Engines of Growth: The Productivity Advance of Indian Railways, 1874-1912

Dan Bogart* Latika Chaudhary†

Draft: September 2012‡

Abstract

Railways were integral to the development of the Indian economy before World War I. In this paper, we present new estimates of total factor productivity (TFP) for railways from 1874 to 1912, which highlight the strong performance of this key industrial sector. We find railway-industry TFP growth to be substantial, averaging 2.6 percent per year and generating a 3 percent social savings for the Indian economy. A combination of factors contributed to TFP growth including greater capacity utilization, technological change, and improvements in organization and governance. The larger conclusion is that railways had higher TFP growth than most sectors in India and compared favorably with TFP growth for railways in other countries.

Keywords: Total Factor Productivity, India, Railways, Long-run Growth.
JEL codes: D2, D23, H54, L33, N75, O2

*UC Irvine, Email: dbogart@uci.edu

†Scripps College, Email: latika.chaudhary@scrippscollege.edu

‡We thank seminar participants at St. Andrews, Stanford and Vanderbilt and conference participants at the All-UC Economic History Meetings in Berkeley, the Economic History Society Meetings in Cambridge, the UCLA Alumni Economics conference, the HI-POD conference on India and Great Divergence in Rajasthan, and the World Economic History Congress in South Africa. We also thank the Center for Global Peace and Conflict Studies for providing valuable grant money. Garrett Neiman, Shivani Pundir, Jennifer Ringoen, Nilopa Shah, and Sanjana Tandon provided able research assistance.

1 Introduction

The Indian economy experienced low productivity growth for much of the late 19^{th} and 20^{th} century up to independence in 1947. Between 1890 and 1910, total factor productivity grew by only 0.4 percent per year (Broadberry and Gupta 2010). Agriculture accounting for more than 70 percent of the economy was the main culprit, but even modern sectors such as cotton textiles exhibited low productivity relative to industrial countries such as the United States and Britain (Clark 1988, Clark and Wolcott 1999, Gupta 2011). Such poor productivity estimates match the disappointing income performance of the Indian economy in the colonial period (Madisson 2003, Roy 2010). Even in the decades before World War I when the economy performed better than in periods before or after, income per capita increased by only 0.6 percent per year from 1870 to 1913. Was poor productivity a hallmark of the colonial Indian economy?

In this paper, we estimate TFP growth for Indian railways and assess its contribution to national income growth from 1874 to 1912. Measuring the rate of productivity growth in railways is important for many reasons. First, railways are one of the most important technological and infrastructure developments of this period. Kerr (2007) describes railways as an 'engine of change' for the Indian economy.[1] By increasing price convergence and trade flows, Hurd (1983) and Donaldson (2010) argue for large social savings from railways on the order of 9 percent of national income by the early 1900s. That said, economic historians offer a mixed assessment of the sector with some scholars arguing that Indian railways were developed to benefit colonial interests and did not lead to rapid economic growth as in other parts of the world (Thorner 1955, 1977, Derbyshire 1987, Hurd 2007, Sweeney 2011). This critical view raises an important question about whether the low overall productivity in colonial India also extends to the railway sector.

Second and more generally, TFP growth is a main contributor to social savings. The conventional social savings methodology quantifies the freight rate difference between some pre-existing technology and railways long after initial construction (see Fogel 1970, Fishlow 1965). Such calculations conflate the effect of adopting railways from any subsequent productivity increase. Railways immediately increased the productivity of transport by displacing horse-drawn wagons and carriages, but the technical and organizational advance of railways continued in the years following construction. Improvements in the design of locomotives and wagons increased capacity and fuel efficiency; better signaling systems lowered

[1]The literature on Indian railways is vast. A selection of these studies includes McAlpin (1974), Hurd (1975, 2007), Adams and West (1979), Christensen (1981), Derbyshire (2007), and Bogart and Chaudhary (2012b).

turnaround times; railway workers became more specialized and had greater experience and skill. The accumulation of these micro-innovations led to a second advance in productivity. Separating the impact of the initial bang from the subsequent advances deepens our understanding of the economic consequences of railways. We use the new growth accounting techniques to isolate the contribution of post-construction productivity to Indian income per-capita as has been done for railways in other countries like the UK and Spain (Crafts 2004, Herranz-Loncán 2006, 2011).

Crucial to our analysis is an accurate calculation of average annual TFP growth. We use detailed railway-level data drawn from official reports published by the Government of India. The Reports contain rich information on freight, passengers, labor, fuel, and capital from which we construct series on outputs and inputs for the principal standard and meter gauge railways operating in India between 1874 and 1912. Our sample accounts for 95 percent of total output in Indian railways. Using these data, we construct the first quality adjusted fuel series and a new capital stock series.

We estimate TFP at the railway-level using the best-practice econometric techniques. The traditional approach is the Index Number method, which subtracts output from a weighted average of inputs. The new approach is to calculate TFP as a residual from an estimated production function (Van Biesebroeck 2008). We employ the latter method and address the potential correlation between unobserved productivity shocks and input choices using the estimator proposed by Levinsohn and Petrin (2003). The estimator uses intermediate inputs such as fuel to address the simultaneity problem. Our Levinsohn-Petrin TFP growth estimates are similar to those derived from the Index Number method, but differ to some degree from the ordinary least squares model. We prefer the LevinsohnPetrin estimator because it best addresses the endogeneity of input choice. After calculating the railway-level TFP estimates, we aggregate them into an industry-level TFP estimate using individual railway-level output shares as weights.

