of the change on such an extensive body of roads, that cannot be stated with any great degree of accuracy till after the work has been accomplished. Reducing the gauge of track is, of course, a simple problem, but the adjusting of engines, equipment, tools and the various paraphernalia connected with the operation of a railroad, is what constitutes the largest proportion of the expense. We have no exact data for estimating the cost of the work, but an approximate idea of the amount required can be gained by using the figures which Mr. William Butler Duncan gives in the report of the Mobile & Ohio for the late fiscal year. The Mobile & Ohio was changed to standard gauge on the 8th of last July, and an itemized statement in the report places the expenditures on that account up to the close of August at $66,329, of which $41,069 was paid out directly for labor and $25,260 for the necessary material. This included all the track, engines, cars, tools, bridges, etc. We infer, however, that it does not comprise the whole charge involved in the work, for in his remarks we find Mr. Duncan saying that the total cost, which had been originally estimated at $95,777, would probably be less than $80,000. The Mobile & Ohio has 527 miles of main line and branches, and on the basis of $80,000 for the whole the cost of effecting the change (including rolling stock and everything else) *per mile of road* would be a little over $150. On the same basis, the 14,000 miles now to be changed would involve an outlay of $2,100,000, showing that the work is not only one of importance, but one also involving in the aggregate a great expense. The roads on which this burden of cost will chiefly fall are of course the larger systems like the Louisville & Nashville, the Richmond & Danville, the Cincinnati New Orleans & Texas Pacific, the East Tennessee, the Norfolk & Western, and the Central R.R. of Georgia; but the minor roads all over the South will also have their expenses increased on the same account.

It is interesting to note how completely the standard gauge of 4ft. 8½in. and 4ft. 9in. has supplanted all other gauges. Only a few years ago, when hardly enough could be said by the advocates of the 3 foot gauge in favor of the narrow guage plan, it seemed as if a new and dangerous rival were about to arise. But a short trial has served to demonstrate that the advantages claimed for the narrow guage system were largely illusory, and the three-foot gauge has now fallen into pretty general disrepute, while nearly all the companies that had built their lines on that guage have become discredited, and are in the hands of the officers of the law. The Toledo Cincinnati & St. Louis was to be the most brilliant exponent of the new theory, "the grandest narrow guage enterprise on the Continent," but alas! there never was a road so deeply involved in financial and other difficulties as this, and when it finally succeeds in getting out of the dilemma in which it now finds itself, the road will be widened to the standard guage. Then there is the Texas & St. Louis, which also has an extensive narrow guage mileage, now to be changed to standard width. The Denver & Rio Grande is the only narrow guage system of consequence remaining, and there the mountainous character of the country renders a comparison with other sections out of the question. For short distances and special kinds of traffic the narrow guage sometimes answers very well, and there are some pieces of this character that pay, but on any large or extensive scale, and with ordinary kinds of traffic, experience seems to have demonstrated that the narrow guage does not meet the requirements called for, and most of the companies of this kind formed in recent years have, as already said, met with disaster.

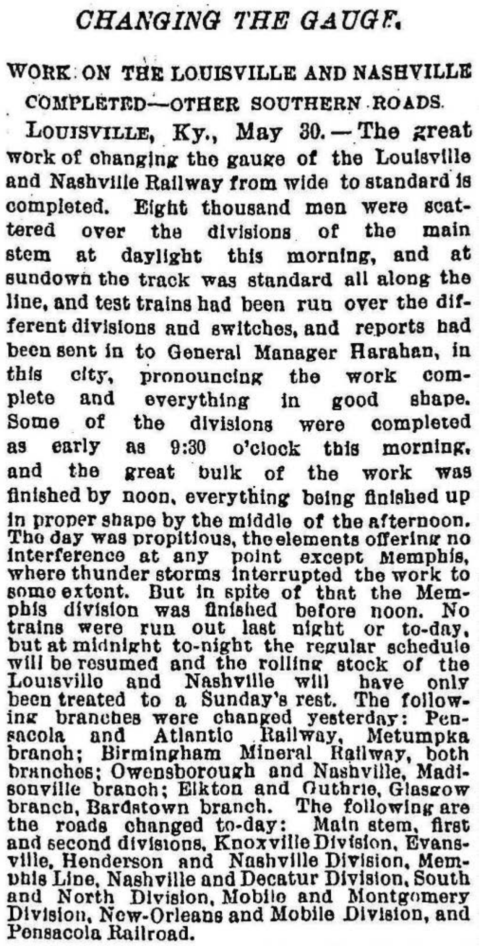
As to the old broad guage, that has long since gone out of fashion. The Erie was constructed on that pattern, but was changed to standard in 1878. Its principal connection—the Atlantic & Great Western—was also of six foot guage, and this was changed in 1880. We may remark that the Canadian system is likewise of standard guage. There were varying gauges in Canada at first, but in 1873 a common movement was made towards the adoption of the standard, and since then that has been generally followed. The Mexican Central (El Paso to City of Mexico)



is also of 4ft. 8½in. gauge, and so is the Mexican Railway (Vera Cruz to City of Mexico), though the Mexican National is narrow gauge. Practically, therefore, it may be said that the whole railroad system of the North American Continent is of standard gauge. And elsewhere this gauge also chiefly prevails, that being the usual width in Great Britain and other European countries. In fact the experience of the world seems to have settled in its favor as offering a maximum of service at a minimum of cost.

Not the least significant feature about the change now to be made on Southern roads, is that it is undertaken voluntarily and without any external pressure whatever. In this it is like the adoption of a uniform time standard, effected not so very long ago. The roads are yielding simply to the demands of necessity. They find that a gauge at variance with that of the roads in most other sections of the country is an impediment which interferes greatly with the free operation and full development of their business. So they determine to remove the impediment. But there is no force or compulsion—no law except the natural law of trade, in obedience to which they make the change. They are exercising their own volition entirely. Nevertheless, the agreement between them is unanimous. Is there not in that a lesson to those who never weary in calling for legal enactments and Government intervention to accomplish this or that? When the necessity for an important step is clear and imperative—and who can be a better judge of this than those most directly concerned—railroad managers take that step (whether it be a reduction of rates or a change of custom or condition) promptly and without hesitation or complaint. In fact in this way the laws of trade and the instinct of self preservation effect reforms and improvements that all the legislative bodies combined could not accomplish, as is so evident in the present case.

Figure C.4: Report on the Conversion (*New York Times*, May 31, 1886)

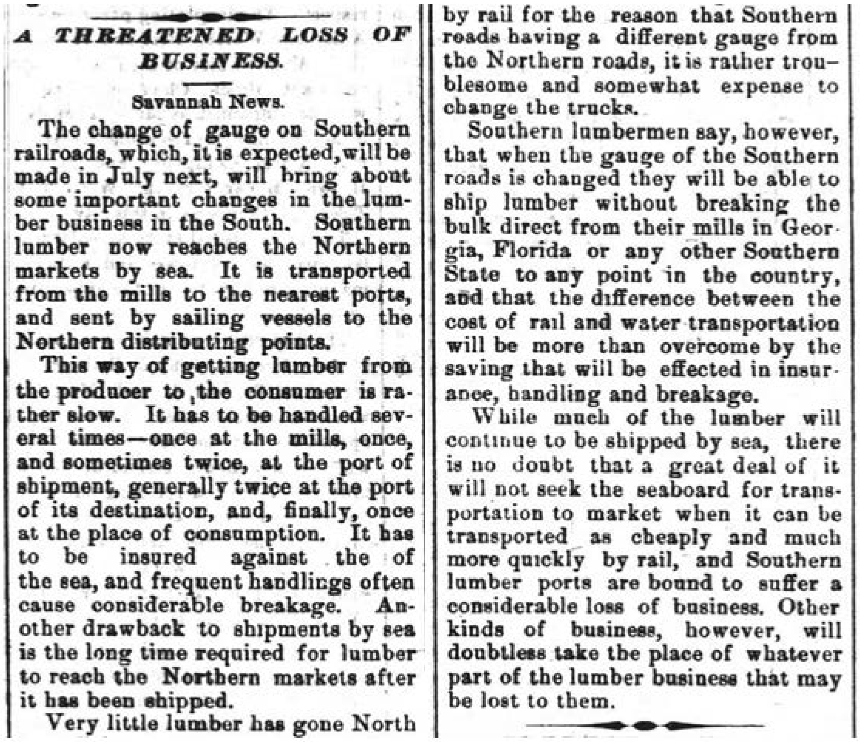


### *CHANGING THE GAUGE.*

#### WORK ON THE LOUISVILLE AND NASHVILLE COMPLETED—OTHER SOUTHERN ROADS.

LOUISVILLE, Ky., May 30.—The great work of changing the gauge of the Louisville and Nashville Railway from wide to standard is completed. Eight thousand men were scattered over the divisions of the main stem at daylight this morning, and at sundown the track was standard all along the line, and test trains had been run over the different divisions and switches, and reports had been sent in to General Manager Harahan, in this city, pronouncing the work complete and everything in good shape. Some of the divisions were completed as early as 9:30 o'clock this morning, and the great bulk of the work was finished by noon, everything being finished up in proper shape by the middle of the afternoon. The day was propitious, the elements offering no interference at any point except Memphis, where thunder storms interrupted the work to some extent. But in spite of that the Memphis division was finished before noon. No trains were run out last night or to-day, but at midnight to-night the regular schedule will be resumed and the rolling stock of the Louisville and Nashville will have only been treated to a Sunday's rest. The following branches were changed yesterday: Pensacola and Atlantic Railway, Metumpka branch; Birmingham Mineral Railway, both branches; Owensborough and Nashville, Madisonville branch; Elkton and Guthrie, Glasgow branch, Bardstown branch. The following are the roads changed to-day: Main stem, first and second divisions, Knoxville Division, Evansville, Henderson and Nashville Division, Memphis Line, Nashville and Decatur Division, South and North Division, Mobile and Montgomery Division, New-Orleans and Mobile Division, and Pensacola Railroad.

Figure C.5: Example of Anticipated Effects (*Wilmington Morning Star*, April 16, 1886)



## *A THREATENED LOSS OF BUSINESS.*

Savannah News.

The change of gauge on Southern railroads, which, it is expected, will be made in July next, will bring about some important changes in the lumber business in the South. Southern lumber now reaches the Northern markets by sea. It is transported from the mills to the nearest ports, and sent by sailing vessels to the Northern distributing points.

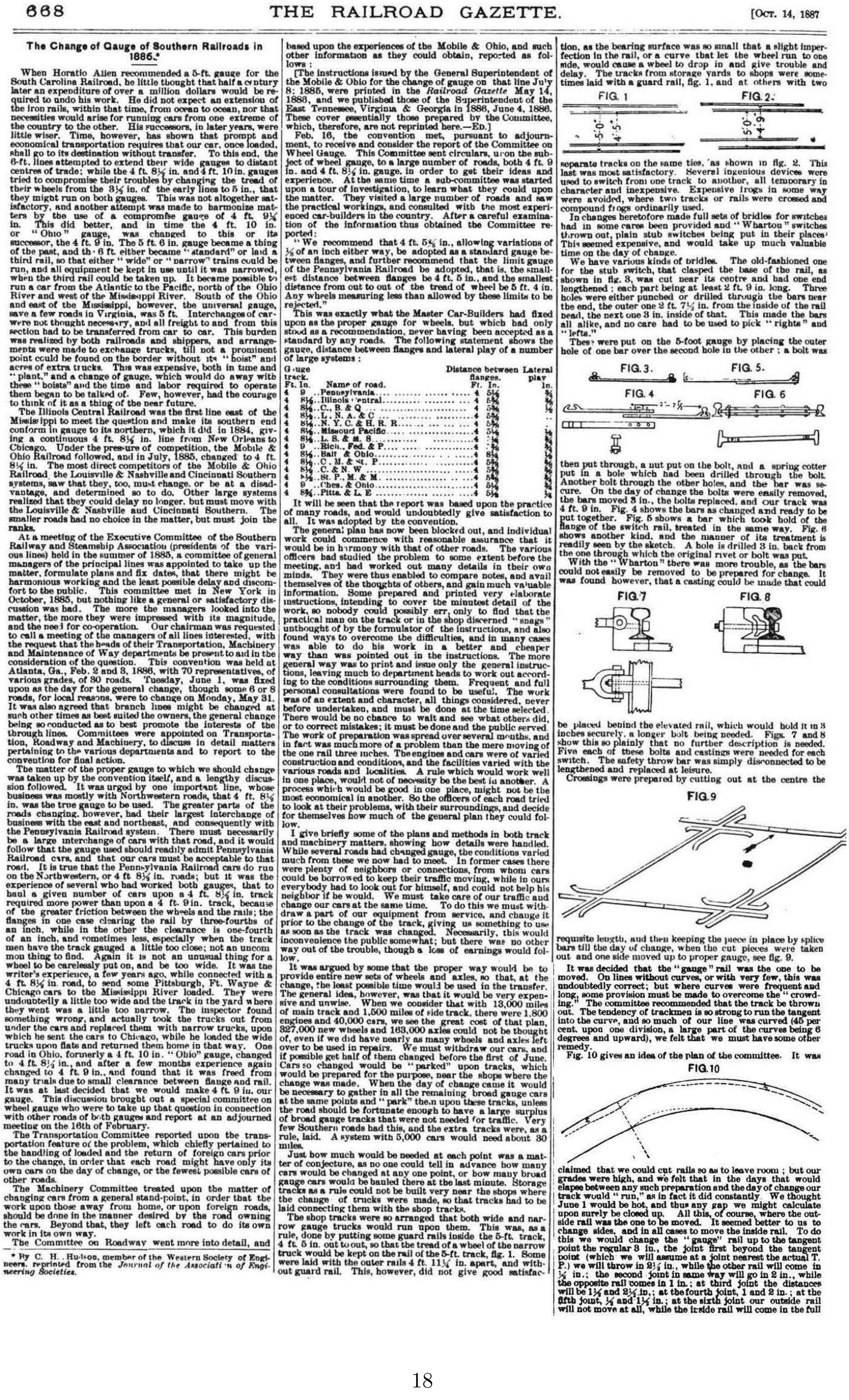
This way of getting lumber from the producer to the consumer is rather slow. It has to be handled several times—once at the mills, once, and sometimes twice, at the port of shipment, generally twice at the port of its destination, and, finally, once at the place of consumption. It has to be insured against the of the sea, and frequent handlings often cause considerable breakage. Another drawback to shipments by sea is the long time required for lumber to reach the Northern markets after it has been shipped.

Very little lumber has gone North by rail for the reason that Southern roads having a different gauge from the Northern roads, it is rather troublesome and somewhat expense to change the trucks.

Southern lumbermen say, however, that when the gauge of the Southern roads is changed they will be able to ship lumber without breaking the bulk direct from their mills in Georgia, Florida or any other Southern State to any point in the country, and that the difference between the cost of rail and water transportation will be more than overcome by the saving that will be effected in insurance, handling and breakage.

