Postwar Railroad Productivity Measurement: Refining the Statistical Analysis

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Abstract
A number of studies have found that postwar railroad productivity increased at a high rate both prior to and after deregulation. Important innovations, such as the steam locomotive, roller bearings, and loading truck trailers onto rail cars, likely resulted in productivity improvements. Simultaneously, though, railroads were under increasingly tight financial constraints with declining passenger traffic and an increase in competition from other modes of transportation, such as trucks. As a result, during this time period, railroads notably deferred investment in maintenance and in capital expenditures, to deal with these financial conditions and to paint a better picture of their financial position than reality. The end result of this period of deferred maintenance and tight financial positions was a shrinkage in the rail network. Not accounting for this deferral in maintenance overstates the short-term productivity and thus may misstate productivity improvements. In this paper, we use detailed firm-level and aggregate data to calculate the amount of deferred maintenance and update productivity estimates. We show a stairstep decline in maintenance of rail and ties that is triggered by recessions and consistent with a managerial response to financial conditions. In addition, we illustrate that accounting for maintenance deferral will lead to lower estimates of productivity improvements.

Key Words: railroads; microdata; productivity measurement; economic history

1. Introduction

The technical, statistical analysis of changes in firms' productivity over time and of the differences in productivity between firms has made significant advances in recent years.[1] Such analyses include ones of firms with multiple outputs. However, it is substantially less usual to have detailed, internal data of the firms' internal information for productivity analyses.[2]

American railroads, likely due to their regulation since the late 19th century, have long provided detailed information on their operations. Further, that information not only covers overall inputs (person-hours, fuel, raw materials, etc.) and output but also inputs and outputs of various vertical functional areas/segments (e.g., maintenance of way) *within* the enterprise.

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[1] See, for example Sickles and Zelenyuk (2019). See also Grifell-Tatje and Lovell (2015).

[2] For example, Schmitz Jr (2005) breaks down sources of productivity gains but not at a firm level. In a summary of productivity literature, Syverson (2011) concludes: "economists should push for more directed efforts to measure business-level production practices" (p. 360).

However, the existing literature on railroads does not generally exploit this micro, vertical information to evaluate either the overall rate of productivity advance or that for the individual vertical components. Further, existing studies, at aggregate levels, have reached quite different estimates on the rate of productivity growth.[3] For example, an index of output per man-hour from the Bureau of Labor Statistics (BLS)[4] indicated an increase in labor productivity of 5.2% per year over 1947-70 and an even higher 6% per year over the 1957-70 subperiod. The latter figure was apparently the eighth highest among the 35 industrial industries examined by the BLS for that sub period.[5] But the Task Force on Railroad Productivity (1973) suggested a much lower rate of advancement, after accounting for changes in both labor and capital improvements.

Subsequent econometric papers found much lower rates of productivity growth in the (early) postwar period than the BLS estimates. In particular, Caves *et al.* (1980) found an increase of 1.5% per year using a generalized translog multiproduct cost function, which accounts for both capital and labor inputs[6], to estimate cost elasticities; this contrasted with their estimate of 3.6% per year using conventional index methods. While their 1980 paper utilized aggregate railroad data, their subsequent AER paper (Caves *et al.*, 1981) supplemented it using panel data for a sample of large railroads and found a similar estimate of 1.8% per year.

This paper reports the preliminary results of our use of more detailed, "micro" (within firm) data to investigate changes in the "postwar" (1946-1970) railroad industry.[7] Our

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[3] Caves, *et al***.** (1980) cover the 1951-1974 period. Related papers include Caves, *et al*. (1981) covering a slightly different period (1955-1974), Caves, *et al.* (1985), and Brown, *et al. (*1979). In addition, the paper by Kumbhakar (1988), which analyzes railroad performance in 1951-1975 from a frontier production function standpoint, apparently relies (see its footnote 7) upon data from the Caves *et al.* papers. The surveys by Oum and Waters (1997) and Oum, *et al.* (1999) cover many papers on railroad productivity and cost changes for the period after 1970.

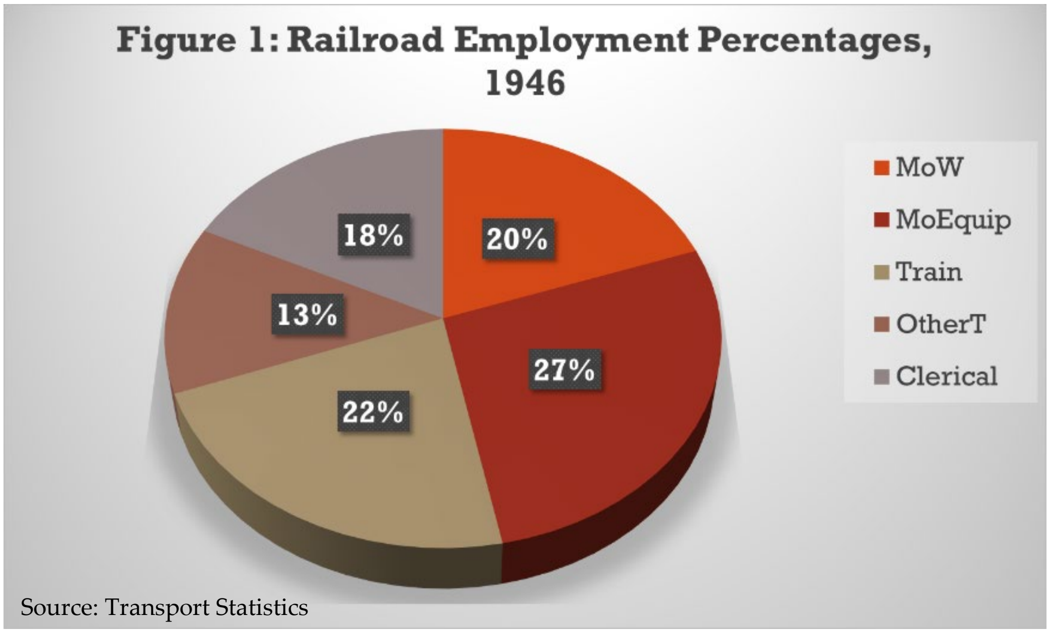
[4] A later BLS study, Duke, *et al.* (1992), found a 4.2% rate of increase in "multifactor" productivity for the overlapping period of 1958 to 1973 (p. 51).

[5] The statements in this paragraph about the BLS findings are based on the Task Force's summary (1973, p. 33). (The Task Force was created by units within the Executive Office of the President, in conjunction with the National Commission on Productivity in 1972. The Task Force was comprised of transportation economists and chaired by Professor John R. Meyer of Harvard.)

[6] Their approach avoids restrictive assumptions underlying index number procedures, including, among others, assumptions of constant returns to scale and assumed predetermined elasticities of substitution and transformation (relevant for substitution between freight and passenger service, for instance).

[7] The start of our study period is simply the first full year after the end of World War II and its intensive demands on the railroad system. The end of the study period was chosen in part because 1971-85 represented an era of massive regulatory and legislative changes, including moves that facilitated line abandonments, reductions in the size of train crews, and mergers.

Moreover, changes in freight cars after 1970 forced significant enhancements in the track structure and road. First, the cargo capacity of the average car steadily and substantially increased, pressuring railroads to upgrade their routes, such as by deploying heavier weight rail. Second, starting in the mid 1980s, cars that could accommodate double-stack containers were introduced and rapidly became a major factor in "piggyback" (TOFC/COFC) capacity. (Between 1984 to long run goal is to recompute productivity changes, based on micro segment analyses, for many of the large railroad systems and for panel groupings of them. However, this paper's preliminary analysis examines productivity effects for one segment, that of maintenance of way, with a particular focus on some large Southeastern railroads.