Unlike the overall Indian economy, we find surprising evidence of significant productivity growth in railways. TFP growth averaged 2.6 percent per year from 1874 to 1912. TFP growth was especially high in the period from 1900 to 1912 growing at an average rate of more than 3 percent per year. Railway TFP growth outpaced most Indian sectors like agriculture (Broadberry and Gupta, 2010). TFP growth in Indian railways was also similar to or higher than railways in developed economics like the United States, Britain and Spain. The international comparison is especially striking because labor productivity in Indian textiles, another key industrial sector, was amongst the lowest in the world circa 1900 (Clark 1988). Thus, the performance of railways stands in marked contrast to the rest of the Indian economy.

The rapid rate of railway TFP growth had important implications. We estimate that TFP growth in the period between 1874 and 1912 contributed to a 3.1 percent increase in Indian national income by 1912. The combined effect of capital accumulation and TFP growth accounts for 22 percent of the total increase in Indian income per capita. Relative to social savings, TFP growth in the period from 1874 to 1912 accounts for around one-third of the total estimated impact of railways up to the 1930s. Consumers also benefited from these productivity gains in the form of lower freight rates: 1912 freight rates were 42 percent of their level in 1874 indicating a large increase in consumer surplus.

What explains the good productivity performance of colonial Indian railways? In the last section of the paper we examine a number of candidate explanations. First, we find that reallocation effects, including entry, exit, and changes in market share, explain only a limited portion of industry TFP growth. Rather, TFP growth within large railway systems was very critical. Second, we find that greater capacity utilization accounts for a small share of total TFP growth. To assess the quantitative significance of capacity utilization, we modify the production function estimation to include utilization variables, such as train miles run per track mile. The TFP estimates are 83 percent of the original estimates. Third, we study the effects of railway gauges, which differed greatly across India. We show that TFP growth was generally similar for the two major gauges, broad and meter, indicating that TFP growth was not necessarily hindered by gauge diversity. Fourth, we investigate the role of technology adoption. Drawing on a set of technology adoption measures from the 1900s we show that several of the major technologies emphasized by contemporaries, such as interlocking signal stations, are positively correlated with TFP. Although significant, the documented technological innovations of the 1900s account for a relatively modest share of TFP growth in this period. This suggests a role for other factors such as undocumented technological and organizational changes, including improved governance and regulation led by the Government of India.

We draw two main conclusions from our study. First, railways were one of the leading sectors in India in the decades before World War I. They helped initiate a limited process of economic growth from 1870 to 1912. Second, our results re-emphasize the importance of TFP in assessing the developmental impact of railways. If India had failed to improve the productivity of its railway system after their initial construction, then the social savings from railways would have been smaller and their overall impact would have been lessened.

2 Background on Indian Railways

After the first passenger line opened in 1853, the subsequent development of the rail network was rapid especially in the 1880s and 1890s. By the early 20^{th} century, India had the fourth largest rail network in the world and was of similar or greater size than Brazil, China and Japan, but smaller than the Unites States that had the largest rail network in the world. The initial network was constructed on a broad gauge (5 feet 6 inches) and consisted of trunk lines connecting the major ports of Bombay, Calcutta, Karachi and Madras to the interior. Subsequent lines broke from the standard gauge and were constructed on a cheaper meter gauge (3 feet 3¾ inches). These lines often served as feeder lines connecting to the main trunk route. A few narrow gauge (2 feet) lines were also constructed connecting to different hill stations, but they carried less than 1 percent of the overall traffic. While economic and military concerns dictated route placement in the earlier decades (Thorner 1955), social concerns following the devastating famines of the 1870s led to the construction of some protective famine lines in the 1880s. Figure 1 displays the rail and river network as of 1909.

Private British companies managed the initial construction and operation of the lines. They were also known as 'guaranteed' railways because they received a 5 percent dividend guarantee on invested capital. Railways operated under concession contracts with the Secretary of State, a cabinet member of the British government. The Government of India (GOI) enforced the contracts and regulated railway companies. The largest and most important of the early railway companies were the East Indian railway and the Great Indian Peninsula railway. The East Indian served Calcutta and was constructed in the 1850s. The Great Indian Peninsula railway served Bombay beginning in the 1850s. Jointly these two railway companies accounted for over 50 percent of all traffic in the 1870s.

There was a shift in ownership and operation beginning in the 1870s when the GOI began to construct and manage new railway lines.[2] The period was short-lived and in the 1880s a hybrid GOI owned but privately operated structure emerged. The GOI owned a majority of the capital and private companies operated the railway under a concession contract for 25 years. The profits were split between the GOI and the company in proportion to their capital. The dividend guarantee was retained, but lowered significantly to 3 to 4 percent. The public-private partnership model was the dominant organization form in Indian railways until the 1920s when complete nationalization was gradually introduced.[3]

[2]The Princely States were also involved in railways with many of them outsourcing the construction and operations to private companies.