While much of the lumber will continue to be shipped by sea, there is no doubt that a great deal of it will not seek the seaboard for transportation to market when it can be transported as cheaply and much more quickly by rail, and Southern lumber ports are bound to suffer a considerable loss of business. Other kinds of business, however, will doubtless take the place of whatever part of the lumber business that may be lost to them.

Figure C.6: Technical Summary of the Gauge Change (*Railroad Gazette*, October 14, 1887)



668 THE RAILROAD GAZETTE. [Oct. 14, 1887

## The Change of Gauge of Southern Railroads in 1886.*

When Horatio Allen recommended a 5-ft. gauge for the South Carolina Railroad, he little thought that half a century later an expenditure of over a million dollars would be required to undo his work. He did not expect an extension of the iron rails, within that time, from ocean to ocean, nor that necessities would arise for running cars from one extreme of the country to the other. His successors, in later years, were little wiser. Time, however, has shown that prompt and economical transportation requires that our car, once loaded, shall go to its destination without transfer. To this end, the 6-ft. lines attempted to extend their wide gauges to distant centres of trade; while the 4 ft. 8½ in. and 4 ft. 10 in. gauges tried to compromise their troubles by changing the tread of their wheels from the 3½ in. of the early lines to 5 in., that they might run on both gauges. This was not altogether satisfactory, and another attempt was made to harmonize matters by the use of a compromise gauge of 4 ft. 9¼ in. This did better, and in time the 4 ft. 10 in. or "Ohio" gauge, was changed to this or its successor, the 4 ft. 9 in. The 5 ft. 6 in. gauge became a thing of the past, and the 6 ft. either became "standard" or laid a third rail, so that either "wide" or "narrow" trains could be run, and all equipment be kept in use until it was narrowed, when the third rail could be taken up. It became possible to run a car from the Atlantic to the Pacific, north of the Ohio River and west of the Mississippi River. South of the Ohio and east of the Mississippi, however, the universal gauge, save a few roads in Virginia, was 5 ft. Interchanges of cars were not thought necessary, and all freight to and from this section had to be transferred from car to car. This burden was realized by both railroads and shippers, and arrangements were made to exchange trucks, till not a prominent point could be found on the border without its "hoist" and acres of extra trucks. This was expensive, both in time and "plant," and a change of gauge, which would do away with these "hoists" and the time and labor required to operate them began to be talked of. Few, however, had the courage to think of it as a thing of the near future.

The Illinois Central Railroad was the first line east of the Mississippi to meet the question and make its southern end conform in gauge to its northern, which it did in 1884, giving a continuous 4 ft. 8½ in. line from New Orleans to Chicago. Under the pressure of competition, the Mobile & Ohio Railroad followed, and in July, 1885, changed to 4 ft. 8½ in. The most direct competitors of the Mobile & Ohio Railroad, the Louisville & Nashville and Cincinnati Southern systems, saw that they, too, must change, or be at a disadvantage, and determined so to do. Other large systems realized that they could delay no longer, but must move with the Louisville & Nashville and Cincinnati Southern. The smaller roads had no choice in the matter, but must join the ranks.

At a meeting of the Executive Committee of the Southern Railway and Steamship Association (presidents of the various lines) held in the summer of 1885, a committee of general managers of the principal lines was appointed to take up the matter, formulate plans and fix dates, that there might be harmonious working and the least possible delay and discomfort to the public. This committee met in New York in October, 1885, but nothing like a general or satisfactory discussion was had. The more the managers looked into the matter, the more they were impressed with its magnitude, and the need for co-operation. Our chairman was requested to call a meeting of the managers of all lines interested, with the request that the heads of their Transportation, Machinery and Maintenance of Way departments be present to aid in the consideration of the question. This convention was held at Atlanta, Ga., Feb. 2 and 3, 1886, with 70 representatives, of various grades, of 30 roads. Tuesday, June 1, was fixed upon as the day for the general change, though some 6 or 8 roads, for local reasons, were to change on Monday, May 31. It was also agreed that branch lines might be changed at such other times as best suited the owners, the general change being so conducted as to best promote the interests of the through lines. Committees were appointed on Transportation, Roadway and Machinery, to discuss in detail matters pertaining to the various departments and to report to the convention for final action.

The matter of the proper gauge to which we should change was taken up by the convention itself, and a lengthy discussion followed. It was urged by one important line, whose business was mostly with Northwestern roads, that 4 ft. 8½ in. was the true gauge to be used. The greater parts of the roads changing, however, had their largest interchange of business with the east and northeast, and consequently with the Pennsylvania Railroad system. There must necessarily be a large interchange of cars with that road, and it would follow that the gauge used should readily admit Pennsylvania Railroad cars, and that our cars must be acceptable to that road. It is true that the Pennsylvania Railroad cars do run on the Northwestern, or 4 ft 8½ in. roads; but it was the experience of several who had worked both gauges, that to haul a given number of cars upon a 4 ft. 8½ in. track required more power than upon a 4 ft. 9 in. track, because of the greater friction between the wheels and the rails; the flanges in one case clearing the rail by three-fourths of an inch, while in the other the clearance is one-fourth of an inch, and sometimes less, especially when the track men have the track gauged a little too close; not an uncommon thing to find. Again it is not an unusual thing for a wheel to be carelessly put on, and be too wide. It was the writer's experience, a few years ago, while connected with a 4 ft. 8½ in. road, to send some Pittsburgh, Ft. Wayne & Chicago cars to the Mississippi River loaded. They were undoubtedly a little too wide and the track in the yard where they went was a little too narrow. The inspector found something wrong, and actually took the trucks out from under the cars and replaced them with narrow trucks, upon which he sent the cars to Chicago, while he loaded the wide trucks upon flats and returned them home in that way. One road in Ohio, formerly a 4 ft. 10 in. "Ohio" gauge, changed to 4 ft. 8½ in., and after a few months experience again changed to 4 ft. 9 in., and found that it was freed from many trials due to small clearance between flange and rail. It was at last decided that we would make 4 ft. 9 in. our gauge. This discussion brought out a special committee on wheel gauge who were to take up that question in connection with other roads of both gauges and report at an adjourned meeting on the 16th of February.

The Transportation Committee reported upon the transportation feature of the problem, which chiefly pertained to the handling of loaded and the return of foreign cars prior to the change, in order that each road might have only its own cars on the day of change, or the fewest possible cars of other roads.

The Machinery Committee treated upon the matter of changing cars from a general stand-point, in order that the work upon those away from home, or upon foreign roads, should be done in the manner desired by the road owning the cars. Beyond that, they left each road to do its own work in its own way.

The Committee on Roadway went more into detail, and based upon the experiences of the Mobile & Ohio, and such other information as they could obtain, reported as follows:

[The instructions issued by the General Superintendent of the Mobile & Ohio for the change of gauge on that line July 8, 1885, were printed in the *Railroad Gazette* May 14, 1888, and we published those of the Superintendent of the East Tennessee, Virginia & Georgia in 1886, June 4, 1886. These cover essentially those prepared by the Committee, which, therefore, are not reprinted here.—Ed.]

Feb. 16, the convention met, pursuant to adjournment, to receive and consider the report of the Committee on Wheel Gauge. This Committee sent circulars, upon the subject of wheel gauge, to a large number of roads, both 4 ft. 9 in. and 4 ft. 8½ in. gauge, in order to get their ideas and experience. At the same time a sub-committee was started upon a tour of investigation, to learn what they could upon the matter. They visited a large number of roads and saw the practical workings, and consulted with the most experienced car-builders in the country. After a careful examination of the information thus obtained the Committee reported:

"We recommend that 4 ft. 5⅜ in., allowing variations of ⅛ of an inch either way, be adopted as a standard gauge between flanges, and further recommend that the limit gauge of the Pennsylvania Railroad be adopted, that is, the smallest distance between flanges be 4 ft. 5 in., and the smallest distance from out to out of the tread of wheel be 5 ft. 4 in. Any wheels measuring less than allowed by these limits to be rejected."

This was exactly what the Master Car-Builders had fixed upon as the proper gauge for wheels, but which had only stood as a recommendation, never having been accepted as a standard by any roads. The following statement shows the gauge, distance between flanges and lateral play of a number of large systems:

| Gauge track. Ft. | In. | Name of road. | Distance between flanges. Ft. | In. | Lateral play In. |
|---|---|---|---|---|---|
| 4 | 9 | Pennsylvania | 4 | 5⅛ | ¾ |
| 4 | 8½ | Illinois Central | 4 | 5⅜ | ⅜ |
| 4 | 8½ | C., B. & Q | 4 | 5⅜ | ½ |
| 4 | 8½ | L. N. A. & C | 4 | 5⅜ | .. |
| 4 | 8½ | N. Y. C. & H. R. R | 4 | 5⅜ | . |
| 4 | 8½ | Missouri Pacific | 4 | 5⅛ | ⅛ |
| 4 | 8½ | L. S. & M. S | 4 | 5⅛ | ¾ |
| 4 | 9 | Rich., Fed. & P | 4 | 5⅜ | ¾ |
| 4 | 8½ | Balt & Ohio | 4 | 8¼ | ½ |
| 4 | 8½ | C. M. & St. P | 4 | 5⅜ | ⅝ |
| 4 | 8½ | C. & N. W | 4 | 5⅜ | ⅝ |
| 4 | 8½ | St. P., M. & M | 4 | 5⅜ | ¾ |
| 4 | 9 | Ches. & Ohio | 4 | 5½ | ¾ |
| 4 | 8¾ | Pitts. & L. E | 4 | 5½ | ¼ |

It will be seen that the report was based upon the practice of many roads, and would undoubtedly give satisfaction to all. It was adopted by the convention.

The general plan has now been blocked out, and individual work could commence with reasonable assurance that it would be in harmony with that of other roads. The various officers had studied the problem to some extent before the meeting, and had worked out many details in their own minds. They were thus enabled to compare notes, and avail themselves of the thoughts of others, and gain much valuable information. Some prepared and printed very elaborate instructions, intending to cover the minutest detail of the work, so nobody could possibly err, only to find that the practical man on the track or in the shop discerned "snags" unthought of by the formulator of the instructions, and also found ways to overcome the difficulties, and in many cases was able to do his work in a better and cheaper way than was pointed out in the instructions. The more general way was to print and issue only the general instructions, leaving much to department heads to work out according to the conditions surrounding them. Frequent and full personal consultations were found to be useful. The work was of an extent and character, all things considered, never before undertaken, and must be done at the time selected. There would be no chance to wait and see what others did, or to correct mistakes; it must be done and the public served. The work of preparation was spread over several months, and in fact was much more of a problem than the mere moving of the one rail three inches. The engines and cars were of varied construction and conditions, and the facilities varied with the various roads and localities. A rule which would work well in one place, would not of necessity be the best in another. A process which would be good in one place, might not be the most economical in another. So the officers of each road tried to look at their problems, with their surroundings, and decide for themselves how much of the general plan they could follow.

I give briefly some of the plans and methods in both track and machinery matters, showing how details were handled. While several roads had changed gauge, the conditions varied much from these we now had to meet. In former cases there were plenty of neighbors or connections, from whom cars could be borrowed to keep their traffic moving, while in ours everybody had to look out for himself, and could not help his neighbor if he would. We must take care of our traffic and change our cars at the same time. To do this we must withdraw a part of our equipment from service, and change it prior to the change of the track, giving us something to use as soon as the track was changed. Necessarily, this would inconvenience the public somewhat; but there was no other way out of the trouble, though a loss of earnings would follow.

It was argued by some that the proper way would be to provide entire new sets of wheels and axles, so that, at the change, the least possible time would be used in the transfer. The general idea, however, was that it would be very expensive and unwise. When we consider that with 13,000 miles of main track and 1,500 miles of side track, there were 1,800 engines and 40,000 cars, we see the great cost of that plan, 327,000 new wheels and 163,000 axles could not be thought of, even if we did have nearly as many wheels and axles left over to be used in repairs. We must withdraw our cars, and if possible get half of them changed before the first of June. Cars so changed would be "parked" upon tracks, which would be prepared for the purpose, near the shops where the change was made. When the day of change came it would be necessary to gather in all the remaining broad gauge cars at the same points and "park" them upon these tracks, unless the road should be fortunate enough to have a large surplus of broad gauge tracks that were not needed for traffic. Very few Southern roads had this, and the extra tracks were, as a rule, laid. A system with 5,000 cars would need about 30 miles.

Just how much would be needed at each point was a matter of conjecture, as no one could tell in advance how many cars would be changed at any one point, or how many broad gauge cars would be hauled there at the last minute. Storage tracks as a rule could not be built very near the shops where the change of trucks were made, so that tracks had to be laid connecting them with the shop tracks.

The shop tracks were so arranged that both wide and narrow gauge trucks would run upon them. This was, as a rule, done by putting some guard rails inside the 5-ft. track, 4 ft. 5 in. out to out, so that the tread of a wheel of the narrow truck would be kept on the rail of the 5-ft. track, fig. 1. Some were laid with the outer rails 4 ft. 11¼ in. apart, and without guard rail. This, however, did not give good satisfaction, as the bearing surface was so small that a slight imperfection in the rail, or a curve that let the wheel run to one side, would cause a wheel to drop in and give trouble and delay. The tracks from storage yards to shops were sometimes laid with a guard rail, fig. 1, and at others with two separate tracks on the same ties, as shown in fig. 2. This last was most satisfactory. Several ingenious devices were used to switch from one track to another, all temporary in character and inexpensive. Expensive frogs in some way were avoided, where two tracks or rails were crossed and compound frogs ordinarily used.

FIG. 1

FIG. 2.

In changes heretofore made full sets of bridles for switches had in some cases been provided and "Wharton" switches thrown out, plain stub switches being put in their places. This seemed expensive, and would take up much valuable time on the day of change.

We have various kinds of bridles. The old-fashioned one for the stub switch, that clasped the base of the rail, as shown in fig. 3, was cut near its centre and had one end lengthened: each part being at least 2 ft. 9 in. long. Three holes were either punched or drilled through the bars near the end, the outer one 2 ft. 7½ in. from the inside of the rail head, the next one 3 in. inside of that. This made the bars all alike, and no care had to be used to pick "rights" and "lefts."

These were put on the 5-foot gauge by placing the outer hole of one bar over the second hole in the other; a bolt was then put through, a nut put on the bolt, and a spring cotter put in a hole which had been drilled through the bolt. Another bolt through the other holes, and the bar was secure. On the day of change the bolts were easily removed, the bars moved 3 in., the bolts replaced, and our track was 4 ft. 9 in. Fig. 4 shows the bars as changed and ready to be put together. Fig. 5 shows a bar which took hold of the flange of the switch rail, treated in the same way. Fig. 6 shows another kind, and the manner of its treatment is readily seen by the sketch. A hole is drilled 3 in. back from the one through which the original rivet or bolt was put.

FIG. 3.

FIG. 5.

FIG. 4

FIG. 6

With the "Wharton" there was more trouble, as the bars could not easily be removed to be prepared for change. It was found however, that a casting could be made that could be placed behind the elevated rail, which would hold it in 3 inches securely, a longer bolt being needed. Figs. 7 and 8 show this so plainly that no further description is needed. Five each of these bolts and castings were needed for each switch. The safety throw bar was simply disconnected to be lengthened and replaced at leisure.