Source: Transport Statistics

Our choice of the maintenance of way (MOW) segment for this initial analysis reflects, principally, five aspects of it: (i) MOW workers accounted for a large portion, about one fifth, of all railroad employment at the end of World War II[8]; (ii) MOW work changed from largely using hand tools to being "mechanized" within this postwar period[9]; (iii) MOW employment fell more (and therefore apparent productivity rose more) than in the other railroad labor segments[10]; (iv) its principal outputs[11] to other parts of the firm are relatively straightforward to quantify; and (v) because of the long-lived nature of the track/roadway, the yearly level of these outputs was subject to more managerial

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1992 their capacity share increased from 2% to about 42% of total "slots" (DeBoer, 1992, p. 160). Apart from the heavy weight of such cars, their loaded height entailed changes in road structure (e.g., in tunnels) to accommodate them (see DeBoer, particularly pp. 151-165 for discussion of "double-stack cars). The "system" character of the rail network meant that such changes affected most railroads. (See, for example, Resor, *et al.*, 2001.)

[8] See US Department of Labor (BLS), 1963, p. 8 which reports 265,000 MOW employees, 19.6% of the railroad total, in 1947. This was almost as many as the total "train, engine, and yard" employees in that year. See Figure 1 above.

[9] See Haber, *et al.* (1957), particularly pp. 45-53. See also, US Department of Labor (BLS), 1963, particularly p. 14 and US Department of Labor (BLS), 1949, particularly p. 43.

[10] MOW employment fell 55% between 1947 and 1960, whereas overall railroad employment fell by 42% and "train" employment by 31% over that period (BLS, 1963, p. 8).

[11] For example, yearly new and relaid rail and new ties.

discretion than in some of the other railroad segments, such as train crew staffing.[12,13] Because the need for MOW investments is usually primarily driven by climate, as well as total freight ton-miles per mile of track,[14] our initial analysis focuses on MOW activity in a single geographic region, the Southeast.

Section 2 provides information on the changes over this postwar period for railroad traffic (freight ton-miles per mile and passenger miles) at both the aggregate US and Southeastern levels as well as for the two large Southeastern systems (Seaboard Air Line "SAL" and the Atlantic Coast Line "ACL"). As explained there, traffic changes affect the need for maintenance expenditures. Section 3 first provides information on changes in employment and maintenance of way (MOW) expenses and then on measures of MOW output and relationships between these output measures. In Section 4, we consider possible explanations of MOW output changes, including that of deferral or system shrinkage, and provide preliminary tests of them. Section 5 compares apparent MOW productivity advances assuming that none of the reduction in inputs represented deferral with estimated productivity advances assuming that all such reductions represented deferral.

Section 6 briefly discusses our preliminary conclusions and identifies steps to refine, extend, and broaden the current analysis.[15] These preliminary conclusions can be summarized as follows. First, MOW output fell substantially over the period overall,

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[12] The incentive of some managers to exercise such discretion may have been increased because of railroad accounting treatment of yearly MOW expenditures. ("Expenditures" are the sum of "expenses" plus "capital investments.) Until the early 1980's, railroads, per ICC requirements, employed "betterment" accounting for maintenance of way expenditures. (See the discussion in GAO, 1981). Under that system, most MOW expenditures were directly expensed thereby directly reducing yearly (reported) net income: such expenditures could be capitalized *only* to the extent that they represented improvements to what was already in place. (For example, only the difference in cost between new heavier weight rail and the current cost of lighter weight rail equivalent to what it was replacing could be capitalized. Further, the costs of all the labor used in making the replacement could not be capitalized under "betterment" accounting.)

This "betterment" accounting system, along with the long-lived nature of road investments, could have affected some managements' decisions to defer maintenance in order to increase reported net income. And, as noted by Haber, *et al.*, (1957), "Deferral of maintenance is feasible with rather wide limits without immediately endangering safety and has been widely practiced" (p. 82) and "Railroad managements typically make maintenance of way activities serve as the balancing item in the total annual capital budget" (p. 71). The efforts of railroad managers before World War II to prevent the ICC from eliminating betterment accounting is consistent with their using MOW deferrals to affect their railroads' apparent financial condition (Heier & Gurley, 2007).

[13] While deferral may or may not be consistent with long-run profitability, there is a substantial literature demonstrating that managers' decisions reflect shorter time horizons due to, for example, the effects of management turnover (see, e.g., Palley, 1997).

[14] For the influence of these variables, see, for example, Zarembski and Kondapalli (2007). As noted in footnote 7 above, major changes in freight car weight (or size) can also affect the need for roadway investment.

[15] Appendices provide additional information including on the relationship between new rail purchases and changes in the distribution by rail weight (lbs/yard) of all installed rail. This information allows testing of alternative explanations of the changes in MOW output measures.

particularly prior to 1962. This decline was not simply limited to the Northeast "problem"; railroads in the Southeast also had very substantial output declines in new and relaid rail and in ties. Second, such declines were not occasioned by significant declines in traffic. Additionally, other factors (average train speed; average freight car capacity) which would affect the "need" for MOW effort did not decline but, instead, increased over the period. Third, while there are various possible explanations of these declines, it currently appears that the most plausible hypothesis is that rail managements gradually adopted a "two network" framework: a "core" subsystem, which would be at least maintained and the remainder, which would be "harvested" over time. Under this hypothesis, the stages of adoption may have been triggered by recessions; this may underlie the "stair step" decline pattern of the output measures. Fourth, under this (or similar hypotheses) the decline in MOW output implies a substantially lower rate of productivity growth for the MOW segment than in conventional analyses.

2. Postwar Traffic and MOW Changes

In general, the principal drivers of railroad road maintenance need are the damages resulting from rainfall, humidity, and other climatic factors.[16] However, traffic also affects the "wear and tear" on the road structure. Such traffic effects primarily depend on the overall level of freight traffic (measured by the (yearly) gross ton-miles of freight traffic per mile of track or "GTM/mile") and on that traffic's speed and "wheel loadings".[17]

Aggregate ("all" railroads) ton-miles were static over the 1946-60 period but rose moderately beginning in the early 1960s. However, track miles declined over both of these subperiods. Hence, aggregate (gross) ton miles per mile grew somewhat over both sub-periods. Table 1 shows these values for all (Class 1) US railroads, for those in the Southeast, and for two large Southeastern railroads.[18]

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[16] See, for example, Haber *et al.* (1957), particularly pp. 67-70.

[17] "GTM" differs from "revenue/net ton miles" principally by also including the empty weight of the freight cars. (In 1946, GTM, excluding locomotives and tenders, was about 2.2 "net" ton miles, where "net" ton miles includes some nonrevenue freight such as materials for the railroad. Including locomotives increases this ratio by about 10%, to about 2.44 These relationships were fairly stable over the study period.) The freight traffic effects on the track structure also depend, *inter alia***,** on train speed and "wheel loadings" (the total weight – empty ("tare") plus cargo – of the car divided by the number of car wheels: throughout this period, almost all freight cars had two "trucks", each with four wheels – two to a side).

Passenger traffic is not accounted for in GTM/mile: with the exception of a very few lines with intensive commuter use, passenger traffic adds little to the GTM traffic weight on the road. However, passenger *service* may have effects (apart from weight) on maintenance needs. Even apart from "safety" issues, if passenger trains' (point-to-point) speed on a line is greater than even "fast" freight trains, passenger service may increase the line's maintenance requirements. Thus, the "scope" of a railroad's passenger service (i.e., the proportion of its route miles with passenger service) may affect its MOW expenditures.