[3]See Sanyal 1930, Kerr 2007, and Chaudhary and Bogart 2012b for details about the changing organiza-

Although capital costs per mile were high in the first wave of construction, they declined in our period of study as the GOI became a majority owner of the lines and the cheaper meter gauge lines were constructed. Passenger and freight traffic also increased significantly in this period growing at comparable rates with freight accounting for almost 65 percent of total revenues. While net returns on railways were below 5 percent in the 1860s and 70s, they increased to over 5 percent in the 1880s and averaged over 6 percent by 1913 (Chaudhary and Bogart 2012b). Thus, our period of study is an important one encompassing the construction of the second generation of railway lines, the partial nationalization of the network and an increase in returns over the guarantees.

The literature has generally viewed British railway companies operating in India with a high degree of skepticism. Hurd (2007) argues that railways missed opportunities for development and that management was often complacent. Sweeney (2011) highlights the revolving door between the public and private sector in this period when many public regulators joined the boards of private railway companies after retiring from service. This critique of railways fits into a larger picture of an unproductive Indian economy constrained by colonial polices and unable to achieve economic growth. But, in our view railway performance has not been assessed by any clear metric. Much of the evidence relies on qualitative arguments on the negative effects of public guarantees. In particular, there is no estimate of TFP growth to compare with other sectors and railways in other countries. In part data has been one of the stumbling blocks. There is no consistent fuel series and the precise value of the capital stock has been questioned (Morris and Dudley 1975). We now turn to a discussion of our data, which we use to estimate TFP.

3 Data

We construct a new dataset of Indian railways from 1874 to 1912 using the *Administration Reports on the Railways in India*, published annually from 1884, and the *Report to the Secretary of State for India in Council on Railways in India*, published annually from 1860 to 1883. The *Report to the Secretary* is less detailed than the *Administration Reports*, but we were able to obtain information on annual ton miles (i.e., the number of tons carried one mile), passenger miles, track miles, fuel, labor, and the value of capital starting in 1874. Although it would be ideal to estimate productivity before 1874 and after 1913, we do capture a key period of expansion and organizational change in Indian railways. Our time span also covers a period of rapid technological change world-wide in railways.

tion structure of railways.

Our sample of railways includes all the major standard and meter gauge railways operating between 1874 and 1912. Any exits during this period are due to mergers with other lines. Nine railways were operating at the start of our period in 1874 and continued to operate until 1912. They largely represented the trunk lines. Our sample also includes nine railways that began operations after 1874 but continued to operate until 1912. Many of these were built on the meter gauge and some were designated as famine lines. The remaining railways began operations after 1874 but ceased to operate by 1912 because of mergers. We track information on all lines in our dataset even if they subsequently merge to another system.[4]

We measure output using ton miles and passenger miles.[5] We convert them into a single output measure using a weighted average. Following Caves, Christensen, and Swanson (1980), the weights are defined using the cost elasticity of ton miles and passenger miles. Based on an earlier study (Bogart and Chaudhary 2012a) that calculates cost elasticity estimates, we assign a weight of 0.56 to ton miles and a weight of 0.44 to passenger miles.[6] Overall freight represented about two thirds of total revenues throughout the period from 1874 to 1912. In terms of passenger travel, the lowest class passengers (i.e., third or fourth) represented around 85 percent of passenger revenues throughout the period.

In addition to output, we construct annual series for labor, fuel, and capital inputs. The labor data are disaggregated into numbers of Europeans, Anglo-Indians, and native Indians with the latter representing over 95 percent of total workers on average. The small number of Europeans dominated the high skilled jobs of managers and engine drivers, while Indians dominated the lower skill jobs. The analysis uses total employees as our measure of labor, but disaggregation by race does not affect the results.

The fuel series presents numerous challenges and explains why the existing literature on Indian railways is largely silent about fuel consumption. Most railways shifted from British coal and wood to Indian coal between 1874 and 1912. Wood obviously yielded less British thermal units (BTU) per ton than British coal, but Indian coal was also less efficient than British coal. One ton yielded 80 to 90 percent as much BTU as one ton of British coal.

[4]Unfortunately, we are unable to follow a few of the smaller lines (less than 50 miles in track on average) in the years before they merge to a bigger railway system because their information is not consistently reported. We are in the process of creating a detailed online appendix that will explain how the data are reported in the Reports, changes pre- and post- 1900 and the railway system unit that we employ in our analysis.

[5]Passenger miles are only reported for private railways between 1874 and 1879. To construct passenger miles for state railways in these years, we multiply the reported total passengers with average trip length in 1880. Trip lengths change slowly and so the error from this imputation for state railways is likely to be small.

[6]As a robustness check we also used the annual revenue shares for each railway as weights. The results were unchanged.

Hence, the fuel series needs to account for differences in quality. Unfortunately, all the *Reports* do not list fuel consumption by type. We use this information in the few years when it is available to construct a quality-adjusted measure of fuel, which is reported in terms of Indian Kurharbaree coal (the main fuel source of the East Indian Railway).