FIG. 7

FIG. 8

Crossings were prepared by cutting out at the centre the requisite length, and then keeping the piece in place by splice bars till the day of change, when the cut pieces were taken out and one side moved up to proper gauge, see fig. 9.

FIG. 9

It was decided that the "gauge" rail was the one to be moved. On lines without curves, or with very few, this was undoubtedly correct; but where curves were frequent and long, some provision must be made to overcome the "crowding." The committee recommended that the track be thrown out. The tendency of trackmen is so strong to run the tangent into the curve, and so much of our line was curved (45 per cent. upon one division, a large part of the curves being 6 degrees and upward), we felt that we must have some other remedy.

Fig. 10 gives an idea of the plan of the committee. It was claimed that we could cut rails so as to leave room; but our grades were high, and we felt that in the days that would elapse between any such preparation and the day of change our track would "run," as in fact it did constantly. We thought June 1 would be hot, and thus any gap we might calculate upon surely be closed up. All this, of course, where the outside rail was the one to be moved. It seemed better to us to change sides, and in all cases to move the inside rail. To do this we would change the "gauge" rail up to the tangent point the regular 3 in., the joint first beyond the tangent point (which we will assume at a joint nearest the actual T. P.) we will throw in 2½ in., while the other rail will come in ½ in.; the second joint in same way will go in 2 in., while the opposite rail comes in 1 in.; at third joint the distances will be 1½ and 2½ in.; at the fourth joint, 1 and 2 in.; at the fifth joint, ½ and 1½ in.; at the sixth joint our outside rail will not move at all, while the inside rail will come in the full

FIG. 10

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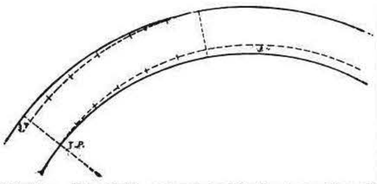
* By C. H. Hudson, member of the Western Society of Engineers, reprinted from the *Journal of the Association of Engineering Societies*.

3 in.; we continue to move the inside rail till within six joints of the next tangent point, when we commence to reverse the process. In the process of preparation spikes have been driven at each of the points mentioned. Fig. 11 shows this plan. The outside or elevated rail is the one usually used as the line rail upon a curve, so we were following the plan on which we started, viz.: to move the "gauge" rail. The wisdom of the plan was shown when the day of change came and curves changed on this plan were found to be in better line than those changed by any other method. We tried all three plans spoken of.

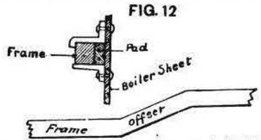
FIG. 11



In the matter of locomotives the conditions varied much. Of the engine builders, the Baldwin Locomotive Works had probably been the most far-seeing. For twenty years they had looked forward to this change, and had during that time so constructed their frames and fire-boxes that, by using new driving wheel centres, the change could be made without changing other parts. Few other builders had, until comparatively recently, given the matter any thought, and, as a result, many engines were found that could be changed only by moving the frames in, and not unfrequently the fire-box had to be altered; this meant a new fire-box and heavy expense. Many engines were thrown out of service by the fact of the great cost of changing them.

The 5-ft. engines measured between flanges of drivers (and other wheels as well) 4 ft. 8⅝ in. As the gauge was narrowed 3 in. it followed that the new measurement would be 4 ft. 5⅝ in., and this in fact was the measure fixed upon by the convention, with a limit of variation of ⅛ in. either way; so the frames must be enough less than this from out to out to give a reasonable clearance, or say 4 ft. 5 in. I think all our Baldwins was within this limit; but we found other engines wider from out to out of frames, the frames being set out from the fire-box and a "pad" placed between them; see fig. 12. The "pad" could be cut out and the frame set in against side of the fire-box; but to do it, this frame had to be offset, as shown in fig. 12. This was done behind the rocker arm and in front of the pedestal or "jaw" thus rendering unnecessary the changing of machinery, but enabled us to set in the boxes and wheels or tires to the proper width without cutting into the frame.

FIG. 12



To get proper information about all the engines, accurate measurements were taken of width of fire-box, width between frames, from out to out frames, between hubs, between inside of tires, between rims of wheels, sizes of boxes and wedges, thickness of hubs, rims of wheels, etc. Blue print diagrams were prepared upon which were placed all these measurements with the number of the engine. From these the head of the machinery department could see at a glance what was required for each engine. It was expected at the start that new driving wheel centres would be required for all engines; but examination of our blue prints showed that upon our lines, at least in a majority of cases, this was not necessary. Some few engines, notably some of the old Rogers, had wheels that were dished to such an extent that by pressing them off and putting on again, with the outside face inside, an inch and a half could be gained and the tire could go on as originally placed, squarely upon the wheel. See fig. 13 as originally, and fig. 14 as turned. It was found in practice that a new crank pin had to be put in. In many cases we found that we had thick hubs and heavy flanges to both driving boxes and wedges, so that by taking from ½ to ¾ of an inch from the insides of the hubs, and ⅛ to ¼ from the box and wedge flanges, we could gain at least one inch, and in some cases did more. This left not to exceed half an inch for the tire to project over the wheel centre on the inside, neither an unreasonable nor an unusual projection. This change was a trifling one and done at a cost per engine of about $180.67, including new crank pins. A new set of wheel centres, finished and in place, including pins, which would probably be needed, would cost $264.46. When changes were decided upon, and an engine was in the shop, they were made, and the tires were then put on at the old gauge, projecting outside the centres. They were used in this way without trouble until the day of change came; fig. 15, original; fig. 16, changed. Some of the more recent engines had their wheel centres built expressly with a view to changing. They were placed upon the axle, and would be required with the new gauge; but the rim projected outwardly an inch and a half more than usual, so that the tire could be placed for the 5 ft. gauge and still have its full support. See fig. 17. When the tire was eventually moved to the narrow gauge this outward rim would be turned off.

FIG. 13

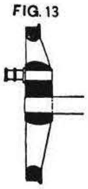


FIG. 14

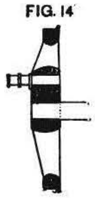


FIG. 15

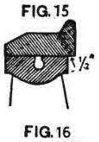


FIG. 17

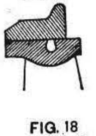


FIG. 19

FIG. 16

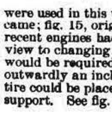


FIG. 18

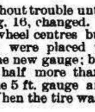
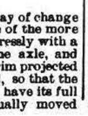


FIG. 20



Of course, we were not able to take all our engines into the shop and press in their wheel centres, and had to be satisfied with some temporary arrangements that would give us the use of the engine until such time as it could be taken into the shop. We decided to set tires in, leaving the centres unchanged. This gave an inside projection of 1⅛ in., plus what little projection there might have originally been. When the rim was solid, there was no trouble in this (fig. 18), provided the tire was not too thin. We fixed upon 2 in. as a limit safe beyond doubt. When the coring was in the middle and not large this was still safe, see fig. 19. We sometimes, however, found very large cores, and at one side (see fig. 20), which gave us a very small hold for our tire, and it was not deemed safe for road service. To overcome this danger we purchased a few new tires 6¾ in. wide with the outer corner cut away, as shown in fig. 21. This gave us a bearing over the entire rim of the wheel, and was safe, no matter how large or in what position was the core. The corner was cut off to save material, and at the same time, to save the bad effects of a wide tire upon frogs and switches. The edge was left 1 in. thick. At some future time when the engine goes into the shop and has new centres put on, or the old ones pressed in, this extra width of tire can be turned off.

As to engine trucks: The frames had, in many cases, been made of the proper width for the narrow gauge, and the wheels had been built with a heavy hub projecting an inch and a half inward (fig. 22), so that it would bear against the truck box. It was expected that these wheels would be taken out and 1⅛ in. of the hub taken off when the change came, so that the wheel could be pressed on the new gauge. This would have taken too much time, so the inch and a half extra hub was left off of all new wheels, but a cast iron collar or washer 1⅛ in. thick was placed upon the axle inside each wheel and between it and the box (fig. 23). When the day of change came a few blows of the hammer upon a cold chisel split this collar off and we were ready to press the wheel the needed inch and a half upon the axle.

FIG. 21

FIG. 23

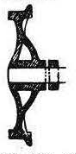


FIG. 24

FIG. 25

FIG. 22

Many of the wheels that were still in use with the long hub were put into a lathe and a groove was cut an inch and a half back from the face, leaving our cast collar; which was easily split off as before. (Fig. 24.)

With tender wheels, as with our car wheels, the case was different. Originally, the axle for the 5-ft. gauge was longer than for the 4 ft. 9 in.; but latterly the 5-ft roads had used a great many Master Car-Builders' axles for the 4 ft. 9 in. gauge, namely, 6 ft. 11¼ in. over all, thus making the width of the truck the same as for 4 ft. 9 in. gauge. To do this a dished wheel, or rather a wheel with a greater dish by 1⅛ in. than previously used was needed, so that the tread of the wheel could be at its proper place; see fig. 25. There were, of course, many of the wheels with small dish and long axles still in use. Their treatment, however, when the day of change came, did not vary from that of the short axles. It had been the rule for some years that all axles should be turned back 1½ in. further than needed; but unfortunately the rule had not been closely followed, and many were found not to be so turned. To make the matter worse, quite a number of the wheels were found to have been counterbored about ½ in. deep at the back end, and the axle turned up to fit this counterbore; a good idea to prevent the running in, in case the wheel worked loose, but bad from the standpoint of a change of gauge. In such cases the wheels had to be started off before the axle could be turned back, so that the wheels could be pushed on in their proper position. (Fig. 26.) If the work was done where they had a lathe large enough to swing a pair of wheels, they were pressed off but half an inch, the wheels swung in the lathe, the axles turned back 1⅛ in., and the wheels then pressed on 2 in. or 1⅛ in. inside of their first position. Where no large lathe was in use, the wheels came entirely off before the axles could be turned back. The work in the former case was both the quicker and the cheaper. Where the large lathes were used they were either set down into the floor, so a pair of wheels would easily roll into place, or a raised platform was put before the lathe, with an incline up which the wheels were rolled and then taken to the lathe. These arrangements were found much quicker and cheaper than to hoist the wheels up, as is usually done. In pressing the wheels on, where the axles had previously been turned back, much trouble was at first experienced because of the rust that had gathered upon the turned part behind the wheel, forming a ridge over or upon which the wheel must be pushed. Some of the roads, at the start, burst 10 or 15 per cent. of the wheels so pressed on. By saturating this surface with coal oil, however, it was found that the rust was easily removed and little trouble was had. It was found, sometimes, that upon axles newly turned back a careless workman would leave a ridge at the starting point of the turning. Frequently, also, the axles were a little sprung, so that the new turning would be a little scant upon one side when compared with the old surface, and upon the opposite side a little full. As an indication that these difficulties were overcome as they appeared, I will say that upon our line only 202 wheels burst, out of nearly 27,000 pressed on, an exceedingly small percentage.

FIG. 26

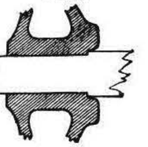


FIG. 27

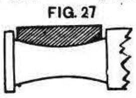
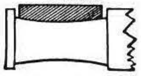


FIG. 28



After the change upon the early roads they were troubled for weeks with hot boxes, caused, as we believed, by the changing of brasses. A brass once fitted to a journal will work upon it without trouble; but when placed upon some other journal will probably not fit. If the journal had been worn hollow (and it was surprising to see how many were so worn), the brass would be found worn down to fit it. See fig. 27, exaggerated of course. The next wheel may have an axle worn little or none, as in fig. 28. Now, if these brasses are exchanged, we have the conditions, as shown in figs. 29 and 30, and we must expect they will heat. The remedy was simply to keep each brass upon its own journal. To do this the brasses were fastened to the axle by a piece of small wire, and went with it to the lathe and press. When its truck was reached, the brass was there with its journal. Worn out brasses, of course, could not be put in, and new ones were substituted. The little trouble from that source that followed the change showed the efficacy of the remedy.

FIG. 29

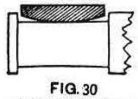


FIG. 30

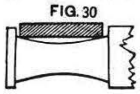
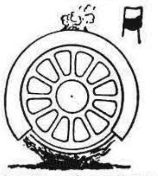


FIG. 31



The manner in which the tires of engines were to be changed, when the final day came, was a serious question. The old fashioned fire upon the ground could not be thought of. The Mobile & Ohio had used a fire of pine under the wheel, which was covered by a box of sheet iron, so arranged that the flame and heat would be conveyed around the tire, and out at an aperture at the top; fig. 31. Many thought this perfect, while others were not satisfied, and began experiments for something better. A device for using gas had been patented, but it was somewhat complicated, as well as expensive, and did not meet with general favor. A very simple device was soon hit upon. A two-inch pipe was bent around in a circle a little larger than the outer rim of the wheel. Holes $\frac{1}{10}$ inch in diameter and 3 or 4 inches apart were drilled through the pipe on the inside of the circle. To this pipe was fastened another with a branch or fork upon it. To one branch or fork was connected a gas-pipe from the meter, while to the other was connected a pipe from an air-pump. With the ordinary pressure of city gas upon this pipe it was found that the air-pump must keep an air-pressure of 40 lbs., that the air and gas might mix properly at the branch or fork, so we could get the best combustion and most heat from our "blow-pipe," for such it was. See fig. 32. We were able to heat a tire so it could be moved in ten to twenty minutes, and the machine may be said to have been satisfactory. Gas, however, was not to be had at all places where it would be necessary to change tires, and the item of cost was considerable. To reach a result as good, if possible, experiments were begun with coal oil (head-light oil). They were crude and unsatisfactory at first, but soon success was reached. A pipe was bent to fit the lower half of a wheel pretty closely, and then turned back under itself about the diameter of the pipe distant from it. This under part had holes $\frac{1}{10}$ in. in diameter and 3 or 4 in. apart, drilled upon its upper side, or under the upper pipe. Connected with the upper pipe at its centre was a pipe which ran to one side and up to the can containing the kerosene. Between the can and the pipe under the wheel was a stop-cock by which the flow of oil could be controlled. To use the device, open the cock and let a small amount of oil flow; apply fire to the pipe under the wheel, and the oil in the upper pipe is converted into gas, which flows out of the small holes in the lower pipes, takes fire and heats not only the tire, but the upper pipe, thus converting more oil into gas. We had here a lot of blue flame jets and the same result as with gas, but at less cost. We had also a machine that was inexpensive and easily handled anywhere. Boxes were placed over the upper part of the wheels, that the heat might pass close to the tire. This device was extensively used by our people, and with great satisfaction. Care had to be taken that in starting the fire it did not smoke and cover the tire with carbon or "lampblack," which is a non-conductor of heat. Experiments were made with air forced through gasoline, and with oil heated in a can to form gas. There was more danger in either of these than with our blow-pipe device, and no better results were obtained, though the cost was greater.