[18] The average GTM/mile values shown in Table 1 are interesting and important. First, in 1946 the average train amounted to somewhat more than 2.3 thousand gross tons (excluding locomotive). Hence, a section of track with yearly traffic of 2.9 million GTM/mile might have only about 1.75 trains in each direction a day. Thus, the Table's GTM/mile values suggest a somewhat low *average* usage of these systems' networks. Second, studies cited by DOT indicated that

Further, average freight train speeds also rose over the 1946-70 period, from 16 to 20 mph. And average car cargo capacity also rose from 51 to 67 tons; since almost all freight cars had 8 wheels, the average weight borne by the rail and track structure per wheel of a loaded car approached 12 tons by the end of the study period.[19] All of these changes would, *ceteris paribus,* increase the demand for MOW effort because they increased the "wear and tear" on the road.

Table 1: Gross Ton Miles in Thousands / Track Miles

	Average 1946	*% Change 1946 - 1960*	*% Change 1960 - 1970*
US Overall	5069.53	0.85%	51.33%
Southern District	5652.36	23.91%	16.73%
Atlantic Coast Line (through '67)	2959.65	24.49%	59.38%
Seaboard Airline	4252.32	25.28%	39.10%
Average Freight Train Speed (mph)	16	21.88%	4.10%
Average Capacity per Car (tons)	51.3	7.99%	21.12%

The longevity of road investments changes less than proportionately to changes in yearly GTM/mile. For example, a change of GTM/mile from 10 to 50 million, a fivefold increase in traffic, may reduce the life of wooden crossties by less than 30% in humid climates, such as in the Southeastern US.[20] The studies cited in footnote 18 likewise find that a fourfold increase in traffic (from 5 million GTM/mile to 20 million) would result in less than a doubling of (required) maintenance.

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maintenance costs per ton fall rapidly as GTM/mile increased up to 20 million (DOT, 1976b, Figure 2, p. 7) Indeed, DOT's Figure 2, based on two consultant studies, indicated that unit maintenance costs at 20 million GTM/mile are less than half of those at 5 million. Contrast either of the 5 or 20 million GTM/mile figures with the average values shown in Table 1.

[19] The increase in average car weight reflected, in substantial part, the introduction (circa 1960) of unit trains carrying coal and other bulk commodities, such as grain. See, for example, Starr (1976) and MacAvoy and Sloss (1967). Such cars tended to have substantially larger cargo capacity than the average values in Table 1. After 1970 the size, number, and spread over the rail system of such large cars increased substantially.

[20] This percentage change in (wooden) tie longevity with increased GTM/mile depends on the area's climate. The tie longevity values in the text reflect a "humid" climate such as the Southeastern US; slightly different longevity values would apply under other climatic conditions. See, for example, Zarembski and Kondapalli (2007), Table 2, p. 17.

3. MOW Output Measures

Our principal measures of MOW output are the quantities of new rail and of cross ties laid. However, at the individual railroad level we also examine the quantity of rail relaid. As we discuss in Section 4 and in Appendix C, the relationships between these three measures help to understand the changes in MOW effort levels over the period.

MOW employment, illustrated as a share of total railroad employment in Figure 1 above, does include some activities other than the laying and maintaining of the track, such as building structures (e.g., bridges, control towers, etc.) and equipping and operating signaling (such as centralized traffic control systems). However, even combined, these activities accounted for less than one fifth of MOW employment in 1946 (BLS, 1963, p. 12). And MOW trackage work also includes routine maintenance (e.g., weed spraying) and monitoring. Nonetheless we expect the relationship between new rail and ties on the other hand and MOW expenditures to be a tight one; this is confirmed in our testing.[21]

3.1 MOW Aggregate Statistics[22]

Figure 2 shows the “all” railroads purchase of new rail[23] and of ties over the 1946-70 period.[24] While the time path of new rail and ties are broadly similar (see below), there are some differences: from 1946-1961 new rail fell at an average annual rate of 9.3% as compared to a 6.6% decline rate for new ties. On the other hand, from 1962 to 1970 new rail grew at an average annual rate of 6.5% as compared to a growth rate of new ties of 2.9%. Nonetheless the correlation between Cross Ties Laid (number) and New Rail Laid (miles) is 0.9748 with statistical significance at the 1% level.

That there would be a close relationship between these two series should not be too surprising: among other things, the incremental cost of replacing bad ties is lower when

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[21] In particular, the regressions of MOW expenses (excluding depreciation and including investments in road and normalized by average wages) on new rail and ties for the ACL and the SAL railroads have R-squared values of 0.82 and 0.83, respectively. In addition, correlations of MOW with ties are 0.88 and 0.45 and with new rail are 0.82 and 0.88 for Atlantic and Seaboard, respectively.

[22] The data for the analyses in this paper come from a combination of sources. In particular, data at the individual railroad level come from the ICC’s Transport Statistics. Data for the “all” railroads and Southern District railroads come from a combination of Moody’s Transport Manuals and various AAR publications, including multiple years of the “Yearbook of Railroads Facts.” Although we have done some cross-checking of these sources, this is an area where we plan to do further checking in later research.

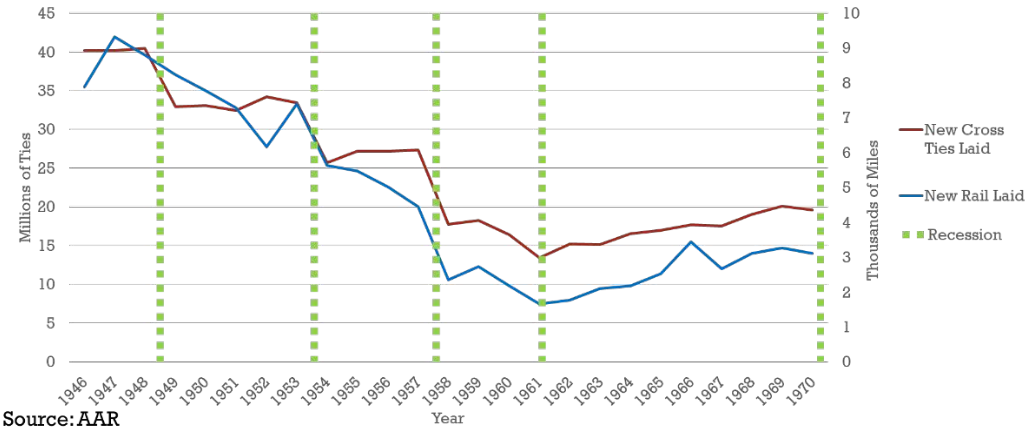
[23] New routes (e.g., new mileage to serve a new plant or industrial park or to convert a curve into a straight –"tangent” – line) accounted for only a small portion (about 2%) of new rail purchases during this period.

[24] The “ties” series shows the installation of new “wooden” ties. While there has been a gradual increase in the use of non-wooden (particularly concrete) cross-ties, over 90% of all ties are wooden. Even now, the Rail Tie Association estimates non-wooden ties to be only about 6.5% of current new tie installations (https://www.rta.org/faqs-main).

such removals occur when new rail is being installed.[25] However, the tightness of the relationship may seem a little surprising in that only a fraction of the new ties is directly needed by the installation of new replacement rail.[26]

One reason for the "tightness" of this relationship and between each of these output measures and the miles of relaid rail[27] may be (per footnote 12) that managements' overall MOW budget, and that of each of its MOW components, is affected by the magnitude of financial pressures on railroads. However, our analysis (below and in Appendix C) indicates that much of the rail removed when new rail is installed is relaid elsewhere on the railroad; the implication of this is that such removed rail, while no longer appropriate for the highest traffic needs is still useful rather than "dead". These relationships are discussed further below: we note here that having three proxies for MOW output, but with differing types of other information about each, helps test explanations of the changes in MOW output over time.