From 1890 to 1901, we have information on total fuel consumption in tons of Kurharbaree coal for each railway. The *Reports* also give BTU conversion rates from more than 20 different types of coal and wood to tons of Kurharbaree coal. Between 1897 and 1901 the *Reports* become more detailed and give the conversion rate from Indian coal, foreign coal, and wood to Kurharbaree coal for each railway. Beginning in 1902, the *Reports* only list the tons of Indian coal, foreign coal, and wood consumed by each railway. To convert the 1902 to 1912 series into tons of Kurharbaree coal we apply the 1901 conversion rates (or 1900 if unavailable). We use a similar approach from 1874 to 1881 because the *Reports* again state the tons of Indian coal, foreign coal, and wood consumed for each railway along with a note describing the variety of Indian coal or wood.[7]

The years from 1882 to 1889 are the most challenging because we only have information on the total tons of fuel consumed without any consistent information on the type of fuel. We use a three-step procedure in this period. First, we calculate a fuel quality adjustment factor for 1881 and 1890, the nearest years for which we have detailed information on fuel type.[8] Second, we linearly interpolate the quality adjustment factor between 1881 and 1890. Third, we multiply the quality adjustment factor with the total tons of fuel consumed to get an estimate of the tons of Kurharbaree coal consumed by each railway.[9]

Railway capital consisted of track miles, locomotive engines, vehicles, stations, warehouses, bridges, and stores of other equipment. The *Reports* state the numbers of track miles, engines, and vehicles annually but not other forms of capital. Fortunately, the *Reports* also state the value of capital outlay on each railway in each year, which includes the cumulative value of all past investments (i.e., new track, vehicles, etc.) minus retirements.

[7]The *Reports* omit tons of fuel consumed in 1875 and 1876. We interpolate the tons for each railway using observations in 1874 and 1877.

[8]If a railway consumed only Kurharbaree coal, their adjustment factor would be 1. If a railway consumed only British coal in both 1881 and 1890, their quality adjustment factor would be 1.25 because 1 ton of British coal normally yielded 1.25 tons of Kurharbaree coal. If they consumed only Indian coal, their adjustment factor would be between 0.8 and 1 depending on the variety used.

[9]There are some special cases that required modifications. For Madras and Southern Mahratta railways, fuel is always expressed in terms of wood. We use the conversion rate from wood to Kurharbaree coal from the 1891 report. For the Nizam's railways fuel is always expressed in terms of wood up to 1887 when there is a shift to coal. We use the 1891 adjustment factor in 1888, 1889, and 1890 for Nizam. The Punjab Northern railway, Indus Valley railway, and Sind, Punjab, Delhi railways were merged to form the Northwestern railway system in 1886. We used the average adjustment factor for the three railways in 1881 and the Northwestern in 1891 to calculate a single interpolation for all three before the merger.

The reliability of the capital outlay series has been called into question, but we do not believe the criticisms are severe enough to render the series unusable.[10] Our main concern is with the implicit assumption of a constant price deflator for investment. To address this problem, we begin by taking the yearly difference in the capital outlay series to get an estimate of nominal investment less depreciation.[11] We then construct a real investment series by multiplying nominal investment with a capital price deflator. The deflator is based on wages for unskilled labor and prices of British capital imports.[12] Finally a capital stock measure is constructed for each railway using the perpetual inventory method, which adds yearly real investment to the previous years' capital stock.

Based on our newly constructed series, we believe the capital outlay series reported in the official publications probably under states the capital stock. For example, the East Indian railway is estimated to have 15 percent more capital by 1881 than the reported capital outlay. Our estimates differ because labor and railway capital goods were less expensive in the 1850s when the East Indian built its railway.

Table 1 summarizes the variables used in the productivity analysis. The average railway transported 294 million ton miles and 328 million passenger miles. In terms of inputs, the average Indian railway employed just under 16,000 employees, consumed 80,000 tons of fuel in terms of Kurharbaree coal, and had 955 miles of track. The average capital stock was 138 million rupees or around 9.2 million pounds sterling using the 1900 exchange rate. It is also worth noting the tremendous variation across railways and over time as captured by the standard deviation. The largest of all railways, the East Indian, averaged 857 million ton miles and 679 passenger miles.

The raw data provide immediate clues on the rate of productivity growth for Indian railways. The bottom of table 2 presents labor, fuel, and capital productivity growth (output-weighted means) disaggregated by time-period. There was a large increase in both output

[10]Morris and Dudley (1975) are critical of the capital series because it does not include the value of land, which was provided free of charge to the various railway companies among numerous other complaints. We have constructed annual series on locomotives and engines, and the temporal patterns in the raw capital outlay series are similar to those for total miles, locomotives and engines.

[11]Capital outlay is measured in pounds before 1882 and rupees afterwards. Therefore, we convert nominal investment into rupees before 1882 using the pound-rupee market exchange rate.

[12]We use Feinstein's (1988, p. 470-471) capital price series on railway rolling stock, ships, and vehicles from 1850 to 1912 converted into rupees using the market exchange rate. For labor we use information on average monthly wages for unskilled agricultural workers in each railways' region between 1874 and 1912 as reported in the *Prices and Wages in India* (Government of India 1896, 1922). The wage data between 1850 and 1874 is not consistently available for all the regions. We apply the United Provinces wage growth rate to all regions. Finally, we use 0.55 as the weight for wages and 0.45 as the weight for British railway capital imports. We draw on Kerr's (1983) estimates of labor costs in railway construction to construct the weights.

per worker and output per capital in the railway sector with annual growth rates of 2 percent and 3 percent respectively. The other measures of capital namely miles also show evidence of productivity growth. Fuel productivity growth is relatively slow and even turns negative in the 1890s. Overall the partial productivity measures suggest we should find TFP growth in Indian railways.