FIG. 32

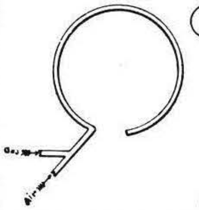
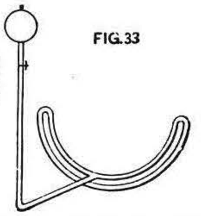
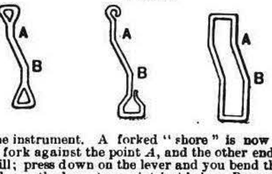


FIG. 33



With the change of the wheels, the brakes had to be changed the same amount, that is, each one set in 1⅛ in. This it was thought would either require new hangers, or a change in the head or shoe in some way. We found that the hangers could easily be bent without removal. Fig. 34 shows three hangers after passing through the bending process. A short lever arranged to clasp the hanger just below the point *A* was the instrument. A forked "shore" is now placed, with the fork against the point *A*, and the other end agains the car sill; press down on the lever and you bend the hanger at *A*; lower the lever to a point just below *B*, reverse the process and you have the bend at *B*; the whole thing taking less than two minutes per hanger. A new bolt hole, of course, has been bored in the brake beam 1⅛ in. inside the old bolt. It takes but a short time after this to change the position of the head and shoe.

FIG. 34

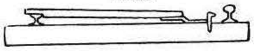


Before the day of change, a portion of the spikes were drawn from the inside of the rail to be moved, and a spike set 3 in. inside of the rail. As a rule two spikes were drawn and the third left. At least every third spike was set for the new gauge, and in some cases every other one. There were several devices with which to set the spike. A small piece of iron 3 in. wide was common, and answered the purpose well. This had a handle, sometimes small, just large enough for the hand to clasp, while others had a handle long enough for a man to use it without stooping down. See figs. 35 and 36. Another device is shown in fig. 37, so arranged that the measurements were made from the head of the other rail. This was liked best, and, it is thought, gave the best results, as the moved rail was more likely to be in good line than when the measurements were taken from the flange. It was intended that great care should be taken in driving the spikes, that they were in the proper place, square with the rail, and left sticking up about an inch. The ties, of course, were all adzed down before the day of change.

FIG. 35

FIG. 36

FIG. 37



Hand-spikes were originally used to throw the rails, as were lining bars. We found, however, that small cant-hooks were more easily handled and did better work. The first were made like fig. 38, with a spike in the end of a stick, while the hook was fastened with a bolt about 10 or 12 in. above the foot. We afterward made them of a 1¼ in. rod, 3½ feet long, pointed at one end, with a ring shrunk on 1 foot from the bottom. Then the hook was made with an eye, as shown in fig. 39, which slipped down over the top of the main rod. This was simple and cheap, and the iron was to be used for repair purposes when this work was done.

FIG. 38

FIG. 39

Upon the system with which the writer was connected we had some branches where we could experiment upon the moving of the rail. Between Selma and Lauderdale the traffic was light, and at Lauderdale it connected with the Mobile & Ohio Railroad, which was narrow, and to which all freight had to be transferred, either by hoisting the cars, or by handling through the house. By changing our gauge we would simply change the point of transfer to Selma. Here was a chance to experiment upon one hundred miles and cause little trouble to traffic. We could see the practical workings of our plans, and, at the same time, leave less to do on the final day. Upon the 20th of April we did this work. It had been our plan to do it somewhat earlier, but floods prevented. Most of the rail was old chair iron, short, and consequently more time was used in making the change than would have been required had our work been on fish plate rail. Our sections here were about eight miles long, and we arranged our men on the basis blocked out by the committee, viz.: 24 to 26 men to the section, consisting of 6 spike pullers, 4 throwing rails, 12 spikers, 2 to push the cars and carry water.

We soon found 5-ft. cars useless and threw them into the ditch to be picked up at some future time.

The men were spread out so as not to be in each other's way, and, when the organization was understood and conformed to, it worked well. One gang changed 5 miles in five hours and ten minutes, including a number of switches. We found, however, and it was demonstrated still more strongly on later work, that after 5 or 6 miles the men began to lag. We believed we had the best results when we had sections of about that length. It was arranged that two sections, alternately, commenced work together at one point, working from each other and continuing until the force of another section was met, working from the opposite direction.

The foreman in charge was expected to examine the work and know that all was right. The push car which followed was a good test as to gauge. A work train was started from each end with a small force (20 or 25 men) to run over the changed track. This train, of course, had been changed on a previous day to be ready for this work. If a force was overtaken by this train with its work not done, the men on the train were at once spread out to aid in its completion. This done, the train ran on. Not until this was done was a traffic train allowed to pass over the track. The same rule was followed upon all the work. Upon the final day it was required that upon all high trestles and in tunnels the track should be full spiked before being left, or a train let over. This took extra time and labor, and possibly was not necessary; but it was a precaution on the side of safety.

Upon the day of the change of the Alabama Central Division (Selma to Lauderdale), superintendents of other divisions, with their road masters, supervisors, master mechanics and many section foremen, were sent over to see the organization and work and the preparations that had been made. Many of them lent a helping hand in the work. They saw here in practice what had only been theory before. About a week before the general change that portion of the road between Rome, Ga., and Selma, Ala., about 200 miles, was changed, and again men from other divisions were sent to see and aid in the work; so when the final day came the largest possible number of men were able to work understandingly.

On the last day of May the Memphis & Charleston, Knoxville & Ohio, and North Carolina Branch were changed, and on June 1 the line from Bristol to Chattanooga and Brunswick. Other roads changed their branch lines a day or two before the 1st of June; but the main lines, as a rule, were changed on that day.

It was no small matter to take care of the cars and arrange the train service so there should be no hitches. It was not expected that connections would move freight during the 48 hours prior to the change, and these days were spent in clearing the road of everything, and taking the cars to the points of rendezvous. All scheduled freight trains were abandoned on the day prior to the change, and only trains run *to* such points. Upon the East Tennessee system these points were Knoxville, Rome, Atlanta, Macon, Huntsville and Memphis, and to these points all cars must go, loaded or empty, and there they were parked upon the tracks prepared for the purpose. Passenger trains were run to points where it had been arranged to change them, generally to the general changing point. Most of the Southern roads have double daily passenger service; upon all roads one of these trains, upon the day of change, was abandoned, and upon some, all. Some, even, did not run till next day. We were able to start the day trains out by 10 o'clock or 11 o'clock a. m., and put them through in fair time. Of course, no freights were run that day, and the next day was used in getting the cars which had been changed, out of the parks and into line. So our freight traffic over the entire South was suspended practically three days.

The work of changing was to commence at 3:30 a. m., but many of the men were in position at an earlier hour and did commence work as soon as the last train was over, or an hour or so before the fixed time. Half-past three a. m., however, can be set down as the general hour of commencement. For five or six hours in the cool morning the work went on briskly, the men working with much more than ordinary enthusiasm; but the day was warm, and after 9 or 10 a. m. it began to lag. All was done, however, before the day was over, and safe, so that trains could pass at full speed. The men all received $1.50 for the work, whether it was finished early or late in the day, and were paid that afternoon as soon as the work was done. Tickets were given the men, which the nearest agent paid, remitting as cash to the treasurer.

On some lines it was deemed best to offer prizes to those who got through first. Reports showed some very early finishes; but the facts seem to have been that under such encouragement the men were apt to pull *too many* spikes before the change and put *too few* in while changing. They were thus reported through early, but their work was not done, and they took great chances. It was by most considered unwise to offer such prizes, preferring to have a little more taken and be sure that all was safe. Such lines seemed to get their trains in motion with as much promptness as others. This, with freedom from accident, was the end sought.

It was found after the work had been done that there had been little inaccuracies in driving the gauge spike, to which the rail was thrown, probably from various causes. The rail to be moved may not always have been exactly in its proper place, and then the template in the hurry may not have been accurately placed, or the spike may have turned or twisted. Whatever was the cause, it was found that frequently the line on the moved side was not perfect, and, of course, many spikes had to be drawn and the rail lined up and re-spiked. The more careful the work had been done, the less of this there was to do afterward. With rough track this was least seen. The nearer perfect the more noticeable it was.

Of course, we all planned to get foreign cars home and have ours sent to us; but when the interchange stopped, we found we had many foreign cars, which, of course, had to be changed. This subject had come up in convention and it had been voted to charge $3 per car when axles did not need turning, and $5 where they did. By comparison with the cost of changing, as shown in this paper, it will be seen that to our company, at least, there was no loss at these figures.

The following statements will explain the work done upon the Louisville & Nashville, and East Tennessee, Virginia & Georgia systems.

It is to be regretted that the writer has not at hand information regarding other roads that fuller statements and comparisons might be made and the showings be of greater value.

The figures of the Mobile & Ohio are added, having been compiled from the annual report of that road.

MOBILE & OHIO RAILROAD.

(*Compiled from Annual Report.*)

| | Number changed. | Cost of labor. | Cost of material. | Total cost. | Average cost. |
|---|---|---|---|---|---|
| Engines and tenders . | 47 | $8,031.42 | $7,276.86 | $15,308.28 | $325 70 |
| Pass., bag. and ex. c's | 55 | 438.37 | 104.25 | 542.62 | 9.87 |
| Freight c's, 1,361 ...<br>Fre't tr'ks, 107½.... | 1,468½ | 5,719.03 | 739.57 | 6,458.60 | 4.40 |
| Lever and push cars. | 143 | 1,427.55 | 476 93 | 1,904.48 | 13.32 |
| | Miles. | | | | |
| Track (including sidings) ... | 583.5 | 17,109.53 | 7,275.14 | 24,384.67 | 41.79 |
| Bridges ... | ..... | 1,896.60 | 190.00 | 2,086.60 | 3.58 |
| Track tools. | .... | 170.72 | 1,405.74 | 1,576.46 | 2.70 |
| Shop tools.. | ..... | 419.70 | 2,982.90 | 3,402 60 | 5.83 |
| Temporary side tracks | 12.09 | 1,958.94 | 372.37 | 2,331.31 | 192 83 |
| Switch'g cars | ...... | 1,398.18 | 16.50 | 1,414.68 | ...... |
| Car hoists ... | ...... | 2,499.38 | 4,419.34 | 6,918.72 | ...... |
| Total cost.. | | $41,060.42 | $25,259.60 | $66,320.02 | .. |
| Total average cost per mile. | | | | | $113 68 |

LOUISVILLE & NASHVILLE RAILROAD.

(*Compiled from Annual Report.*)

Main line, 1,893.7; side track, 196.3; total, 2,090 0.

| *Track :* | | Cost per mile. |
|---|---|---|
| Section labor | $67,910.21 | $32 49 |
| Carpenter labor | 3,799.19 | 1.82 |
| Spikes | 20,873.70 | 9 99 |
| Switches | 6,331.85 | 3.03 |
| Tools | 2,749.50 | 1.31 |
| Hand cars and sundries | 5,691.39 | 2.72 |
| Total | $107,355 84 | $51.36 |

| *Equipment :* | Number. | Total | Average cost. |
|---|---|---|---|
| Locomotives | 264 | $53,480.98 | $202.58 |
| Cars (300 of these passenger—3.5 per cent.) | 8,537 | 49 577 20 | 55.81 |
| Total cost | | $210,414.02 | |
| Total average cost per mile | | | $100.67 |

EAST TENNESSEE, VIRGINIA & GEORGIA SYSTEM.

| | Number changed. | Cost of labor. | Cost of material. | Total cost. | Average cost. |
|---|---|---|---|---|---|
| Engines and tenders ... | 180 | $8,227.47 | $2,904.30 | $11,131.77 | $61.82 |
| Pass., bag. and mail cars ..... | 168 | 734.93 | 59.67 | 794 60 | 4 73 |
| Freight cars and cabo's. | 5,175 | 17 425.57 | 1,224.08 | 18,649.65 | 3.60 |
| M. of W. cars | 439 | 2,038.44 | 549.47 | 2,587.91 | 5.89 |
| | Miles. | | | | |
| Track (inc. sidings)... | 1,532.7 | 27,718.17 | 40,912.09 | 68,630.26 | 44.78 |
| Bridges... | 1,532.7 | 1,808.57 | 200.00 | 2,008 57 | 1.31 |
| Track tools | 1,532.7 | 194.48 | 2,573.83 | 2,768.31 | 1.80 |
| Storage tr'ks, inc. taking up......... | 37.02 | 9,825.41 | 1,481.59 | 11,307.00 | 305.44 |
| Shop tools.. | ........ | 472.20 | 2,728.30 | 3,200.50 | ..... |
| Total cost......... | | $68,445.24 | $52,633.33 | $121,078.57 | ...... |
| Total average cost per mile | | | | | $79.06 |

| | |
|---|---|
| Axles condemned | 577 |
| Wheels condemned | 754 |
| Wheels burst | 202 |
| New axles used | 1,102 |
| New wheels used | 2 783 |
| Axles turned back | 8,316 |
| Wheels pressed on without turning axle | 23,952 |
| New brasses used | 10,723 |
| Cars narrowed (not including lever or push cars) | 5,343 |
| Engines narrowed | 180 |
| Average cost of new centres and crank pins, etc. | $164.46 |
| Average cost of cutting off hub and pressing wheels and new pins | 130.67 |
| Average cost of pressing old tires on old centres | 29.08 |
| Average cost of pressing old tires on broad centres | 31.83 |
| Average cost of labor putting on new tires | 22.94 |

COMPARATIVE STATEMENT OF AVERAGE COST OF VARIOUS ITEMS OF WORK.

| | M. & O. R. R. | L. & N. R. R. | E. T. V. & G. R. R. | Average. |
|---|---|---|---|---|
| Engines and tenders, per engine | $325.70 | $202.58 | $61.82 | $196.70 |
| Pass., bag. and Ex. cars, per car | 9.87 | *5.81 | 4.73 | 6 80 |
| Freight cars, per car. | 4 40 | †5.81 | 3 60 | 4.60 |
| M. of W. cars, per car. | 13.32 | 2.72 | 5.89 | 7.31 |
| Track (inc. sidings, bridges, etc.), per mile | 45.37 | 47.33 | 46.09 | 46.26 |
| Track tools, per mile | 2.70 | 1.31 | 1 80 | 1.94 |
| Temporary side tracks, per mile.. | 192.83 | ........ | 305.44 | 249.13 |
| Total per mile of track, inc. sidings | $113.68 | $100.67 | $79.06 | $97.80 |

*Expense not divided as between passenger and freight cars.

†3.5 per cent. passenger, baggage and express cars; 96.5 per cent. freight cars.

Since the preparation of this paper the general manager of the Norfolk & Western Railroad has kindly furnished the following items of expense for that line:

| | No. | Cost. | Average cost. |
|---|---|---|---|
| Engines and tenders | 95 | $37,730.00 | $397.16 |
| Cars (all kinds). | 3,615 | 37,994.65 | 10.51 |
| Track, miles (including sidings) | 597.5 | | |
| Labor | | 25,296,96 | |
| Tools and supplies | | 3,581.12 | |
| Changing M. of W. equipment | | 813.13 | |
| Switches | | 571.67 | |
| Spikes | | 508.22 | |
| Total track | | $38,721.10 | 64.80 |
| Total | | $114,445.75 | |
| Total average cost per mile | | | $191.53 |

And the superintendent of the Savannah, Florida & Western has also furnished the expenses for that road:

| | No. | Average cost |
|---|---|---|
| Engines and tenders | 75 | $76.31 |
| Cars (passenger) | 95 | 4.67 |
| " (freight) | 1,133 | 3.88 |
| Track, including sidings | 601.76 | 44.49 |

Nothing was said about shop or other tools, storage tracks or changing of maintenance of way equipment.