Figure 2: All Railroads



Source: AAR

The overall changes in both the new rail and ties series seem to have been affected by the changes in GTM/mile: MOW output declines during the period in which GTM was flat but increases when GTM/mile (and wheel loading) increases in the 1960s. However, the

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[25] The costs of replacing crossties in the absence of rail replacement have led to a "rule of thumb" to not replace ties unless at least 25% of the ties are "bad" (Gauntt & Palese, 2004, p. 5). This heuristic is useful as determining the proportion of "bad" ties needed to force either tie renewal or lower train speeds is not straightforward. However, for reference purposes, we note that the Federal Railroad Administration currently sets regulations on the proportion of "good" ties needed for track safety. For example, its 2011 track safety standards state that half of the ties need to be good on a Class 4 or 5 Track with minimal curve; curved trackage is required to have a higher proportion of "good" ties (because of the greater "stress" on rail in curves) to be Class 4 or 5 track. Lower "Class" levels have lesser required "good" proportions but, consequently, have lower allowed train speeds. (See FRA 2011, particularly p. 109).

[26] See Appendix A for a simple calculation of an upper bound for the percentage of ties that are replaced due to new rail.

[27] In particular, the correlation coefficients of relaid rail with cross ties laid are 0.86 and 0.65 for Seaboard and Atlantic, respectively. The correlation coefficients of relaid rail with new rail laid can be found in Footnote 31.

timing pattern of declines during the "flat" GTM period are apparently related to US recessions. Figure 2 relates the changes in yearly new ties and rails to U.S. recessions over this period: each recession brings a significant reduction in ties (and rails) which is *not* reversed after the end of the recession in the 1946-60 period.[28] This "stair step" decline pattern appears to change only when GTM/mile increases significantly during the 1960's (See Table 1).

Formally, we relate, in Tables 2 (for ties) and 3 (for new rail), the respective MOW output variable to variables reflecting the lasting impact of the recession (i.e., for all years after each of the specified recessions), an "impact" variable for all of the recession years as a group, plus other possibly relevant variables such as GTM/mile. For example, as shown in Column (1) of Table 2, each recession led to a persistent decline in new cross ties and that relationship holds after also controlling for both a variable that shows the effect of the group of recession years (Column 2) and for an additional variable representing changes in GTM/mile (Column 3).

Table 2: Cross Ties Laid

VARIABLES	*(1)*	*(2)*	*(3)*
Lagged Total Cross Ties	-0.0413	-0.0564*	0.0347
	(0.03)	(0.03)	(0.03)
Miles of New Construction	6.71	10.07	-16.12
	(27.90)	(25.98)	(20.23)
Miles of Abandoned Road	3.83	5.459	3.991
	(3.92)	(3.74)	(2.76)
1949 or Later (Recession #1)	-7,358***	-8,114***	-6,573***
	(2346.00)	(2218.00)	(1669.00)
1953 or Later (Recession #2)	-4,661**	-5,265**	-6,430***
	(1945.00)	(1836.00)	(1374.00)
1957 or Later (Recession #3)	-9,491***	-10,827***	-8,563***
	(2758.00)	(2663.00)	(2036.00)
1960 or Later (Recession #4)	-5,800**	-4,807**	-4,417**
	(2145.00)	(2064.00)	(1507.00)
1970 or Later (Recession #5)	281.8	-3,200	-6,241**
	(3429.00)	(3706.00)	(2824.00)
Recessions Indicator		2,705*	4,071***
		(1472.00)	(1135.00)
Ton-Miles per Mile of Road			9.902e+06***
			(2705000.00)
Constant	79,425**	93,476***	-21,602
	(29728.00)	(28658.00)	(37729.00)
Observations	24	24	24
R-squared	0.934	0.947	0.974

*Standard errors in parentheses; *** $p<0.01$, ** $p<0.05$, * $p<0.1$*

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[28] Recessions are indicated with vertical bars that are placed near the beginning of the recession, as given by dates from the NBER (https://www.nber.org/cycles.html). Recessions in this period varied in length only slightly, lasting from between 8 to 11 months.

Similarly, in Table 3 for New Rail Laid, Column (1) shows that each recession led to a persistent decline in new rail laid; a relationship that holds in Columns (2) and (3) controlling for variables that both show the effect of recession for the group of recession years and controls for changes in GTM/mile.

Table 3: New Rail Laid

VARIABLES	*(1)*	*(2)*	*(3)*
Lagged Total Miles of Track	-0.0507	-0.0907**	0.0167
	(0.04)	(0.04)	(0.06)
Miles of New Construction	-2.581	-2.447	-6.023
	(8.91)	(7.42)	(6.88)
Miles of Abandoned Road	0.124	0.67	0.675
	(1.23)	(1.05)	(0.94)
1949 or Later (Recession #1)	-1,754**	-2,113***	-1,625**
	(733.50)	(625.00)	(607.40)
1953 or Later (Recession #2)	-1,703**	-2,123***	-1,969***
	(634.20)	(550.00)	(499.10)
1957 or Later (Recession #3)	-3,145***	-3,835***	-3,034***
	(872.50)	(769.00)	(789.00)
1960 or Later (Recession #4)	-1,434	-1,347*	-584.2
	(825.50)	(688.60)	(717.30)
1970 or Later (Recession #5)	140.8	-1,579	-1,610
	(1099.00)	(1108.00)	(994.30)
Recessions Indicator		1,190**	1,315***
		(431.70)	(391.90)
Ton-Miles per Mile of Road			2.354e+06*
			(1124000.00)
Constant	28,243*	43,072***	-3,504
	(15150.00)	(13723.00)	(25420.00)
Observations	24	24	24
R-squared	0.925	0.952	0.964

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

These “stairstep” declines are *not* simply due to the decay or collapse of the Northeast railroads. Even Southern District railroads[29], which were relatively prosperous, had drastic declines in the same period. Figure 3 contains the same types of MOW output series as in Figure 2, but solely for the ICC’s Southern District.

The Southern District results broadly mirror those of “all” districts for the various subsets of time periods. Specifically, from 1946-1961, new rail fell at an average annual rate of 11.3% in the Southern District (vs. 9.3% for all districts) and new ties fell at an average annual rate of 8.4% in the Southern District (vs. 6.6% for all districts). Similarly, in 1962

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[29] The ICC’s Southern District was basically east of the Mississippi and south of the Ohio River. To avoid confusion with the Southern Railway Company we will refer to this District as either the “Southeast” or the “Southern District.”

through 1970 new rail grew at an average annual rate of 15.5% in the Southern District (vs. 6.5% for all districts) as compared to new ties, which grew at an average annual rate of 6.4% in the Southern District (vs. 2.9% for all districts).