4 Methodology

We focus on the production function approach to estimating total factor productivity (TFP) similar to other studies on transportation (Oum, Waters, and Yu 1999). In this framework output is assumed to be the product of a function of inputs (labor, capital and fuel) and a factor neutral shifter representing TFP:

$$Y = AF(L, K, M) \qquad (1)$$

where Y is output, and F is a function of the inputs namely labor (L), capital (K) and fuel (M), and A is TFP. As is common in the literature, we assume a Cobb Douglas production function for $F(\ )$ and then productivity is defined as:

$$TFP = \frac{Y}{L^{\alpha_l} K^{\alpha_k} M^{\alpha_m}} \qquad (2)$$

where α_l, α_k and α_m are the output elasticity with respect to labor, capital, and fuel respectively.[13] In the Cobb Douglas case if the sum of α_l, α_k and α_m is greater than one, then doubling the inputs would generate more than double the output. Thus scale economies provide another channel for increasing output.

Once we know the output elasticity with respect to labor, capital, and fuel, the TFP calculation is trivial. The problem is the elasticities are unobservable and need to be estimated or calculated. One simple solution assumes perfect competition and constant returns to scale in which case, the elasticity equals the share of total costs paid to each input. Taking logs of equation (2) and replacing each elasticity with the appropriate factor share yields an estimate of the log of TFP of each railway in each year:

$$tfp_{it} = y_{it} - (sharelabor) * l_{it} - (sharecapital) * k_{it} - (sharefuel) * m_{it} \qquad (3)$$

where lower case letters correspond to natural logs of TFP, outputs, and inputs, subscript i refers to railways, and subscript t refers to year. Such a calculation generates the so-called Index Number (IN) estimate of TFP.

[13] TFP would similarly be defined for the translog production function, which nests the Cobb Douglas.

We report IN estimates because it is standard in the railways productivity literature. However, it is well known that markets for railway services are not perfectly competitive and the assumption of constant returns to scale is also questionable. Moreover, factor shares are not directly observable in our data. Aggregate figures and evidence from the East Indian railway suggest that capital received an approximate share of 0.55, labor 0.3, and fuel 0.15.[14] These shares are in line with other historical studies. For example, Crafts, Mills, and Mulatu (2007) assume a 0.63 share for capital, 0.34 for labor, and 0.03 for fuel on British railways. Fishlow (1966) assumes shares of 0.52, 0.38, and 0.1 for capital, labor, and fuel respectively on US railroads.

Parametric estimation of TFP is another method and one that is arguably better suited to our data.[15] The goal in this approach is to estimate the elasticity of labor, capital, and fuel using regressions. In the Cobb Douglas case the estimating equation is:

$$y_{it} = \alpha_0 + \alpha_l l_{it} + \alpha_k k_{it} + \alpha_m m_{it} + \varepsilon_{it} \tag{4}$$

where the variables are the same as before and ε_{it} is the error term. After obtaining estimates of the input elasticities, the log of TFP is calculated as the residual:

$$tfp_{it} = y_{it} - (\widehat{\alpha}_0 + \widehat{\alpha}_l l_{it} + \widehat{\alpha}_k k_{it} + \widehat{\alpha}_m m_{it}) \tag{5}$$

where $\widehat{\alpha}$'s are the estimated parameters.

The main challenge in parametric estimation is to obtain unbiased estimates of the elasticities. The standard Ordinary Least Squares (OLS) estimates are likely to be biased because input choices may depend on unobserved productivity shocks, which enter the error term (Griliches and Mareisse 1998). There are several alternatives to get around this endogeneity problem. The most straightforward is to introduce fixed effects when panel data is available. Since the FE approach only exploits the within variation, researchers have also proposed alternative estimators that control for the simultaneity problem by exploiting the cross-sectional variation in the data. Olley and Pakes (1996) is one such approach, which uses investment as a proxy for unobserved productivity shocks. We use the Levinsohn and Petrin (2003) correction that builds on Olley and Pakes but with less stringent data requirements.[16] The Levinsohn and Petrin estimator relies on intermediate inputs such as

[14] The *Reports* indicate that working expenses equaled 45 percent of total revenues on average from 1882 to 1912, with the implication that 55 percent of revenues were paid to the owners of capital. Unfortunately there is no information indicating what proportion of the remaining 45 percent of revenues went to labor versus fuel.

[15] We refer the reader to Van Biesebroeck (2008) for the debate in the productivity literature on whether index number methods are inferior to estimation methods.

[16] Another approach is the Blundell and Bond (2000) estimator, but that is ideal for small T, large N samples, whereas we have a large T, small N sample.

materials, electricity or fuel to proxy for productivity shocks. This correction is the most appropriate for our setting because we have a consistent series on fuel, the intermediate input in our setting, and our data appears to meet the specification tests described in Levinsohn and Petrin (2003).