COMPARATIVE STATEMENT OF AVERAGE COST OF LABOR OF VARIOUS ITEMS OF WORK.

| | M. & O. R. R. | L. & N. R. R. | E. T., V. & G. R. R. | Average. |
|---|---|---|---|---|
| Engines and tenders. | $170.88 | Not divided. | $45.71 | $108 29 |
| Pass. bag. and ex. cars. | 7.97 | | 4 38 | 6 17 |
| Freight cars | 3.89 | | 3 36 | 3.62 |
| M. of W. cars | 9.98 | | 4.64 | 7 31 |
| Miles track (inc. sidings, bridges, etc.) | 32.57 | 34.31 | 19.26 | 28.71 |
| Track tools per mile | .30 | No | .13 | .21 |
| Temporary tracks | 162.03 | divided. | 265.40 | 213.71 |
| Total per mile of track | $70.38 | Not divided. | $44.72 | $57.55 |

COMPARATIVE STATEMENT OF AVERAGE COST OF MATERIAL OF VARIOUS ITEMS OF WORK.

| | M. & O. R. R. | L. & N. R. R. | E. T. V. & G Ry. | Average. |
|---|---|---|---|---|
| Engines and tenders | $154.82 | Not divided. | $16.11 | $85 46 |
| Pass. bag. and ex. cars. | 1 90 | | .35 | 1.12 |
| Freight cars | .51 | | .24 | .37 |
| M. of W cars | 3.34 | | 1.25 | 2.30 |
| Miles track (inc. sidings, bridges, etc.) | 12 80 | 13.02 | 26.83 | 17.55 |
| Track tools per mile | 2.40 | Not | 1.67 | 2.03 |
| Temporary tracks | 162 03 | divided. | 40.04 | 101 03 |
| Total per mile of track | $44 30 | Not divided. | $34.34 | $38.82 |

SUMMARY OF STATEMENTS OF L. & N. AND E. T., V. & G. RAILWAYS.

| | |
|---|---|
| The mileage changed of the L & N. and E T., V. & G. systems combined aggregates | 3,622 miles |
| The total cost of these two roads | $331,492.59 |
| Or an average per mile of | 91.52 |
| Total miles changed was about | 14,500 miles. |
| Which would give total cost, at same rate | $1,327 040 |

We should really add to this a large sum for the great number of new locomotives which were purchased to replace old ones that could not be changed, except at large cost, and which, when done, would have been light and undesirable.

Upon the basis of the work done upon the Louisville & Nashville and East Tennessee, Virginia & Georgia systems, which combined cover about one-fourth the mileage changed, we have made the following estimates, which will perhaps convey a better idea of the extent of the work than can be obtained in any other way

| | |
|---|---|
| Miles of track changed, about | 14 500 |
| Locomotives changed, about | 1,800 |
| Cars (pass. and freight) changed, about | 45 000 |
| New axles used, about | 9 000 |
| New wheels used, about | 20,000 |
| Axles turned back, about | 75,000 |
| Wheels pressed on without turning axles, about | 220,000 |
| New brasses used, about | 90,000 |
| Kegs of spikes used, about | 50,000 |
| Cost of material used, about | $600,000 |
| Cost of labor, about | 730,000 |
| Total cost of work, about | 1,330,000 |
| Amount expended on equipment, about | 650,000 |
| Amount expended on track, about | 680,000 |
| Amount expended on track on day of change in labor, about | 140,000 |

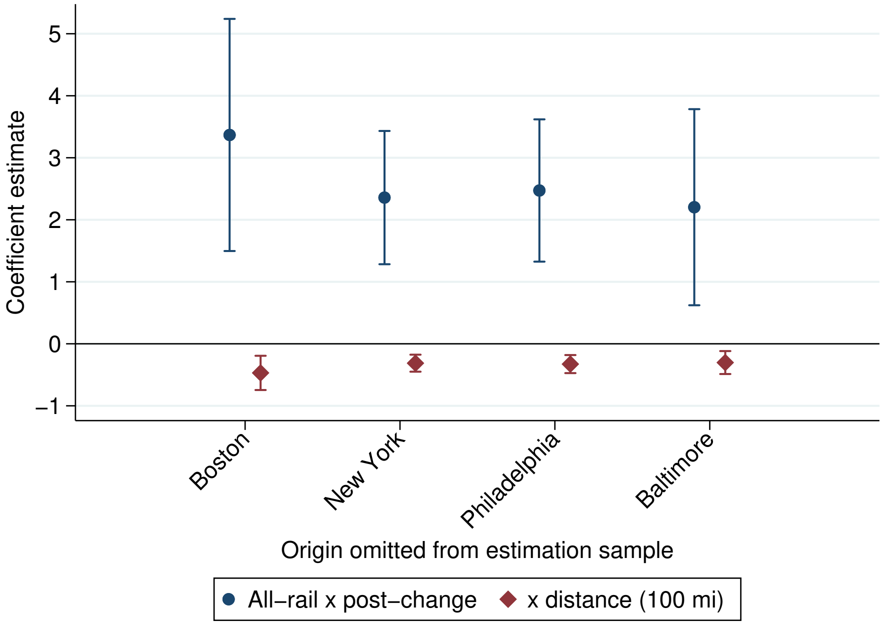
The work was done economically, and so quietly that the public hardly realized it was in progress. To the casual observer it was an every-day transaction. It was, however, a work of great magnitude, requiring much thought and mechanical ability. That it was ably handled is evidenced by the uniform success attained, the prompt changing at the agreed time, and the trifling inconvenience to the public.

# D Sensitivity Checks

## D.1 Sensitivity Checks: Dropping Origins

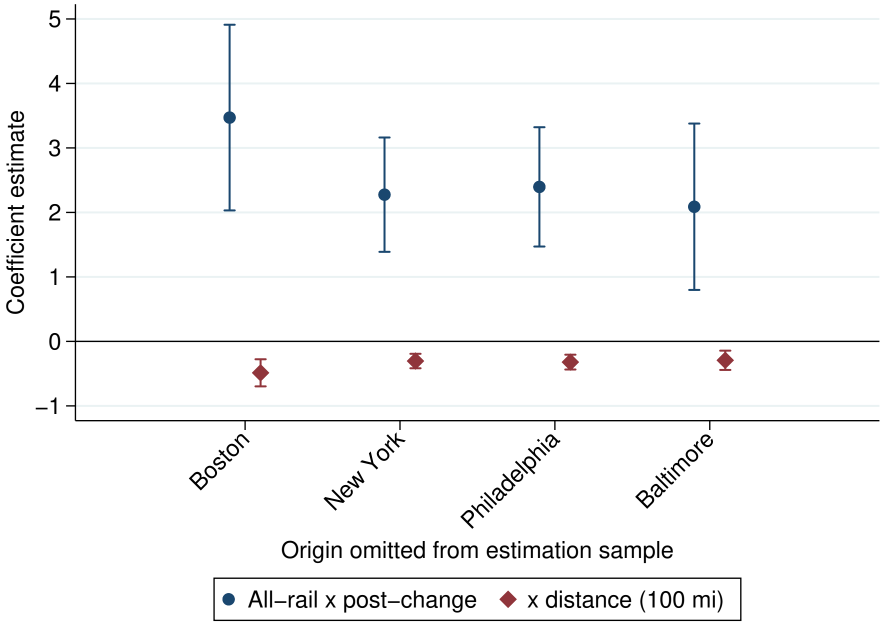
This section evaluates the sensitivity of the main results in Tables 3 and 5 to dropping observations with a given origin. Figure D.1 illustrates the stability of the results in Table 3, plotting the focal coefficient estimates from a specification of log quantities with route-year fixed effects (as in Column 5), omitting the given origin. Figure D.2 does the same for Table 5, plotting the focal coefficient estimates from a specification of traffic shares with route fixed effects (as in Column 2). The 95% confidence interval for each parameter is also provided.

Figure D.1: Focal coefficient estimates from Table 3, omitting the given origin



Notes: Figure plots focal coefficient estimates (and 95% confidence intervals) from a regression of log quantities with route-year fixed effects (as in Column 5 of Table 3), omitting the given origin.

Figure D.2: Focal coefficient estimates from Table 5, omitting the given origin

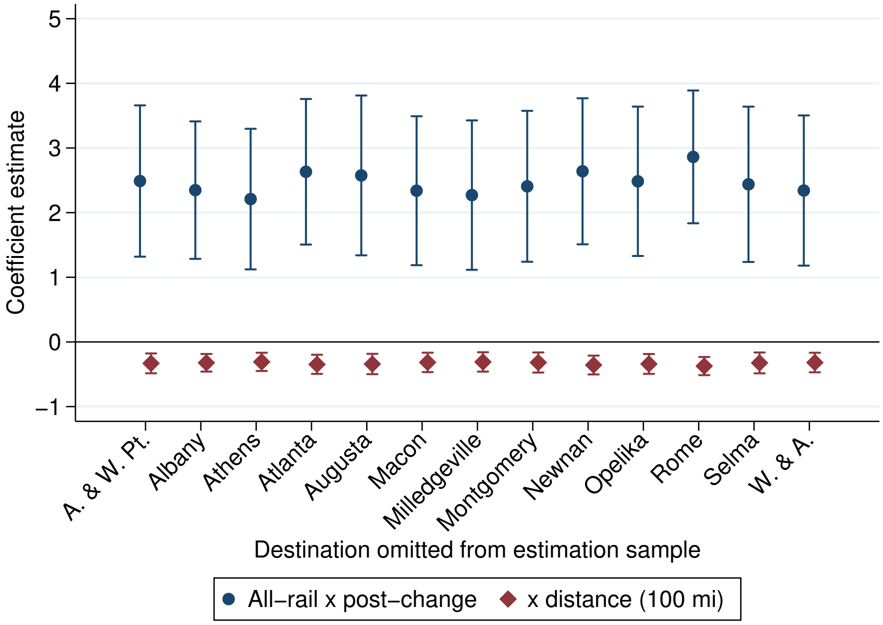


Notes: Figure plots focal coefficient estimates (and 95% confidence intervals) from a regression of traffic shares with route fixed effects (as in Column 2 of Table 5), omitting the given origin.

## D.2 Sensitivity Checks: Dropping Destinations

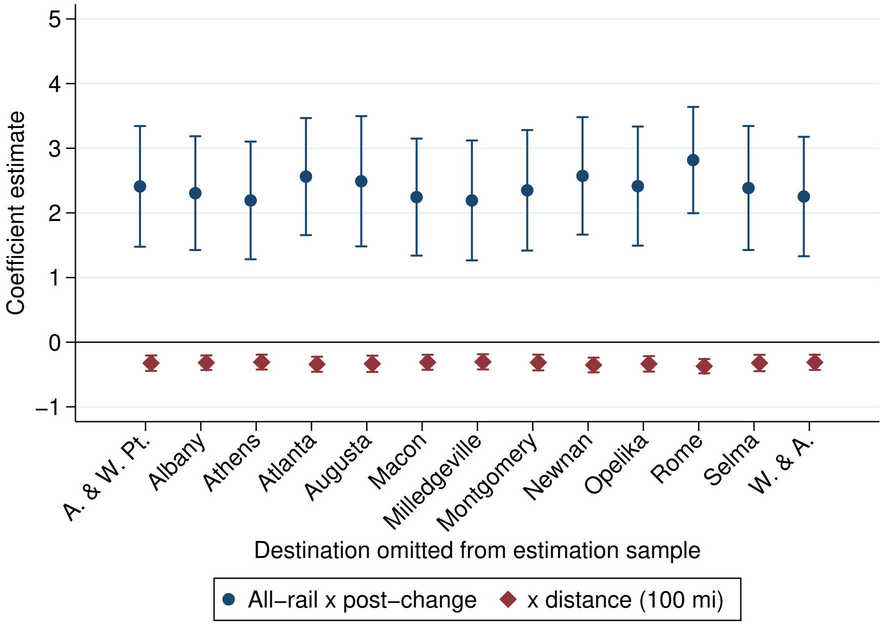
This section evaluates the sensitivity of the main results in Tables 3 and 5 to dropping observations with a given destination. Figure D.3 illustrates the stability of the results in Table 3, plotting the focal coefficient estimates from a specification of log quantities with route-year fixed effects (as in Column 5), omitting the given origin. Figure D.4 does the same for Table 5, plotting the focal coefficient estimates from a specification of traffic shares with route fixed effects (as in Column 2). The 95% confidence interval for each parameter is also provided.

Figure D.3: Focal coefficient estimates from Table 3, omitting the given destination



Notes: Figure plots focal coefficient estimates (and 95% confidence intervals) from a regression of log quantities with route-year fixed effects (as in Column 5 of Table 3), omitting the given destination.

Figure D.4: Focal coefficient estimates from Table 5, omitting the given destination

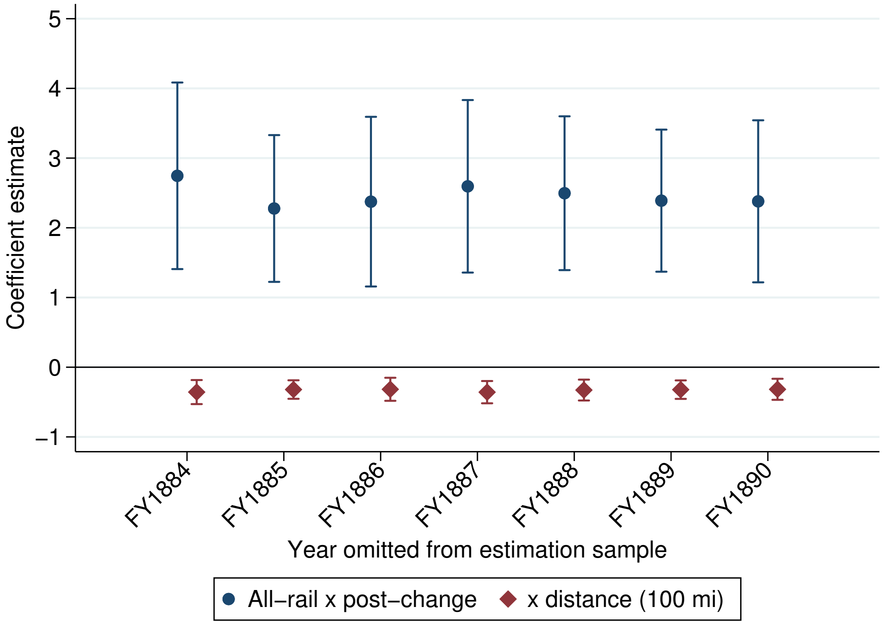


Notes: Figure plots focal coefficient estimates (and 95% confidence intervals) from a regression of traffic shares with route fixed effects (as in Column 2 of Table 5), omitting the given destination.