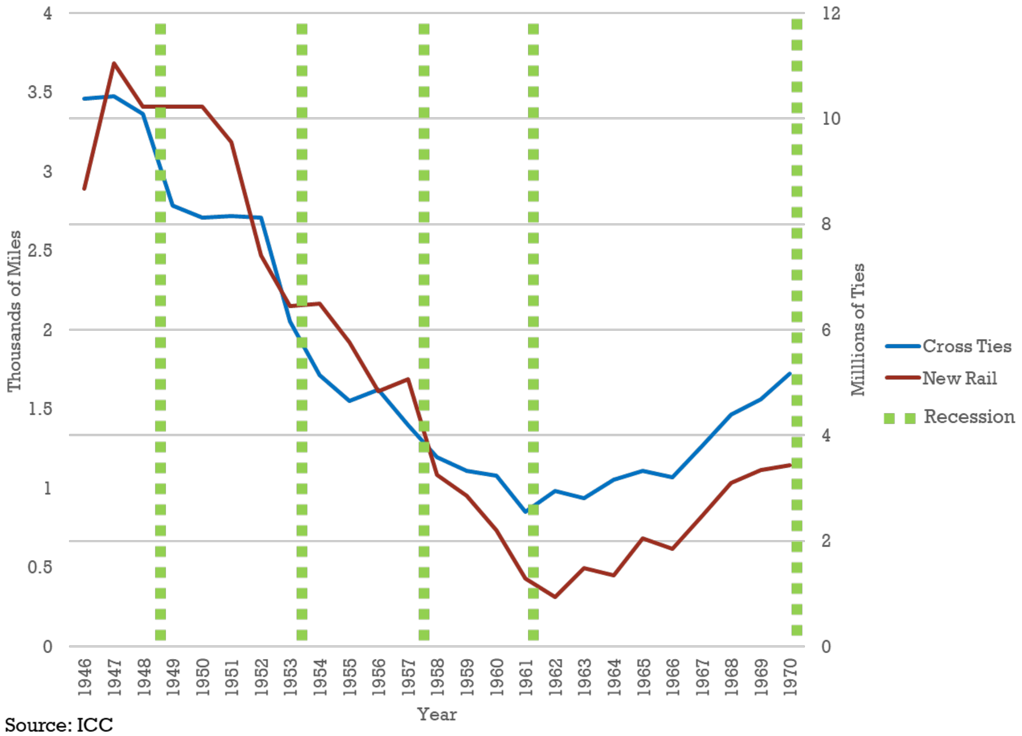

Figure 3: Southern District Railroads

Source: ICC

3.2 MOW Output Statistics for Initial (Southeastern) Sample Railroads

Similar ("stairstep") declines applied even to large ("network"), profitable Southeastern railroads. Our initial sample of such are the Seaboard Air Line (SAL) and the Atlantic Coast Line (ACL). While these charts do not control for these railroads' route mileage, the miles for ACL and SAL were similar.[30]

As indicated above, we also have examined the relationship between new rail laid and the miles of rail relaid for these railroads. We find that for each of them, the correlation is nearly 1.[31] However, for interpretation purposes, the regression coefficients are important: in each case the coefficient of new rail in the rail relaid equation approximates

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[30] SAL and ACL merged in 1967 to form the Seaboard Coast Line. The post-merger relative index values are computed by comparing the post-merger new rails per track mile with the 1966 values of rails per track mile of the separate firms. There were a few, albeit much smaller mergers, involving these railroads in the study period. Figure 4 makes no adjustment for any effects of these other acquisitions.

[31] Specifically, the correlation between rail laid in replacement and new rail laid is 0.96 for both the ACL and the SAL though 1966. (If you include years through 1970 without adjusting for post-merger values, then it is 0.91 for the Seaboard).

2;[32] it is “as if” the rail displaced when new rail is added is not generally disposed because of its “senescence,” but instead is used to displace other rail, some of which in turn may displace other rail. Rather than senescence we might think of this as “demotion”[33] by superior new rail.[34]

Figure 4: Selected Southeast Railroads - New Rail Laid

Source: Moody’s Transportation Manual.

4 Possible Explanations of the MOW Output Changes

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[32] Specifically, in a regression where the dependent variable is the firm’s miles of relaid rail, the coefficients of new rail laid are 1.97 and 1.99 for the premerger values of ACL and SAL, respectively. The R-squared for these regressions are 0.934 and 0.929, respectively.

[33] In Appendix C, we discuss some possible other implications of this “demotion” process.

[34] The new rail might be superior by being heavier. Rail weight is reported in terms of pounds per yard. In 1946, the average weight of main track for the “all” railroad aggregate was just shy of 100 pounds per yard. The mileage of all rail track weighing less than 110 pounds per yard, which accounted for about two-thirds of track miles in 1946, declined throughout the period. In contrast, new rail averaged about 120 pounds per yard throughout the period. (Appendix C provides more details on the distribution of rail weights and its changes over time.)

The new rail might also be superior in terms of the chemical composition/hardness of the steel. And increasingly over the period it was likely to welded. Welding, by reducing the number of joints between rails, a major “failure mode”, provided improvements.

In this section, we consider some hypotheses for the substantial declines in measured output of new rail and ties over the period until the early 1960's. Apart from the intellectual challenge in explaining this phenomenon, the source of decline has implications for correctly estimating and interpreting productivity growth. The following subsections outline and summarize possible explanations.

4.1 War Time/Depression Deferrals

This possible explanation starts with the hypothesis that railroads had deferred way maintenance during the great depression (due to their financial constraints) and during World War II (due to limits on their available manpower and on materials such as steel) while experiencing record traffic levels[35] *but* in the early postwar period they increased their MOW expenditures in order to reduce this deferred backlog. As these deferrals were eliminated, the yearly rate of compensatory MOW and, therefore, of total MOW investments, declined.[36]

There is some contemporary evidence that railroads entered the postwar period with deferred maintenance of either equipment and/or "way". For example, the BLS report suggested that railroad employment opportunities in some areas might be reduced as deferred maintenance was made up (BLS, 1949, p. 41).

However, the *rate* of MOW output, even in the early postwar period, does not appear to have been one that would reduce (significant) MOW deferred amounts. For example, using a 28 year life for treated ties and 14 year life for untreated ties[37] yields a weighted average life in the immediate postwar period of 26.49[38] or an implied 3.77% yearly replacement rate. The actual average replacement rate in 1946-48 was essentially the same at 4.06% per year.

Further, we know that by the end of the study period railroads had a massive amount of deferred "way" maintenance and those deferrals were not simply the property of railroads in the Northeast (GAO, 1981). Such deferred way maintenance also had triggered "slow orders" on much of the rail network (GAO, 1981; Lovett *et al.*, 2015). Even if there were some deferrals at the end of WWII, productivity measures would still be upward biased if deferral at the end of the period were even larger.

4.2 Increasing Rail & Tie Longevity

This possible explanation hypothesizes that rail and tie longevity improved over the study period. Or more precisely, since their longevities were, even at the beginning of the study period, large relative to the length of the study period, it was their improvement in the pre

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[35] Gross ton miles in the early postwar period were about a third higher than the in the previous peak, the 1920s.

[36] The "stair step" pattern might, under this hypothetical, be explained by the consequence of major railroads eliminating their MOW deferrals and/or because recessions prompted railroads to recognize that they were close to reaching their maintenance targets.

[37] See Appendix B for additional details comparing treated and untreated ties.

[38] Untreated ties were about 89.23 % of the total as of 1946 (ICC Transport Statistics, 1946).

study period which is applicable for this possible explanation.[39] For example, if the average longevity of treated ties in 1946 was 28 years, it might have only a small chance of being replaced even in the mid 1960s.

However, there is no evidence for such *relevant* increasing longevity.[40] And, further, increases in traffic levels and in the average loaded weight of freight cars (as discussed above) would tend to act against increasing longevity. In particular, the weight of new rail has steadily increased over time. Hence, the average vintage of embedded rail is earlier: i.e., lighter rail was, on average, installed earlier. Yet the average percentage decline in mileage rate of all rail weights of less than 110 pounds per yard are similar, at 2 or more per cent per year.[41] Further, while new rail of 110-119 pounds per yard continued to be installed during the study period and essentially almost all rail in this weight group had been installed after 1925[42], total installed mileage of such weight began declining as early as 1953, suggesting (average) longevity of less than 30 years. And the analysis above shows the close relationship between installations of new rail and ties.

4.3 Focus on Super Routes

This possible explanation is that over the study period railroads increasingly focused on defining a subset of their route mileage which they viewed as long run viable. By the late 1950s this “core” network was defined to be less than half (45%) of their network. By then they had reduced their MOW expenditures to sustain that portion of their network and no more. The increase in rail traffic and in car weight during the post 1962 US “boom” increased MOW output, for the “core” (and only that) after 1962.

By the early 60’s, railroads were no longer making significant maintenance investments in about half or more of the network. Average new rail weights throughout this period approximated 120 pounds per yard based on aggregate data, Southern District data, and data from our sample of two large Southern railroads.[43] During this period, the miles of each category of installed track less than 110 pounds per yard were declining, by 2% per year or more, as seen in Figure 5 below. Further, to average 120 pounds, almost all new rail was greater than 110 pounds per yard. Even the growth of track greater than 110 pounds per yard had essentially stopped by the late 50’s. The end of the increase in such relatively heavy track did not reflect a falling load on the overall track structure: the number of ton-miles, in total and per mile of road, was not decreasing. While railroads’

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[39] For example, Olson (1971) illustrates that the average service life of the “best white oak crossties” varies from 4 to 10 years depending on climate in the late 19th and early 20th centuries (pp. 12-13).