As a final step the log of industry TFP is calculated as the output weighted average of individual railway TFP measures. Let θ_{it} be the share in total output for railway i in year t and let N be the number of railways. The natural log of industry TFP in year t is given by the formula:

$$Industry\ TFP = \sum_{i=1}^{n} \theta_{it} tfp_{it} \tag{7}$$

5 TFP Estimates

5.1 Industry TFP

Before presenting the industry-level TFP estimates, we first review the production function coefficients on capital, labor and fuel across the different estimation techniques described above. Table 2 presents the coefficient estimates on capital (in rupees), labor and fuel across the different methods. Specification (1) is the standard OLS model, a Cobb Douglas production function augmented by year FE, specification (2) includes railway FE and specification (3) reports the Levinsohn-Petrin (LP) estimates. While the coefficients on labor are somewhat similar across the different methods, the coefficients on capital and fuel are very different. Similar to the original Levinsohn and Petrin (2003) study, we find the LP estimates on capital are higher than OLS suggesting the latter generates a downward bias on capital elasticity. The OLS estimates on fuel and labor appear to be biased upwards because they are significantly larger than the LP estimates. We focus on the well identified LP estimates.

Across the different methods, we find no evidence for economies of scale. The F-statistic reported at the bottom of table 2 shows that the sum of the input coefficients are not statistically different from one in any of the specifications. The absence of scale economies is noteworthy because many Indian railway systems more than doubled in size from the 1870s to the 1910s. Greater scale can be attributed to the large territorial area of colonial India. Railway systems could span vast tracts of land without crossing national borders. The regulatory environment was also favorable for railway consolidation because the GOI actively promoted mergers. However, consolidation and internal growth by themselves did not increase productive efficiency since economies of scale were limited.

The next step in the analysis is to construct a railway-level estimate of TFP using equation 3 for the Index Number (IN) method and equation 5 for the LP and FE. The railway-level TFP estimates are similar across the specifications and methods. Table 3 reports a high correlation between LP, FE, and IN, but a marginally smaller correlation between OLS and the first three. As a result, the TFP trends and fluctuations are similar across methods. However, TFP growth can differ as each method assigns a different weight to labor, capital, and fuel. We now present our industry-level TFP growth estimates, a key indicator of performance in the railway sector.

Table 4 reports the average annual growth rate of industry-level TFP by sub-period and across the different estimation methods. Industry-level TFP is the output weighted average of individual railway-level TFP measures as shown in equation (7). The FE estimation shows an average annual TFP growth rate of 2 percent while the LP generates an average annual rate of 2.58 percent. The IN methods yield a similar growth rate as LP.[17] All the estimates show TFP growth was positive and rapid in the Indian railways sector between 1874 and 1912.

Figure 2 plots the industry-level TFP indices for LP, FE, and IN. The TFP indices are standardized to 100 in 1874. Despite some differences in the growth rates, the graph illustrates similar trends in TFP over time. TFP was volatile in the late 1870s, increasing in 1877 and then decreasing by roughly the same amount in 1878. These fluctuations are linked to famines, which estimates suggest affected 58 million people spread over an area of 250,000 square miles between 1876 and 1878 (Government of India 1880). The famine was particularly severe in 1877 when railways were involved in moving grain between regions. In general railways were influenced by the macro-economic climate of the country. Agricultural shocks probably account for the TFP dip in 1908, which was a bad harvest and trade year. There is a marked change in average TFP growth around 1900. It was stagnant in the 1890s averaging less than 0.5 percent per year, but in the 1900s TFP growth accelerated and was particularly high from 1903 to 1907 and from 1909 to 1912.

Higher TFP growth had a number of implications for railway companies and the users of railway services. Mostly, importantly TFP growth contributed to higher profits and lower freight rates. Figure 3 illustrates the close relationship between real freight rates per ton mile and the inverse of TFP in India. Both series are shown as indices with 1874=100. The real freight rate is a weighted average across all railways with the weights corresponding to

[17] IN and LP yield similar TFP growth rates because the estimated coefficients on labor, capital, and fuel in table 2 are very close to the factor shares of 0.3, 0.55, and 0.15 assigned to labor, capital, and fuel. One implication is that the IN method, commonly used in railway studies, may provide a fairly accurate estimate of TFP growth.

each railways' output.[18] The TFP index is calculated as above and is inverted to correspond with freight rates. The figure shows that TFP went up at about the same rate as freight rates fell. In 1874 TFP was 38 percent of its level in 1912, while real freight rates in 1912 were 42 percent of their level in 1874. The fluctuations in the two series are also strikingly similar. A close connection between freight rates and TFP is perhaps unsurprising. Higher TFP meant that railways could charge lower rates and still earn handsome profits. Indeed that is what happened in India as net earnings on capital outlay exceeded 5 percent for most of the early 1900s (Bogart and Chaudhary 2012b). The 1900s were a golden age for Indian railways.

5.2 Railways in Comparative Perspective

The literature is generally pessimistic about India's economic progress in the colonial period. For example, in cotton textiles it is estimated that capital and labor productivity remained unchanged between 1890/94 and 1910/14 (Clark and Wolcott 1999). Labor productivity in agriculture was unimpressive growing at an average rate of 0.6 percent between 1870 and 1910 versus 1.6 percent in manufacturing and 0.5 percent in services (Broadberry and Gupta 2010). As documented in table 1, labor productivity in railways increased by 2 percent per year on average over the same period and by 3.2 percent in the 1900s. Thus railways were one of the most successful industries in India at this time.