## D.3 Sensitivity Checks: Dropping Years

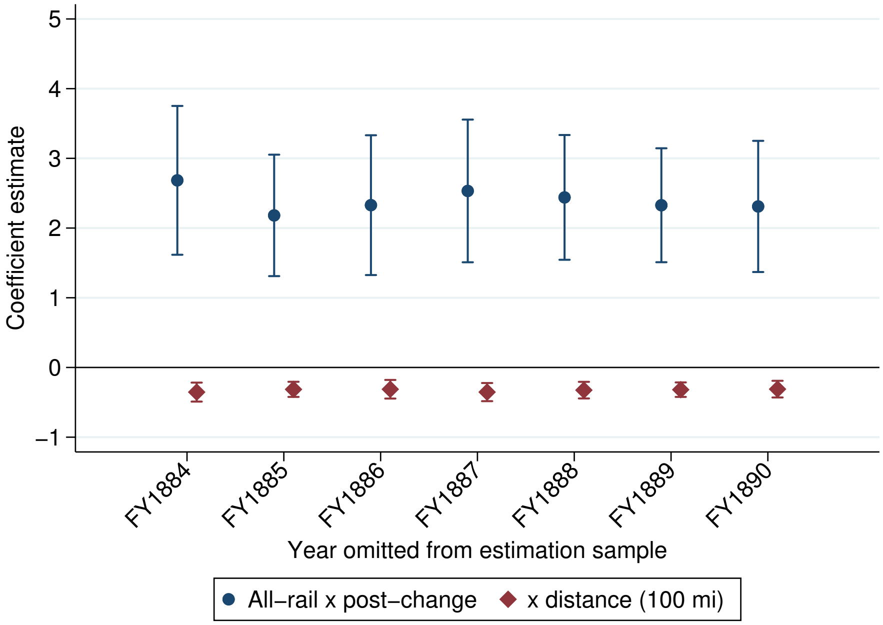
This section evaluates the sensitivity of the main results in Tables 3 and 5 to dropping observations in a given year. Figure D.5 illustrates the stability of the results in Table 3, plotting the focal coefficient estimates from a specification of log quantities with route-year fixed effects (as in Column 5), omitting the given origin. Figure D.6 does the same for Table 5, plotting the focal coefficient estimates from a specification of traffic shares with route fixed effects (as in Column 2). The 95% confidence interval for each parameter is also provided.

Figure D.5: Focal coefficient estimates from Table 3, omitting the given year



Notes: Figure plots focal coefficient estimates (and 95% confidence intervals) from a regression of log quantities with route-year fixed effects (as in Column 5 of Table 3), omitting the given year.

Figure D.6: Focal coefficient estimates from Table 5, omitting the given year



Notes: Figure plots focal coefficient estimates (and 95% confidence intervals) from a regression of traffic shares with route fixed effects (as in Column 2 of Table 5), omitting the given year.

# E Proofs of Propositions

## Proofs for Section 4.1

### 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:*

*a. If R1 converts alone:* $\Delta\pi_{R1}^{10} > 0$, $\Delta\pi_{R2}^{10} = 0$

*b. If R2 converts alone:* $\Delta\pi_{R1}^{01} < 0$, $\Delta\pi_{R2}^{01} < 0$

*c. If R1 and R2 convert jointly:* $\Delta\pi_{R1}^{11} > \Delta\pi_{R1}^{10}$, $\Delta\pi_{R2}^{11} > 0$

**Proof:**

<u>*Part 1.*</u> If neither R1 nor R2 convert to standard gauge:

$$\begin{aligned}
&\Pi_1 = (P_1 - c - \theta)Q_1 = (P_1 - c - \theta)(M_1 - aP_1) \\
&\quad \frac{\partial \Pi_1}{\partial P_1} = M_1 - 2aP_1 + a(c+\theta) = 0 \quad \implies \quad P_1 = \frac{1}{2a}(M_1 + a(c+\theta)) \text{ , } Q_1 = \frac{1}{2}(M_1 - a(c+\theta)) \\
&\quad \Pi_1 = \left(\left[\frac{1}{2a}(M_1 + a(c+\theta))\right] - c - \theta\right)\left[\frac{1}{2}(M_1 - a(c+\theta))\right] \\
&\qquad = \left(\frac{1}{2}\left(\frac{M_1}{a} - c - \theta\right)\right)\left(\frac{1}{2}a\left(\frac{M_1}{a} - c - \theta\right)\right) = \frac{1}{4}a\left(\frac{M_1}{a} - c - \theta\right)^2
\end{aligned}$$

and by symmetry, $\Pi_2 = \frac{1}{4}a\left(\frac{M_2}{a} - 2c - \theta\right)^2$.

R1 and R2 profits are thus:

$$\begin{aligned}
&\pi_1^{00} = \Pi_1 + \frac{1}{2}\Pi_2 = \frac{1}{4}a\left(\frac{M_1}{a} - c - \theta\right)^2 + \frac{1}{2}\left(\frac{1}{4}a\left(\frac{M_2}{a} - 2c - \theta\right)^2\right) \\
&\pi_2^{00} = \frac{1}{2}\Pi_2 = \frac{1}{2}\left(\frac{1}{4}a\left(\frac{M_2}{a} - 2c - \theta\right)^2\right)
\end{aligned}$$

*Part 2.* If only R1 converts to standard gauge:

$$\Pi_1 = (P_1 - c)Q_1 = (P_1 - c)(M_1 - aP_1)$$

$$\frac{\partial \Pi_1}{\partial P_1} = M_1 - 2aP_1 + ac = 0 \quad \Longrightarrow \quad P_1 = \frac{1}{2a}(M_1 + ac)\ ,\ Q_1 = \frac{1}{2}(M_1 - ac)$$

$$\begin{aligned} \Pi_1 &= \left(\left[\frac{1}{2a}(M_1 + ac)\right] - c\right)\left[\frac{1}{2}(M_1 - ac)\right] \\ &= \left(\frac{1}{2}\left(\frac{M_1}{a} - c\right)\right)\left(\frac{1}{2}a\left(\frac{M_1}{a} - c)\right)\right) = \frac{1}{4}a\left(\frac{M_1}{a} - c\right)^2 \end{aligned}$$

$$\Pi_2 = (P_2 - 2c - \theta)Q_2 = (P_2 - 2c - \theta)(M_2 - aP_2)$$

$$\frac{\partial \Pi_2}{\partial P_2} = M_2 - 2aP_2 + a(2c + \theta) = 0 \quad \Longrightarrow \quad P_2 = \frac{1}{2a}(M_2 + a(2c + \theta))\ ,\ Q_2 = \frac{1}{2}(M_2 - a(2c + \theta))$$

$$\begin{aligned} \Pi_2 &= \left(\left[\frac{1}{2a}(M_2 + a(2c + \theta))\right] - c - \theta\right)\left[\frac{1}{2}(M_2 - a(2c + \theta))\right] \\ &= \left(\frac{1}{2}\left(\frac{M_2}{a} - 2c - \theta\right)\right)\left(\frac{1}{2}a\left(\frac{M_2}{a} - 2c - \theta)\right)\right) = \frac{1}{4}a\left(\frac{M_2}{a} - 2c - \theta\right)^2 \end{aligned}$$

R1 and R2 profits are thus:

$$\begin{aligned} \pi_1^{10} &= \Pi_1 + \frac{1}{2}\Pi_2 = \frac{1}{4}a\left(\frac{M_1}{a} - c\right)^2 + \frac{1}{2}\left(\frac{1}{4}a\left(\frac{M_2}{a} - 2c - \theta\right)^2\right) \\ \pi_2^{10} &= \frac{1}{2}\Pi_2 = \frac{1}{2}\left(\frac{1}{4}a\left(\frac{M_2}{a} - 2c - \theta\right)^2\right) \end{aligned}$$

*Part 3.* If only R2 converts to standard gauge:

$$\Pi_1 = (P_1 - c - \theta)Q_1 = (P_1 - c - \theta)(M_1 - aP_1)$$

$$\frac{\partial \Pi_1}{\partial P_1} = M_1 - 2aP_1 + a(c+\theta) = 0 \quad \Longrightarrow \quad P_1 = \frac{1}{2a}(M_1 + a(c+\theta))\ ,\ Q_1 = \frac{1}{2}(M_1 - a(c+\theta))$$

$$\Pi_1 = \left(\left[\frac{1}{2a}(M_1 + a(c+\theta))\right] - c - \theta\right)\left[\frac{1}{2}(M_1 - a(c+\theta))\right]$$

$$= \left(\frac{1}{2}\left(\frac{M_1}{a} - c - \theta\right)\right)\left(\frac{1}{2}a\left(\frac{M_1}{a} - c - \theta)\right)\right) = \frac{1}{4}a\left(\frac{M_1}{a} - c - \theta\right)^2$$

$$\Pi_2 = (P_2 - 2c - 2\theta)Q_2 = (P_2 - 2c - 2\theta)(M_2 - aP_2)$$

$$\frac{\partial \Pi_2}{\partial P_2} = M_2 - 2aP_2 + a(2c+2\theta) = 0 \quad \Longrightarrow \quad P_2 = \frac{1}{2a}(M_2 + a(2c+2\theta))\ ,\ Q_2 = \frac{1}{2}(M_2 - a(2c+2\theta))$$

$$\Pi_2 = \left(\left[\frac{1}{2a}(M_2 + a(2c+2\theta))\right] - c - 2\theta\right)\left[\frac{1}{2}(M_2 - a(2c+2\theta))\right]$$

$$= \left(\frac{1}{2}\left(\frac{M_2}{a} - 2c - 2\theta\right)\right)\left(\frac{1}{2}a\left(\frac{M_2}{a} - 2c - 2\theta)\right)\right) = \frac{1}{4}a\left(\frac{M_2}{a} - 2c - 2\theta\right)^2$$

R1 and R2 profits are thus:

$$\pi_1^{01} = \Pi_1 + \frac{1}{2}\Pi_2 = \frac{1}{4}a\left(\frac{M_1}{a} - c - \theta\right)^2 + \frac{1}{2}\left(\frac{1}{4}a\left(\frac{M_2}{a} - 2c - 2\theta\right)^2\right)$$

$$\pi_2^{01} = \frac{1}{2}\Pi_2 = \frac{1}{2}\left(\frac{1}{4}a\left(\frac{M_2}{a} - 2c - 2\theta\right)^2\right)$$

*Part 4.* If both R1 and R2 convert to standard gauge:

$$\Pi_1 = (P_1 - c)Q_1 = (P_1 - c)(M_1 - aP_1)$$

$$\frac{\partial \Pi_1}{\partial P_1} = M_1 - 2aP_1 + ac = 0 \quad \Longrightarrow \quad P_1 = \frac{1}{2a}(M_1 + ac)\ ,\ Q_1 = \frac{1}{2}(M_1 - ac)$$

$$\Pi_1 = \left(\left[\frac{1}{2a}(M_1 + ac)\right] - c\right)\left[\frac{1}{2}(M_1 - ac)\right]$$

$$= \left(\frac{1}{2}\left(\frac{M_1}{a} - c\right)\right)\left(\frac{1}{2}a\left(\frac{M_1}{a} - c)\right)\right) = \frac{1}{4}a\left(\frac{M_1}{a} - c\right)^2$$

and by symmetry, $\Pi_2 = \frac{1}{4}a\left(\frac{M_2}{a} - 2c\right)^2$.

R1 and R2 profits are thus:

$$\pi_1^{11} = \Pi_1 + \frac{1}{2}\Pi_2 = \frac{1}{4}a\left(\frac{M_1}{a} - c\right)^2 + \frac{1}{2}\left(\frac{1}{4}a\left(\frac{M_2}{a} - 2c\right)^2\right)$$

$$\pi_2^{11} = \frac{1}{2}\Pi_2 = \frac{1}{2}\left(\frac{1}{4}a\left(\frac{M_2}{a} - 2c\right)^2\right)$$

*Part 5.* Comparisons to the status quo

If R1 converts alone:

$$\Delta\pi_{R1}^{10} = \pi_{R1}^{10} - \pi_{R1}^{00} = \frac{1}{4}a\left(\frac{M_1}{a} - c\right)^2 - \frac{1}{4}a\left(\frac{M_1}{a} - c - \theta\right)^2$$
$$= \frac{1}{4}a\left(\left(\frac{M_1}{a} - c\right)^2 - \left(\frac{M_1}{a} - c - \theta\right)^2\right) = \frac{1}{4}a\left(2\theta\left(\frac{M_1}{a} - c\right) - \theta^2\right) = \frac{1}{2}\theta\left(M_1 - ac - \frac{1}{2}a\theta\right) > 0$$

$$\Delta\pi_{R2}^{10} = \pi_{R2}^{10} - \pi_{R2}^{00} = 0$$

If R2 converts alone:

$$\Delta\pi_{R1}^{01} = \pi_{R1}^{01} - \pi_{R1}^{00} = \frac{1}{2}\left(\frac{1}{4}a\left(\frac{M_2}{a} - 2c - 2\theta\right)^2\right) - \frac{1}{2}\left(\frac{1}{4}a\left(\frac{M_2}{a} - 2c - \theta\right)^2\right)$$
$$= \frac{1}{8}a\left(\left(\frac{M_2}{a} - 2c - 2\theta\right)^2 - \left(\frac{M_2}{a} - 2c - \theta\right)^2\right)$$
$$= \frac{1}{8}a\left(\left(\frac{M_2}{a} - 2c - \theta - \theta\right)^2 - \left(\frac{M_2}{a} - 2c - \theta\right)^2\right)$$
$$= \frac{1}{8}a\left(-2\theta\left(\frac{M_2}{a} - 2c - \theta\right) + \theta^2\right) = -\frac{1}{4}\theta\left(M_2 - 2ac - \frac{3}{2}a\theta\right) < 0$$

$$\Delta\pi_{R2}^{10} = \pi_{R2}^{10} - \pi_{R2}^{00} = -\frac{1}{4}\theta\left(M_2 - 2ac - \frac{3}{2}a\theta\right) < 0$$

If R1 and R2 convert jointly:

$$\Delta\pi_{R1}^{11} = \pi_{R1}^{11} - \pi_{R1}^{00} = \Delta\pi_{R1}^{10} + \left[\frac{1}{2}\left(\frac{1}{4}a\left(\frac{M_2}{a} - 2c\right)^2\right) - \frac{1}{2}\left(\frac{1}{4}a\left(\frac{M_2}{a} - 2c - \theta\right)^2\right)\right]$$
$$= \frac{1}{2}\theta\left(M_1 - ac - \frac{1}{2}a\theta\right) + \left[\frac{1}{2}\left(\frac{1}{4}a\left(\frac{M_2}{a} - 2c\right)^2\right) - \frac{1}{2}\left(\frac{1}{4}a\left(\frac{M_2}{a} - 2c - \theta\right)^2\right)\right]$$
$$= \frac{1}{2}\theta\left(M_1 - ac - \frac{1}{2}a\theta\right) + \frac{1}{8}a\left(\left(\frac{M_2}{a} - 2c\right)^2 - \left(\frac{M_2}{a} - 2c - \theta\right)^2\right)$$
$$= \frac{1}{2}\theta\left(M_1 - ac - \frac{1}{2}a\theta\right) + \frac{1}{8}a\left(2\theta\left(\frac{M_2}{a} - 2c\right) - \theta^2\right)$$
$$= \frac{1}{2}\theta\left(M_1 - ac - \frac{1}{2}a\theta\right) + \frac{1}{4}\theta\left(M_2 - 2ac - \frac{1}{2}a\theta\right) = \frac{1}{4}\theta\left(2M_1 + M_2 - 4ac - \frac{3}{2}a\theta\right) > 0$$

$$\Delta\pi_{R2}^{11} = \pi_{R2}^{11} - \pi_{R2}^{00} = \frac{1}{4}\theta\left(M_2 - 2ac - \frac{1}{2}a\theta\right) > 0$$

**Proposition 1.**

*In the absence of competition, provided $\Delta\pi^{10}_{R1} < C < \Delta\pi^{11}_{R2}$, 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.*

**Proof:**

As a preliminary, we will establish that $\Delta\pi^{10}_{R1} < \Delta\pi^{11}_{R2}$, so that $\exists\, C$ s.t. $C \in (\Delta\pi^{10}_{R1}, \Delta\pi^{11}_{R2})$:

$$
\begin{aligned}
2M_1 < M_2 &\implies M_1 < \frac{1}{2}M_2 \implies M_1 - \frac{1}{4}a\theta < \frac{1}{2}M_2 \implies M_1 - ac - \frac{1}{2}a\theta < \frac{1}{2}M_2 - ac - \frac{1}{4}a\theta \\
&\implies M_1 - ac - \frac{1}{2}a\theta < \frac{1}{2}\left(M_2 - 2ac - \frac{1}{2}a\theta\right) \\
&\implies \Delta\pi^{10}_{R1} = \frac{1}{2}\left(M_1 - ac - \frac{1}{2}a\theta\right) < \frac{1}{4}\left(M_2 - 2ac - \frac{1}{2}a\theta\right) = \Delta\pi^{11}_{R2}
\end{aligned}
$$

*Status quo equilibrium:* R1 does not convert to standard gauge $\iff$ R2 does not convert.