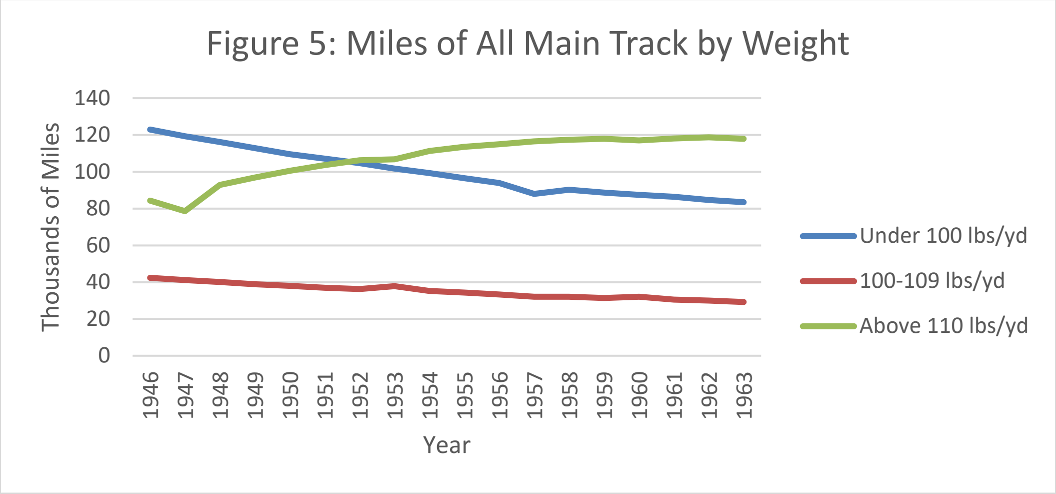
[40] Estimates of tie longevity vary only slightly after the early 20th century. Haber *et al.* (1957) describes the lifespan of a treated tie to be 28 years, and references an ICC Engineering report from the late thirties that reports a 25-year life for treated ties (pp. 37-38).

[41] See Table C1 in the Appendix. Since these decline rates also reflect some shrinkage in main track miles, on their face they suggest an average rail life of about 50 years.

[42] Only 1,763 miles were installed as of 1925 whereas mileage in this weight class were 52,434 as of 1952.

[43] See Footnote 49.

behavior may have been long-run profit maximizing (not examined further in this paper), it is doubtful to treat decreases in MOW labor hours per ton mile of traffic arising from reducing the maintained network as showing gains due to mechanization or improvement in workers' skills.



We think that this third explanation is, by a significant margin, the most plausible. We think that the stair step pattern of tie and rail investment reflects a gradual recognition of railroad management not only that none of the "innovation" and "investment" programs[44] had successfully increased rail traffic or (inflation adjusted) rail revenues through the end of the 1950 but also that challenges to their future (e.g., the Interstate Highway program, signed in 1956 and the St. Lawrence Seaway from 1959 and upgraded in 1973) appeared to be only increasing. In addition, while probably overstating the amount of excess capacity, Keeler (1974) estimated that a substantial majority of the rail network represented "excess tracks" (see Table 1 in his paper).

5 Effect on Productivity Estimation

In this section, we provide a brief illustration of the implications of reduced maintenance on changes in measured MOW labor productivity. Suppose that we were to approach labor productivity estimation similarly to that used in many railroad studies: labor productivity improvement, as measured by revenue ton-miles versus MOW employment over the period 1946 – 1970, would be 5.62% per year. Using relative cost elasticities to account for both freight and passenger miles, similar to Caves *et al.* (1980), labor productivity improvement with MOW employment over the period is 6.33%.

However, this approach treats as productivity improvement the reduction in the maintenance of the network and/or deferral of maintenance. Instead, consider using ties installed and new rail as the output measures. Then, the estimated increase in labor productivity (over the same time period) is found to be 1.61% per year and 0.75% per year, respectively, for ties and rail. Thus, appropriately accounting for the deferral of maintenance has significant implications for estimation of productivity improvements.

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[44] For example, railroads had invested close to 4 billion dollars from 1946 to 1959 to convert to new diesel locomotives, with lower fuel and maintenance costs (AAR, 1965).

Further, we explore the reduced maintenance effects on productivity estimates for individual railroads in Tables 4 and 5 with two different approaches. First, in Table 4, we take an approach similar to that in the previous paragraph; we illustrate how examining productivity changes in terms of a MOW-related output measure (new rail laid) lowers the estimates of productivity changes as compared to using a general output measure (ton-miles). Second, in Table 5, we explore how, even if we use ton-miles as the output measure, if we account for the reduction in MOW employment due to deferral by using MOW employment levels necessary to maintain tie and rail investment levels from 1946, then we still find lower changes in productivity. Thus, either examining MOW-output or accounting for deferral directly is necessary to accurately estimate productivity changes in this period.

Specifically, in Table 4 below, the first column shows changes in labor productivity from 1946-1966 with ton-miles as the output measure, using MOW employment as the input. Using this output measure that does not account for deferral of maintenance shows a high increase in productivity over the period. However, in the second column, when we examine an MOW output, new rail laid, there is a very different picture painted regarding changes in labor productivity over the period. In fact, for the Seaboard Air Line, we find an estimated labor productivity decline over 1946-1966[45] when examining new rail laid versus MOW employment.

Table 4: Apparent MOW Productivity Changes (1946-1966)

	Ton Miles	*New Rail Laid*
Atlantic Coast Line	10.00%	1.49%
Seaboard Air Line	7.36%	-0.27%

Finally, we performed preliminary analysis to incorporate estimated deferral of maintenance of way into calculations of (labor and total) productivity improvements by following the procedures listed below:

1) Estimate the effect of the level of yearly new rail and new ties on the yearly quantity of MOW employment;
2) Estimate how much MOW employment would be needed in later years to maintain 1946 tie and rail investment levels. This allows a quantification of changes in employment due to productivity improvements versus due to deferral of maintenance;
3) Compute increases in labor (and total) productivity, reflecting the delta from step 2 and increases in machinery.

Thus, we run a regression predicting MOW employment on cross ties and new rail laid, allowing coefficients to vary by year:

$$MoWEmployment_{i,t} = \beta_{o,t} + \beta_{1,t} CrossTiesLaid_{i,t} + \beta_{2,t} NewRailLaid_{i,t}$$

Then, we use these coefficients to construct a predicted MOW employment measure if 1946 investment in rail and ties were maintained:

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[45] Average rates between 1946 and 1966 are shown, prior to the 1967 merger between Atlantic Coast Line and Seaboard Air Line.

$$\begin{aligned} MoWEmployment\_1946Level_{i,t} \\ = \beta_{o,t} + \beta_{1,t}1946CrossTiesLaid_{i,t} + \beta_{2,t}1946NewRailLaid_{i,t} \end{aligned}$$

Finally, we use this updated employment to calculate estimated productivity improvements if there were no deferral of maintenance, as seen in Table 5 below. The first column repeats the calculation of productivity changes from 1946-1966 examining ton miles versus MOW employment. The second column uses the MOW employment level estimated to sustain 1946 levels of rail and tie maintenance. We see that for both railroads, there is a significant decline in estimated productivity changes; in particular, the estimated productivity improvement for Atlantic is less than half the value of when deferral is not accounted for.