Indian TFP growth is also impressive by international standards. Table 5 compares average annual rates of TFP growth for railways in Britain, India, Spain, and the United States. Surprisingly, Indian railways had higher TFP growth than US railways (2.1 percent), British railways (0.8 percent) and Spanish railways (1.5 percent) in the same period. Moreover, these patterns are not an artifact of the choice of estimation strategy because even within the set of IN calculations Indian TFP growth at 2.5 percent is above the United States and Britain.

In terms of productivity levels, Indian railways were comparable to many countries circa 1913. Table 6 shows railway output per employee, per ton of coal, per track mile, per locomotive and per vehicle for a large set of countries around the world. We convert ton miles and passenger miles into a single output measure using revenues weights for passenger and freight traffic in each country. Perhaps unsurprisingly labor productivity on Indian railways was below richer countries such as the United States and Canada. The United States, for example, had more than 4 times higher output per railway worker than India.

While labor was not as productive, Indian railways performed better in other dimensions.

[18] See Hurd (2007) and Bogart and Chaudhary (2012b) for more details on freight rates.

India had one of the highest output per ton of fuel, even higher than the United States. India's output per track mile was also higher than most countries, ahead of Canada, France, Norway and Sweden. We can approximate the relative TFP levels of railway systems by calculating a weighted average of the log of the indices for output per worker, output per unit of fuel, and output per track mile. India's TFP was just behind the United States, Canada, Russia, and Belgium, similar to Japan, France, and the UK, and ahead of Brazil and Argentina.[19] The relative TFP measures are preliminary because they do not adjust for quality differences in output, capital, labor and fuel across countries. That said, they provide strong suggestive evidence that Indian railways compared favorably to the rest of the world especially in terms of fuel and track productivity.

Table 6 also presents a series on labor efficiency and capital productivity for cotton textiles from Clark (1988). Labor efficiency is measured as machinery per worker (in loom equivalents). In other words, it captures one aspect of capital per worker in the textile sector. India clearly has low labor efficiency by world standards, For example, English workers manned four times more looms than Indian workers, while Austrian and German workers manned 2.5 times more looms than Indian workers.[20] Unfortunately, we cannot construct the number of employees manning locomotives or engines in railways because the labor data are not disaggregated by task that would allow for a more precise comparison. That said, the aggregate figures on locomotives per worker suggest that capital per worker was relatively low in Indian railways much like it was in cotton textiles. The big difference comes from capital productivity. When output per locomotive or output per engine is compared with hourly output per spindle in cotton textiles, Indian railways fare much better. The UK-India comparison is especially striking in this regard. Output per locomotive in the UK was just a quarter of that in India compared to output per spindle, which was 30 percent higher in the UK. Thus, Indian railway performance compared favorably to higher income countries and to Indian performance in the cotton textile industry.

6 Railways and the Growth of the Indian Economy

The growth of railway TFP had large implications for the colonial Indian economy. In this section, we quantify the contribution to Indian national income and relate it to social savings. As in the pioneering works of Fogel (1970) and Fishlow (1965), economic historians

[19]The weights are 0.35 for labor productivity, 0.15 for fuel productivity, and 0.5 for track productivity.

[20]Clark (1988) argues poor countries such as India and China were unable to exploit their low labor costs in textiles because of the inefficiency of labor in these countries. But, it is difficult to disentangle cause and effect because low wages in of themselves could lead to lower worker productivity (Gupta 2011).

often measure the developmental impact of railways using the social savings methodology. In this framework, the social savings are calculated as the freight rate difference between the pre-existing technology and railways multiplied by railway output in some benchmark year. Dividing the social savings by national income in the benchmark year gives the percentage of income that would have been lost in the absence of railways.

In this methodology, the freight rate is said to reflect the marginal cost of shipping goods and passengers under each technology. As Crafts (2004) highlights, the decrease in marginal cost is equivalent to an increase in TFP from the adoption of railways to the benchmark date. Thus the social savings can also be calculated using the change in TFP instead of the change in freight rates. Crafts argued for an additional effect from railways through embodiment effects. The idea is that without railways the economy would have had less capital because railway technology was embodied in track, locomotives, and vehicles.

Our calculation follows Crafts (2004) 'new' growth accounting equation where the growth of income per capita is divided into a contribution from the railways sector and the non-railways sector:

$$\Delta(y/l) = s_{rail}\Delta(k_{rail}/l) + s_{nonrail}\Delta(k_{nonrail}/l) + \eta\Delta TFP_{rail} + \phi_{nonrail}\Delta TFP_{nonrail} \quad (8)$$

where $\Delta(y/l)$ is the growth of income per capita, s_{rail} is the share of railway profits in national income, $\Delta(k_{rail}/l)$ is the growth in railway capital per worker, η is the gross output share of railways, ΔTFP_{rail} is TFP growth in railways, and ϕ is the gross output share of other sectors. The contribution of railways to annual per capita income growth is equal to the first term in equation 8, capturing railway technology embodied in capital, and the third term, capturing TFP growth from railways. Our main emphasis is on the role of TFP growth, so we focus on $\eta\Delta TFP_{rail}$.