- ($\Longrightarrow$) Suppose R1 does not convert to standard gauge. Then R2 will not convert to standard gauge, because $0 > \Delta\pi^{01}_{R2} - C$, by Lemma 1.
- ($\Longleftarrow$) Suppose R2 does not convert to standard gauge. Then R1 will not convert to standard gauge, because $0 > \Delta\pi^{10}_{R1} - C$, by the condition assumed.

*Standardization equilibrium*: R1 converts to standard gauge $\iff$ R2 converts.

- ($\Longrightarrow$) Suppose R1 converts to standard gauge. Then R2 will also convert to standard gauge, because $\Delta\pi^{11}_{R2} - C > 0 = \Delta\pi^{10}_{R2}$, by Lemma 1 and the condition assumed.
- ($\Longleftarrow$) Suppose R2 converts to standard gauge. Then R1 will also convert to standard gauge, because $\Delta\pi^{11}_{R1} - C > 0 > \Delta\pi^{01}_{R1}$, by Lemma 1 and the condition assumed.

**Proposition 2.**

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

**Proof:**

The proof consists of two parts: (1) Collective standardization is *not* an equilibrium with competition, and (2) it *can* be an equilibrium with collusion. For the sake of exposition we will set the fixed cost $C$ of changing the gauge to $C = 0$, but the results hold with $C > 0$ subject to the regularity conditions below. We also assume that in the collusive scenario, R1-R2 and R3-R4 set a single, common price $P$ to maximize joint profits, consistent with this paper's setting.

The requisite regularity conditions are:

- (RC1) Each party can unilaterally break the cartel but cannot unilaterally form it.
- (RC2) When R1-R2 standardizes alone, its profits in a competitive market (subject to limit pricing) are greater than its profits in a collusive market (subject to side payments).
- (RC3) The fixed cost of standardization ($C$) is less than half of monopoly profits under standardization (in the notation used below: $C < \frac{1}{2}\Pi^{11}_{joint}$).

Part 1. Collective standardization is *not* an equilibrium with competition.

With symmetric, undifferentiated competition, prices will be competed to marginal costs, as per the Bertrand paradox. Profits in the status quo are thus zero for both R1-R2 and R3-R4.

If either R1-R2 or R3-R4 standardizes, it can set the monopolist profit-maximizing price or a limit price that prices the other out of the market and earns positive profits. Concretely: WLOG, suppose R1-R2 standardizes and R3-R4 doesn't, and let $P^*$ denote the monopolist profit-maximizing price. Then, if (i) $P^* < c_2 + \theta$, then R1-R2 can price at $P = P^*$, whereas if (ii) $P^* > c_2 + \theta$, then R1-R2 can set a limit price of $P = c_2 + \theta -$ in both cases, pricing R3-R4 out of the market, and yielding positive profits. If both R1-R2 and R3-R4 standardize, prices will again be competed to marginal costs (such that R3-R4 has no incentive to then do so). In this case, the model has two equilibria, whether one (and only one) of R1-R2 and R3-R4 standardizes.

Part 2. Collective standardization *can* be an equilibrium with collusion.

To show that collective standardization is an equilibrium under collusion, we'll begin by calculating payoffs to R1-R2 and R3-R4 under status quo, one-party, and joint standardization.

If neither or both routings standardize, they will be symmetric and split profits. If neither standardizes, equilibrium cartel price, quantity, and profits can be identified as follows:

$$\begin{aligned}
\Pi &= (P - 2c - \theta)(Q_{R_{12}} + Q_{R_{34}}) = 2(P - 2c - \theta)(M - \lambda - aP) \\
&= 2(P(M - \lambda) - aP^2 - (2c + \theta)(M - \lambda) + (2c + \theta)aP \\
\frac{\partial \Pi}{\partial P} &= 2(M - \lambda - 2aP + (2c + \theta)a) = 0 \\
&\implies \quad P^{00} = \frac{1}{2a}[M - \lambda + (2c + \theta)a] \\
&\implies \quad Q^{00}_{R_{12}} = Q^{00}_{R_{34}} = \frac{1}{2}(M - \lambda - (2c + \theta)a)
\end{aligned}$$

such that:

$$\begin{aligned}
\Pi^{00}_{joint} &= (P - 2c - \theta)(Q_{R_{12}} + Q_{R_{34}}) \\
&= \left[\frac{1}{2a}(M - \lambda + (2c + \theta)a) - 2c - \theta\right](M - \lambda - (2c + \theta)a) \\
&= \frac{1}{2a}(M - \lambda + (2c + \theta)a - 4ca - 2\theta a)(M - \lambda - (2c + \theta)a) \\
&= \frac{1}{2a}(M - \lambda - (2c + \theta)a)(M - \lambda - (2c + \theta)a) \\
&= \frac{1}{2a}(M - \lambda - (2c + \theta)a)^2
\end{aligned}$$

If both standardize, $\theta = 0$ and $\lambda$ drops out, such that:

$$\begin{aligned}
P^{11} &= \frac{1}{2a}[M + (2c)a] \\
Q^{11}_{R_{12}} &= Q^{11}_{R_{34}} = \frac{1}{2}(M - (2c)a) \\
\Pi^{11}_{joint} &= \frac{1}{2a}(M - (2c)a)^2
\end{aligned}$$

Now suppose WLOG that R1-R2 standardizes alone. In this event, the cartel maximizes profits by having R1-R2 carry all traffic (at lower cost, as there are no capacity constraints), charge monopoly prices ($P^{11}$), and split the profits ($\Pi^{11}_{joint}$) with R3-R4. In principle this scenario could be sustained with side payments: to make R3-R4 indifferent between this and joint standardization, R1-R2 must pay R3-R4 ($\frac{1}{2}\Pi^{11}_{joint} - C$) and would then retain profit of $\frac{1}{2}\Pi^{11}_{joint}$.

However, because R1-R2 can unilaterally leave the cartel (RC1), side payments are not incentive compatible: once it has standardized, R1-R2 can increase profits by exiting the cartel and reverting to the competitive equilibrium where it is a monopolist subject to limit pricing (RC2), and R3-R4 makes zero profits and has no incentive to standardize. With collusion, the R3-R4 best response to standardization by R1-R2 is thus to standardize as well.

## Proofs for Section 4.2

**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* $\frac{1}{2}\theta(a-b)$*.*

**Proof:**

*Part 1.* In the pre-period, where $B_R = B_S = 1$:

$$\begin{aligned}
\Pi &= (P-c)(Q_R+Q_S) - \theta(Q_R+Q_S) = (P-c-\theta)(Q_R+Q_S) \\
&= (P-c-\theta)[(1-(a-b)P) + (1-(a-b)P)] \\
&= 2(P-c-\theta)(1-(a-b)P) \\
&= 2(P-c-\theta-(a-b)P^2+(c+\theta)(a-b)P) \\
\frac{\partial \Pi}{\partial P} &= 2(1-2(a-b)P+(c+\theta)(a-b)) = 0 \quad \Longrightarrow \quad P = \frac{1}{2(a-b)} + \frac{1}{2}(c+\theta)
\end{aligned}$$

Quantities $Q_R$ and $Q_S$ are then as follows:

$$\begin{aligned}
Q_R &= 1-(a-b)P = 1-(a-b)\left[\frac{1}{2(a-b)} + \frac{1}{2}(c+\theta)\right] \\
&= 1 - \frac{1}{2} - \frac{1}{2}(a-b)(c+\theta) = \frac{1}{2}(1-(a-b)(c+\theta))
\end{aligned}$$

and by symmetry, $Q_S = \frac{1}{2}(1-(a-b)(c+\theta))$.

*Part 2.* In the post-period, where $B_R = 0$ and $B_S = 1$:

$$\begin{aligned}
\Pi &= (P-c)(Q_R+Q_S) - \theta(Q_S) = (P-c)Q_R + (P-c-\theta)Q_S \\
&= (P-c)(1+\lambda-(a-b)P) + (P-c-\theta)(1-\lambda-(a-b)P) \\
&= 2(P-c)(1-(a-b)P) - \theta(1-\lambda-(a-b)P) \\
&= 2(P-c-(a-b)P^2+c(a-b)P-\theta(1-\lambda-(a-b)P))
\end{aligned}$$

$$\frac{\partial \Pi}{\partial P} = 2(1-2(a-b)P+c(a-b)) + \theta(a-b) = 0 \quad \Longrightarrow \quad P = \frac{1}{2(a-b)} + \frac{1}{2}(c+\frac{1}{2}\theta)$$

Quantities $Q_R$ and $Q_S$ are then as follows:

$$\begin{aligned} Q_R &= 1 + \lambda - (a-b)P = 1 + \lambda - (a-b)\left[\frac{1}{2(a-b)} + \frac{1}{2}(c + \frac{1}{2}\theta)\right] \\ &= 1 + \lambda - \frac{1}{2} - \frac{1}{2}(a-b)(c + \frac{1}{2}\theta) = \lambda + \frac{1}{2}(1 - (a-b)(c + \frac{1}{2}\theta)) \end{aligned}$$

and

$$\begin{aligned} Q_S &= 1 - \lambda - (a-b)P = 1 - \lambda - (a-b)\left[\frac{1}{2(a-b)} + \frac{1}{2}(c + \frac{1}{2}\theta)\right] \\ &= 1 - \lambda - \frac{1}{2} - \frac{1}{2}(a-b)(c + \frac{1}{2}\theta) = -\lambda + \frac{1}{2}(1 - (a-b)(c + \frac{1}{2}\theta)) \end{aligned}$$

*Part 3.* Pre vs. Post Comparisons

Part 3a. Prices

Post-gauge change, the change in the collusive price is:

$$\begin{aligned} \Delta P &= P^{post} - P^{pre} \\ &= \left[\frac{1}{2(a-b)} + \frac{1}{2}(c + \frac{1}{2}\theta)\right] - \left[\frac{1}{2(a-b)} + \frac{1}{2}(c + \theta)\right] = \frac{1}{4}\theta - \frac{1}{2}\theta = -\frac{1}{4}\theta < 0 \end{aligned}$$

Part 3b. Quantities

Post-gauge change, the change in all-rail shipments is:

$$\begin{aligned} \Delta Q_R &= Q_R^{post} - Q_R^{pre} \\ &= \left[\lambda + \frac{1}{2}(1 - (a-b)(c + \frac{1}{2}\theta))\right] - \left[\frac{1}{2}(1 - (a-b)(c + \theta))\right] = \lambda + \frac{1}{4}(a-b)\theta \end{aligned}$$

whereas the change in steamship shipments is:

$$\begin{aligned} \Delta Q_S &= Q_S^{post} - Q_S^{pre} \\ &= \left[-\lambda + \frac{1}{2}(1 - (a-b)(c + \frac{1}{2}\theta))\right] - \left[\frac{1}{2}(1 - (a-b)(c + \theta))\right] = -\lambda + \frac{1}{4}(a-b)\theta \end{aligned}$$

Adding the two together, the change in total shipments is:

$$\Delta Q_{TOT} = \Delta Q_R + \Delta Q_S = \frac{1}{2}(a-b)\theta$$

**Corollary 3.1.** Conditions under which prices and total quantity may not change

*(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, $\frac{1}{8}\theta^2(a-b)$.*

**Proof:**

Part 1.

When $\theta = 0$: $\Delta P = \frac{1}{4}\theta = 0$ and $\Delta Q_{TOT} = \frac{1}{2}(a-b)\theta = 0$.

Part 2.

To demonstrate this statement, we'll need to calculate post-gauge change profits under unadjusted prices (optimized for pre-gauge change period) and adjusted prices (optimized for post-gauge change period), which we can denote $P^{pre}$ and $P^{post}$:

$$\begin{aligned}
\Pi(P^{pre}) &= (P^{pre} - c) \cdot Q_{TOT} - \theta \cdot Q_S \\
&= (P^{pre} - c) \cdot 2\left[1 - (a-b)P^{pre}\right] - \theta \cdot \left[1 - \lambda - (a-b)P^{pre}\right] \\
\Pi(P^{post}) &= (P^{post} - c) \cdot Q_{TOT} - \theta \cdot Q_S \\
&= (P^{post} - c) \cdot 2\left[1 - (a-b)P^{post}\right] - \theta \cdot \left[1 - \lambda - (a-b)P^{post}\right]
\end{aligned}$$

Taking the difference:

$$\begin{aligned}
&\Pi(P^{post}) - \Pi(P^{pre}) \\
&\quad = \left[2(1-(a-b)P^{post})(P^{post}-c) - (1-\lambda-(a-b)P^{post})\theta\right] \\
&\qquad - \left[2(1-(a-b)P^{pre})(P^{pre}-c) - (1-\lambda-(a-b)P^{pre})\theta\right] \\
&\quad = \left[2(P^{post} - (a-b)(P^{post})^2 + c(a-b)P^{post}) + \theta(a-b)P^{post}\right] \\
&\qquad - \left[2(P^{pre} - (a-b)(P^{pre})^2 + c(a-b)P^{pre}) + \theta(a-b)P^{pre}\right] \\
&\quad = (2 + (2c+\theta)(a-b))(P^{post} - P^{pre}) - 2(a-b)((P^{post})^2 - (P^{pre})^2) \\
&\quad = (P^{post} - P^{pre})(2 + (2c+\theta)(a-b) - 2(a-b)(P^{post} + P^{pre})) \\
&\quad = \left(-\frac{1}{4}\theta\right)\left((2 + (2c+\theta)(a-b) - 2(a-b)\left(\frac{1}{a-b} + c + \frac{3}{4}\theta\right)\right) \\
&\quad = \left(-\frac{1}{4}\theta\right)\left((2 + (2c+\theta)(a-b) - 2 - 2c(a-b) - \frac{3}{2}\theta(a-b)\right) \\
&\quad = \left(-\frac{1}{4}\theta\right)\left(-\frac{1}{2}\theta(a-b)\right) = \frac{1}{8}\theta^2(a-b)
\end{aligned}$$

If the cartel does not adjust its price, then the cost of the price adjustment must be greater than this amount, which is the incremental profit it would realize by re-optimizing $P$.