Table 5: Apparent MOW Productivity Changes with No Deferral (1946-1966)

	Ton Miles	*Ton-Miles with Employment to Sustain 1946 Rail/Ties*
Atlantic Coast Line	10.00%	4.10%
Seaboard Air Line	7.36%	6.06%

Thus, we illustrate that accounting for deferral of MOW expenses has significant implications for the productivity estimates of these railroads.

6 Next Steps and Conclusions

This paper has begun the reconsideration of postwar (1946-70) productivity change in the US railroad industry based on detailed analysis of “micro” data from individual functional segments for individual firms and the industry. In particular, it has focused on the maintenance of way (MOW) segment and used data for that segment both at aggregate levels (for “all” railroads and for “Southeastern” railroads as groups) as well as for two major Southeastern roads (the Atlantic Coast Line (“ACL”) and the Seaboard Air Line (“SAL”)).

We have found that there were major reductions in the output of this segment at the aggregate level (and for the two railroads) even though the traffic demands placed on the segment (measured by changes in traffic levels or GTM/mile, freight train speed, and wheel loadings or loaded car weight) generally increased over the period, particularly during the 1960s.

We have examined possible explanations of this behavior. Among those, the most likely, based on our analysis to date, is that railroad managements gradually distinguished between a group of “core” routes, constituting less than one-half of the mileage of the overall railroad network, which were worth sustaining, and the remainder, which were not. Further, based on our preliminary examination of ACL and SAL data, if this hypothesis is correct, there are major implications for the true increase in MOW productivity over the period.

Our testing of the hypotheses for the declining MOW output, determining the role of individual railroad managements in reacting to industry changes, and more precisely measuring the implications for MOW (and overall) productivity entails significant additional analysis. Some of the key next steps are: (i) refining the analysis of the ACL and SAL railroads, including examining their post-merger behavior;[46] (ii) extending the analysis to other large Southeastern systems (e.g., the Southern Railway), thereby considering the effects of disparate management, and to Southeastern railroads that faced quite different circumstances, particularly those that were all "core" (i.e., lines such as the Clinchfield and the Cincinnati, New Orleans and Texas Pacific that had few branches); (iii) applying the approach to "Western" railroads, both those that were Midwest/Great Plains railroads (e.g., the Chicago & Northwestern and the Kansas City Southern) and those that extended to the West Coast (e.g., Santa Fe).

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[46] These lines were merged in 1967. However, the post-merger performance of the combined entity, Seaboard Coast Line, might have been affected by labor merger conditions. (For a summary of the various types of post merger conditions in railroads, see Saunders, 2001.)

Appendix A: Relationship Between New Ties and Rail

In this appendix, we calculate the percentage of cross ties that are associated with new rail. Note that if all ties are replaced when new rail is laid, then a mile of new rail would require 3250 new ties (e.g., Zarembski & Kondapalli, 2007). However, unless the railroad's route changes, this is a strict upper bound for the number of new ties.

There is a cost complementarity between the laying of new rails and of new ties: the incremental (labor) cost for replacing ties is lower if you are also replacing the associated track rails at the same time[47]. However, as shown in Figure A1, the number of new ties, even if all ties were replaced for each newly laid track mile, is substantially larger than the maximum needed to support the new rail.

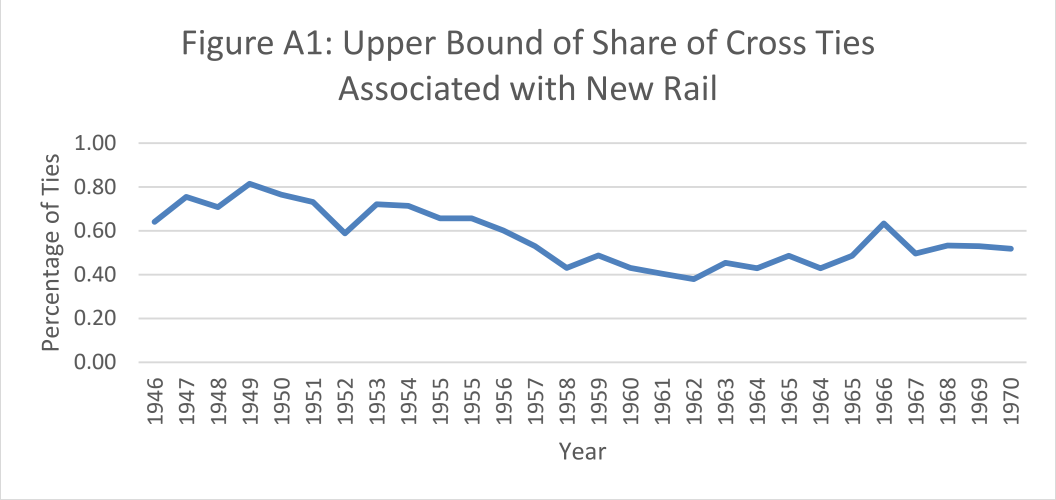
Figure A1: Upper Bound of Share of Cross Ties Associated with New Rail

Appendix B: Estimate of Change in MOW Requirements due to Treated Ties

In this section, we provide an estimate of the decline in new installations of ties that could be accounted for by a conversion of route miles with untreated ties to treated ties. Given that treated ties have a longer life span, a portion of the decline in new ties can be attributed to using ties with a longer life span. However, in this section, we will show that the decline in maintenance for ties cannot be reasonably attributed to the conversion of untreated to treated ties.

As a starting point for this calculation, we first need to establish the average length of life of both untreated and treated ties. The study of Haber, *et al.* (1957) discusses the average life of ties. It states that a treated tie may have a lifetime of 28 or more years but that untreated ties are only half that (p. 37). It cites an ICC study that about 89% of all currently installed ties were treated as of 1946 but 94% of the installed base had been treated as of 1952. It further cites an ICC Engineering Section that reported a 25-year life for treated ties (and half that for untreated), based on studies from the late thirties (p. 38). And it also opines that in the future (from 1957), while tie life may lengthen, no "… vast

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[47] And a rule of thumb is that it is "uneconomic" to replace ties unless "bad" ties amount to 25% of the ties on a stretch of rail.

improvement is on the horizon" (p. 40). Other, more recent studies (e.g. Lovett *et al.*, 2015) cite the U.S. Forest Service products curve when they use 30 years as a tie life value. Thus, as a conservative estimate, we will use 30 and 14 years as the life span of treated and untreated ties, respectively.

Then, an approximate calculation is as follows. Suppose that all ties are replaced at the end of their *expected* lifespan.[48] Then, assuming that at the beginning of the sample, maintenance was up to date, we would calculate that the average annual replacement is:

$$Replacement_t = \frac{1}{30} * (Number\ of\ Treated\ Ties\ in\ Tracks_t) + \frac{1}{14} * (Number\ of\ Untreated\ Ties\ in\ Tracks_t)$$

Two adjustments to this simple calculation account for: (1) rail (and ties) for new route mileage and (2) ties that need not be replaced because of abandoned rail track miles. First, given that new track requires ties to be laid, and if we assume that only new ties will be used for the new miles, then each new route mile would require 3250 new ties (e.g., Zarembski & Kondapalli, 2007). Second, each abandoned route mile reduces tie replacement in each subsequent year. Thus, we multiple the net change in track miles by 3250 to account for a net change in ties needed due to new and abandoned rail.

From 1946 through 1970, the percent of treated ties in maintained track went from 89.23% to 99.91% (ICC Transport Statistics). Thus, we expect that average life span changed from 28.28 to 29.99 years. In Figure B1 below, we see that accounting for the extended life span of ties, as well as for the declining number of ties in maintained track does lead us to expect a decline in the number of cross ties laid over the sample period. However, the cross ties laid falls fall below this line for much of the sample period, indicating deferral of maintenance of ties that cannot be accounted for by the use of treated ties.