## Proofs for Section 4.3

**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* $\frac{a\theta(a-b)}{2a-b}$.

**Proof:**

<u>*Part 1.*</u> In the pre-period, where $B_R = B_S = 1$:

$$\Pi_R = (1 - aP_R + bP_S)(P_R - c - \theta) = (P_R - aP_R^2 + bP_SP_R) + (1 - aP_R + bP_S)(-c - \theta)$$
$$\frac{\partial \Pi_R}{\partial P_R} = 1 - 2aP_R + bP_S + a(c+\theta) = 0 \quad \Longrightarrow \quad P_R = (1 + bP_S + a(c+\theta))/2a$$

$$\Pi_S = (1 - aP_S + bP_R)(P_S - c - \theta) = (P_S - aP_S^2 + bP_RP_S) + (1 - aP_S + bP_R)(-c - \theta)$$
$$\frac{\partial \Pi_S}{\partial P_S} = 1 - 2aP_S + bP_R + a(c+\theta) = 0 \quad \Longrightarrow \quad P_S = (1 + bP_R + a(c+\theta))/2a$$

Combining the two, we can solve for $P_R$ and $P_S$:

$$P_R = \frac{1 + b\left(\frac{1+bP_R+a(c+\theta)}{2a}\right) + a(c+\theta)}{2a} = \frac{1}{2a} + \frac{b}{4a^2} + \frac{b^2}{4a^2}P_R + \frac{b}{4a}(c+\theta) + \frac{1}{2}(c+\theta)$$

$$\frac{4a^2 - b^2}{4a^2}P_R = \frac{1}{2a} + \frac{b}{4a^2} + \left(\frac{b}{4a} + \frac{1}{2}\right)(c+\theta) = \frac{2a}{4a^2} + \frac{b}{4a^2} + \left(\frac{ab}{4a^2} + \frac{2a^2}{4a^2}\right)(c+\theta)$$

$$\begin{aligned} P_R &= \frac{1}{4a^2 - b^2}((2a+b) + (ab + 2a^2)(c+\theta)) \\ &= \frac{1}{(2a+b)(2a-b)}((2a+b) + a(2a+b)(c+\theta)) = \frac{1}{2a-b}(1 + a(c+\theta)) \end{aligned}$$

and by symmetry, $P_S = \frac{1}{2a-b}(1 + a(c+\theta))$.

Quantities $Q_R$ and $Q_S$ are then as follows:

$$\begin{aligned} Q_R &= 1 - aP_R + bP_S = 1 - a\left[\frac{1}{2a-b}(a(c+\theta)+1)\right] + b\left[\frac{1}{2a-b}(a(c+\theta)+1)\right] \\ &= 1 - (a-b)\left[\frac{1}{2a-b}(a(c+\theta)+1)\right] = 1 - \frac{a-b}{2a-b}(a(c+\theta)+1) \end{aligned}$$

and by symmetry, $Q_S = 1 - \frac{a-b}{2a-b}(a(c+\theta)+1)$.

*Part 2.* In the post-period, where $B_R = 0$ and $B_S = 1$:

$$\Pi_R = (1 + \lambda - aP_R + bP_S)(P_R - c) = (P_R + \lambda P_R - aP_R^2 + bP_S P_R) + (1 + \lambda - aP_R + bP_S)(-c)$$

$$\frac{\partial \Pi_R}{\partial P_R} = 1 + \lambda - 2aP_R + bP_S + ac = 0 \quad \Longrightarrow \quad P_R = (1 + \lambda + bP_S + ac)/2a$$

$$\Pi_S = (1 - \lambda - aP_S + bP_R)(P_S - c - \theta) = (P_S - \lambda P_S - aP_S^2 + bP_R P_S) + (1 - \lambda - aP_S + bP_R)(-c - \theta)$$

$$\frac{\partial \Pi_S}{\partial P_S} = 1 - \lambda - 2aP_S + bP_R + a(c + \theta) = 0 \quad \Longrightarrow \quad P_S = (1 - \lambda + bP_R + a(c + \theta))/2a$$

Combining the two, we can solve for $P_R$ and $P_S$:

$$\begin{aligned} P_R &= \frac{1 + \lambda + b\left(\frac{1-\lambda+bP_R+a(c+\theta)}{2a}\right) + ac}{2a} \\ &= \frac{1}{2a}(1 + \lambda) + \frac{b}{4a^2}(1 - \lambda) + \frac{b^2}{4a^2}P_R + \frac{b}{4a}(c + \theta) + \frac{1}{2}c \end{aligned}$$

$$\begin{aligned} \frac{4a^2 - b^2}{4a^2}P_R &= \frac{1}{2a}(1 + \lambda) + \frac{b}{4a^2}(1 - \lambda) + \left(\frac{b}{4a} + \frac{1}{2}\right)c + \frac{b}{4a}\theta \\ &= \frac{2a}{4a^2}(1 + \lambda) + \frac{b}{4a^2}(1 - \lambda) + \left(\frac{ab}{4a^2} + \frac{2a^2}{4a^2}\right)c + \frac{ab}{4a^2}\theta \end{aligned}$$

$$\begin{aligned} P_R &= \frac{1}{4a^2 - b^2}(2a(1 + \lambda) + b(1 - \lambda) + (ab + 2a^2)c + ab\theta) \\ &= \frac{1}{4a^2 - b^2}(2a(1 + \lambda) + b(1 - \lambda) + (ab + 2a^2)(c + \theta) - 2a^2\theta) \\ &= \frac{1}{(2a + b)(2a - b)}((2a + b) + a(2a + b)(c + \theta) + (2a - b)\lambda - 2a^2\theta) \\ &= \frac{1}{2a - b}(1 + a(c + \theta)) + \frac{1}{2a + b}(\lambda) - \frac{1}{(2a + b)(2a - b)}(2a^2\theta) \end{aligned}$$

and

$$\begin{aligned}
P_S &= \frac{1-\lambda+b\left(\frac{1+\lambda+bP_S+ac}{2a}\right)+(c+\theta)}{2a} \\
&= \frac{1}{2a}(1-\lambda)+\frac{b}{4a^2}(1+\lambda)+\frac{b^2}{4a^2}P_S+\frac{b}{4a}c+\frac{1}{2}(c+\theta)
\end{aligned}$$

$$\begin{aligned}
\frac{4a^2-b^2}{4a^2}P_S &= \frac{1}{2a}(1-\lambda)+\frac{b}{4a^2}(1+\lambda)+\left(\frac{b}{4a}+\frac{1}{2}\right)c+\frac{1}{2}\theta \\
&= \frac{2a}{4a^2}(1-\lambda)+\frac{b}{4a^2}(1+\lambda)+\left(\frac{ab}{4a^2}+\frac{2a^2}{4a^2}\right)c+\frac{2a}{4a^2}\theta
\end{aligned}$$

$$\begin{aligned}
P_S &= \frac{1}{4a^2-b^2}(2a(1-\lambda)+b(1+\lambda)+(ab+2a^2)c+2a\theta) \\
&= \frac{1}{4a^2-b^2}(2a(1-\lambda)+b(1+\lambda)+(ab+2a^2)(c+\theta)-ab\theta) \\
&= \frac{1}{(2a+b)(2a-b)}((2a+b)+a(2a+b)(c+\theta)-(2a-b)\lambda-ab\theta) \\
&= \frac{1}{2a-b}(1+a(c+\theta))-\frac{1}{2a+b}(\lambda)-\frac{1}{(2a+b)(2a-b)}(ab\theta)
\end{aligned}$$

Quantities $Q_R$ and $Q_S$ are then as follows:

$$\begin{aligned}
Q_R &= 1+\lambda-aP_R+bP_S \\
&= 1+\lambda-a\left[\frac{1}{2a-b}(a(c+\theta)+1)+\frac{1}{2a+b}(\lambda)-\frac{1}{(2a+b)(2a-b)}(2a^2\theta)\right] \\
&\quad +b\left[\frac{1}{2a-b}(a(c+\theta)+1)-\frac{1}{2a+b}(\lambda)-\frac{1}{(2a+b)(2a-b)}(ab\theta)\right] \\
&= 1+\lambda-\frac{a-b}{2a-b}(a(c+\theta)+1)-\frac{a+b}{2a+b}(\lambda)+\frac{a(2a^2-b^2)}{(2a+b)(2a-b)}(\theta)
\end{aligned}$$

and

$$\begin{aligned}
Q_S &= 1-\lambda-aP_S+bP_R \\
&= 1-\lambda-a\left[\frac{1}{2a-b}(a(c+\theta)+1)-\frac{1}{2a+b}(\lambda)-\frac{1}{(2a+b)(2a-b)}(ab\theta)\right] \\
&\quad +b\left[\frac{1}{2a-b}(a(c+\theta)+1)+\frac{1}{2a+b}(\lambda)-\frac{1}{(2a+b)(2a-b)}(2a^2\theta)\right] \\
&= 1-\lambda-\frac{a-b}{2a-b}(a(c+\theta)+1)+\frac{a+b}{2a+b}(\lambda)+\frac{a(ab-2ab)}{(2a+b)(2a-b)}(\theta)
\end{aligned}$$

*Part 3.* Pre vs. Post Comparisons

Part 3a. Prices

Post-gauge change, the change in the all-rail price is:

$$\begin{aligned}\Delta P_R &= P_R^{post} - P_R^{pre}\\ &= \left[\frac{1}{2a-b}(1+a(c+\theta)) + \frac{1}{2a+b}(\lambda) - \frac{1}{(2a+b)(2a-b)}(2a^2\theta)\right] - \left[\frac{1}{2a-b}(1+a(c+\theta))\right]\\ &= \underbrace{\frac{1}{2a+b}(\lambda)}_{\text{Demand effect}} - \underbrace{\frac{1}{(2a+b)(2a-b)}(2a^2\theta)}_{\text{Cost effect}} \quad \Longrightarrow \quad \Delta P_R \begin{cases} > 0 \text{ if } \lambda > \frac{1}{2a+b}(2a^2\theta) \\ < 0 \text{ if } \lambda < \frac{1}{2a+b}(2a^2\theta) \end{cases}\end{aligned}$$

which consists of both a demand effect driven by the improvement in the relative quality of all-rail shipment (relative to steamships), which puts upward pressure on $P_R$, and a cost effect driven by the reduction in the cost of all-rail carriage, which puts downward pressure on $P_R$. The net effect on $P_R$ may be positive or negative.

The change in the steamship price is:

$$\begin{aligned}\Delta P_S &= P_S^{post} - P_S^{pre}\\ &= \left[\frac{1}{2a-b}(1+a(c+\theta)) - \frac{1}{2a+b}(\lambda) - \frac{1}{(2a+b)(2a-b)}(ab\theta)\right] - \left[\frac{1}{2a-b}(1+a(c+\theta))\right]\\ &= \underbrace{-\frac{1}{2a+b}(\lambda)}_{\text{Demand effect}} - \underbrace{\frac{1}{(2a+b)(2a-b)}(ab\theta)}_{\text{Competitor cost effect}} \quad \Longrightarrow \quad \Delta P_S < 0\end{aligned}$$

which consists of both a demand effect driven by the reduction in the relative quality of steamships (relative to all-rail), which puts downward pressure on $P_S$, and a competition effect driven by the reduction in the all-rail costs of carriage, which puts further downward pressure on $P_S$. The combined effect on $P_S$ is negative.

Part 3b. Quantities

Post-gauge change, the change in all-rail shipments is:

$$\begin{aligned}\Delta Q_R &= Q_R^{post} - Q_R^{pre}\\ &= \left[1 + \lambda - \frac{a-b}{2a-b}(a(c+\theta)+1) - \frac{a+b}{2a+b}(\lambda) + \frac{a(2a^2-b^2)}{(2a+b)(2a-b)}(\theta)\right] - \left[1 - \frac{a-b}{2a-b}(a(c+\theta)+1)\right]\\ &= \lambda - \frac{a+b}{2a+b}(\lambda) + \frac{a(2a^2-b^2)}{(2a+b)(2a-b)}(\theta)\end{aligned}$$

whereas the change in steamship shipments is:

$$\begin{aligned}\Delta Q_S &= Q_S^{post} - Q_S^{pre}\\ &= \left[1 - \lambda - \frac{a-b}{2a-b}(a(c+\theta)+1) + \frac{a+b}{2a+b}(\lambda) + \frac{a(ab-2ab)}{(2a+b)(2a-b)}(\theta)\right] - \left[1 - \frac{a-b}{2a-b}(a(c+\theta)+1)\right]\\ &= -\lambda + \frac{a+b}{2a+b}(\lambda) + \frac{a(ab-2ab)}{(2a+b)(2a-b)}(\theta)\end{aligned}$$

Adding the two together, the change in total shipments is:

$$\Delta Q_{TOT} = \Delta Q_R + \Delta Q_S = \frac{a(2a^2 - ab - 2b^2)}{(2a+b)(2a-b)}(\theta) = \frac{a(2a+b)(a-b)}{(2a+b)(2a-b)}(\theta) = \frac{a(a-b)}{(2a-b)}(\theta)$$

**Corollary 4.1.** Comparing the effects by market structure

*Standardization generates a larger increase in total shipments under competition than collusion.*

**Proof:**

The increase in shipments is $\frac{a\theta(a-b)}{2a-b}$ under competition (Proposition 4), compared to $\frac{1}{2}\theta(a-b)$ under collusion (Proposition 3, although Corollary 3.1 also points out that the increase in shipments may be zero if cartel price changes are costly).

The formal comparison is as follows:

$$\begin{aligned}&\left(\frac{a\theta(a-b)}{2a-b}\right) - \left(\frac{1}{2}\theta(a-b)\right) = \frac{a\theta(a-b) - \frac{1}{2}\theta(a-b)(2a-b)}{2a-b}\\ &= \frac{a\theta(a-b) - a\theta(a-b) + \frac{1}{2}b\theta(a-b)}{2a-b} = \frac{1}{2}b\theta\left(\frac{a-b}{2a-b}\right) > 0\end{aligned}$$