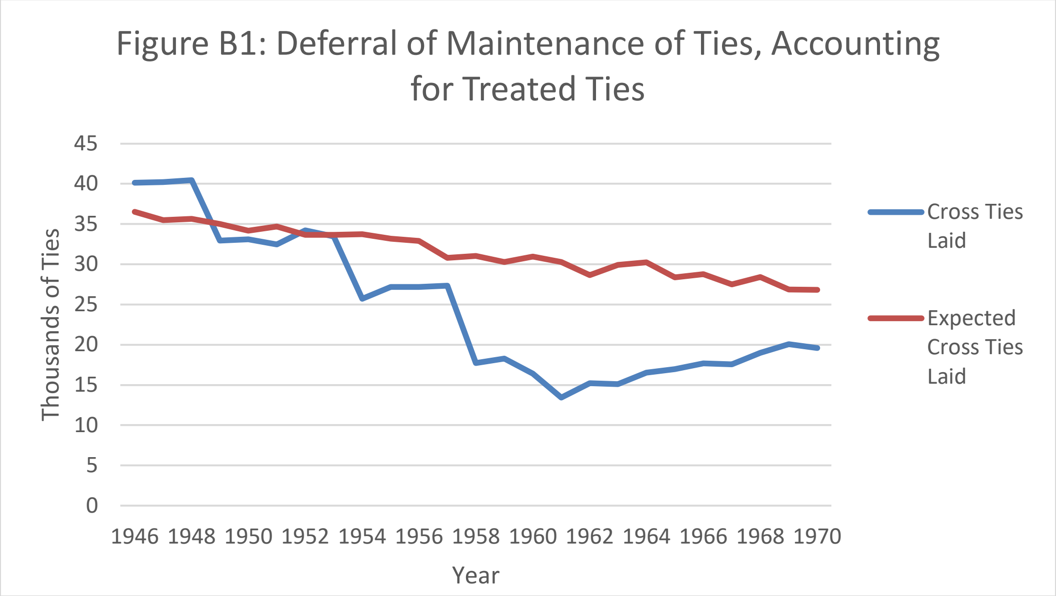

Figure B1: Deferral of Maintenance of Ties, Accounting for Treated Ties

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[48] Of course, as discussed below, we modify this assumption to reflect a distribution around the ties expected lifespans.

Appendix C: Rail Cascades

The text identifies a close relationship between the quantity of new rail and the miles of relaid rail over time (as well as that between new rail and new ties). Thus, for both the SCL and the ACL, the correlation between their mileage of new and relaid rail approaches 1. And the regression coefficient of new rail in the regression equation for relaid rail was approximately 2 for each railroad; i.e. 2 miles of additional relaid rail for each additional mile of new rail.

The size of these coefficients indicates a type of "pinball" action, in which the old rail displaced by new rail is not simply scrapped but frequently displaces other existing old rail which in turn frequently displaces…. This "cascade" may well arise because such railroad's internal valuation of the removed rail exceeds its "external" value, where the external value may well be heavily influenced by the rail's steel scrap value. If so, the size and diversity, in terms of rail age and rail weights, of a firm's rail portfolio may affect, *inter alia*, the magnitude of the regression coefficient between relaid and new rail laid.

Examining such hypotheses regarding the magnitude of the regression coefficients is not central for the current paper. However, analysis of rail weights and changes in its distribution over time is helpful in distinguishing between alternative hypotheses for the causes of the changes in new rail (and new tie) purchases over time.

Data for "all" railroads provides information on the distribution over time for main track of rail weight: e.g., the number of miles within various rail weight ranges such as between 110 to 119 pounds (per yard).

As seen in Table C1, this data shows that in all rail weight categories below 110 pounds per yard, the number of miles consistently fell after 1946. In each such weight class the yearly decline rates were more than 2% per year. And that decline rate for each greatly exceeded the rate of decline in total route mileage.

Thus, the rate of decline of miles in the lower rail weight categories reflected the combined effects of some shrinkage in the overall mileage of the rail system plus the reduction in mileage due to "old age" retirement plus displacement due to the cascades from new equipment purchases.

Throughout this period, the average weight of new rail was about 120 or so pounds per year.[49] Using that figure, we can roughly convert total new rail purchases in tons to miles of new track. The decline rates in Table C1 suggest that little new track was purchased below 110 pounds per yard as mileage in all of the lower rail weight categories fell at substantial, similar rates.

If so, we can compare the number of miles of new track with the net change in miles of 110 and greater rail weight to compute the apparent retirements in the heavier rail categories and the net change. The results of this preliminary comparison are shown in Figure C2, where we see a high correlation (0.83) between these two series. And we see

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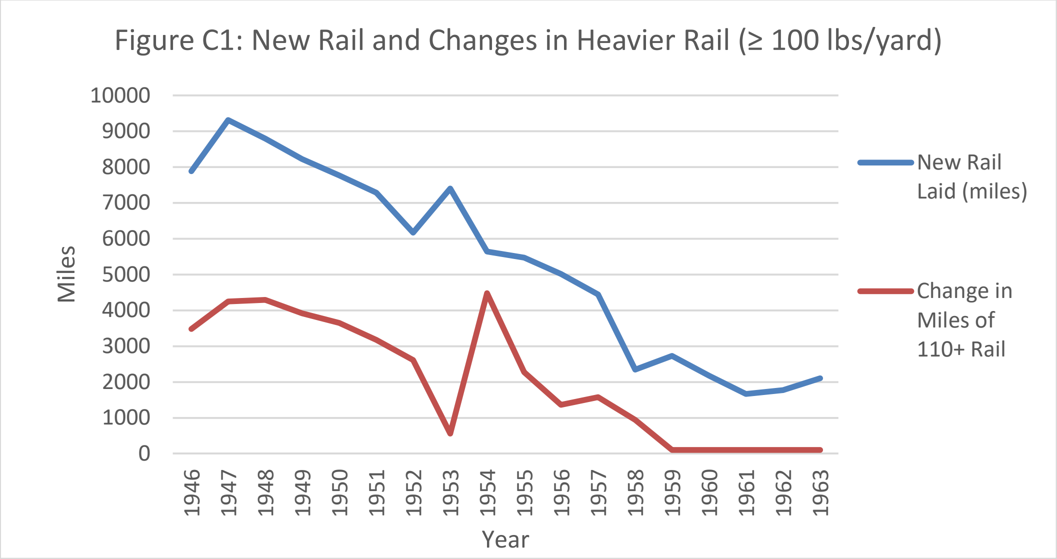
[49] For example, the average weight of new rail for 1946 to 1963 for the Atlantic Coast Line was 126 pounds per yard and for the Seaboard Air Line was 117 pounds per yard (Moody's Transportation Manuals from relevant years).

that even in these heavier categories, removals approximated new rail purchases in 1959-1963.

Table C1: Percentage Change in Miles of All Main Track, of the Weight per Yard Indicated

	Share of Track 1946	*Share of Track 1963*	*Average Yearly % Change 1946-1963*	*Average Yearly % Change 1946-1958*	*Average Yearly % Change 1959-1963*
Lighter Rail					
Under 80	16.26%	11.12%	-2.62%	-2.81%	-2.13%
80 to 89	14.11%	10.67%	-2.08%	-2.35%	-1.36%
90 to 99	18.89%	14.41%	-2.07%	-2.39%	-1.23%
100 to 109	16.97%	12.67%	-2.09%	-2.20%	-1.81%
Average	16.56%	12.22%	-2.21%	-2.44%	-1.63%
Heavier Rail					
110 to 119	17.07%	24.96%	1.93%	2.61%	0.16%
120 to 129	2.52%	2.81%	0.40%	1.75%	-3.12%
130 to 139	13.73%	21.31%	2.28%	2.28%	0.41%
Over 139	0.46%	2.07%	9.52%	12.83%	0.91%
Average	8.44%	12.78%	3.53%	4.87%	-0.41%
Total Average	12.50%	12.50%	0.66%	1.21%	-1.02%



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