Compounding the railway TFP growth component over the lifespan of railways, from adoption to the benchmark year, gives the social savings as a percent of national income. The difficulty comes in measuring the increase in TFP at the time railways were adopted. Railways increased transport productivity in large part by displacing wagons and coaches, or in the case of India bullock carts. We estimate TFP growth starting in 1874 when most of the trunk-lines had been built. Moreover, when new railways enter our sample, we do not incorporate their displacement effect on carts. Thus our social savings estimate only captures the increase in TFP post-1874 and the increase in TFP post-railway construction. Our estimates also omit spillovers, say from railways to urbanization, much like the conventional social savings methodology.

The results are summarized in table 7 for the FE and LP estimates.[21] The growth in

[21] The gross output share is equal to nominal railway revenues divided by nominal gross domestic product.

TFP between 1874 and 1912 contributed between 0.06 and 0.08 percent per year to income per capita. The growth in railway capital contributed 0.05 percent per year. The total growth contribution of Indian railways, post-1874 and post-construction, is between 0.11 and 0.13 percent per year. Indian GDP per capita is estimated to have grown at 0.6 percent per year from 1870 to 1913. Thus the gains from railway TFP growth and embodied capital investment were equal to 18 or 22 percent of the total income per capita growth.

The social savings from TFP growth also point to the significance of railway performance for the Indian economy. The social savings from TFP are equivalent to compounding the annual growth contribution to income per capita (0.06% or 0.08%) over a 38 year period. The resulting calculation shows that higher railway TFP between 1874 and 1912 increased Indian national income in 1912 by 3.1 percent. It is worth pausing to consider the significance of this number. It suggests that the Indian economy would have been 3 percent smaller in 1912 had railway productivity remained at its 1874 level. In short, it mattered a lot how railways were operated in India.

How do the social savings, post-1974 and post-construction, compare with other estimates of social savings? Hurd (1983) and Donaldson (2010) estimate social savings on the order of 9 to 10 percent of Indian GDP in 1900 or 1930.[22] The estimated TFP contribution reported here is around one-third of the total social savings. We regard one-third as a relatively large share given we focus on a more narrow time period from 1874 to 1912. The TFP growth of railways in the 1850s and 1860s is omitted because we lack good data on this period. We also miss the TFP contribution of railways from 1913 to 1930 when Donaldson's study ends. The railway sector also increased in size relative to GDP between 1913 and 1930, which would further magnify the effects of railway TFP growth.

The relative importance of TFP growth can also be seen in a comparison of freight rates before railways, shortly after railway construction, and by the 1900s. Derbyshire (1987)

Railway revenues in 1912 are taken from the *Administration Reports*. Nominal GDP comes from Sivasubramonian (2000). The growth in railway capital per person is measured by the growth in the average capital stock per railway (weighted by output) divided by the Indian population. Net earnings provided in the *Administration Reports* are used to measure railway profits. The total income per capita growth rate is taken from Maddison's (2003) GDP per capita figures in 1870 and 1912.

[22] Their estimates are based on evidence concerning freight rates. Hurd (1983) and Derbyshire (1987) argued that freight rates for bullock carts during the mid-19th century were 80 to 90 percent higher than railway freight rates in the 1900s. Donaldson (2010) gives more precise estimates using an innovative approach with district salt prices. He finds that road transport increased inter-district price gaps by a factor of 8 relative to rail, implying that railways could lower trade costs by as much as 87 percent in markets that were only served by roads. The estimated effects of river or coastal transport relative to rail are smaller in magnitude (price gaps are nearly 4 times larger), but still quite substantial. We should also note that Donaldson (2010) generally expresses the impact of railways in terms of their effects on real agricultural income. He finds railways increased real agricultural income in a district by 16 percent.

reports that for North India in the 1850s freight rates for a 2 bullock cart were 1.0 pies per maund per mile and for a 4 bullock cart rates were 0.8 pies per maund per mile. By the 1900s railway freight rates were 0.18 pies per maund per mile representing a 60 to 80 percent decline from bullock carts in the 1850s. The large decline in freight rates is the key factor in generating large social savings. How much of this decline was due to TFP growth of railways from the 1870s to the 1900s? Our figures show that TFP and freight rates evolved together, declining by 47 percent from 1874 to 1905. Using Derbyshire's 1900s rate as a base and our percentage change implies that railway freight rates were around 0.34 pies per maund in 1874. Thus greater productivity in railways can account for around 20 to 25 percent of the total decline in freight rates from the 1850s to the 1900s and is broadly similar to our one-third estimate of the social savings.

7 Sources of TFP growth

Railway TFP growth was clearly a major factor in Indian income growth from 1874 to 1912. In this final section, we explore the sources of TFP growth. There have been major advances in the study of productivity over the last ten to twenty years, including TFP growth decomposition and attention to the identification of TFP determinants (see Syverson 2011 for an overview). We draw on this literature to estimate the importance of reallocation effects, capacity utilization, gauge diversity and technological adoption.

7.1 Reallocation Effects

It is obvious that industries will become more productive if their firms increase in productivity. Probing deeper though reveals several components. Industries can become more productive simply because the market share of more productive firms increases. Industry-level productivity can also rise if firms entering the market are more productive than the average firm or if exiting firms are less productive than the average. The combination of the last three factors is known in the productivity literature as 'reallocation.' The Foster, Haltiwanger, and Krizan (2001) decomposition, or FHK for short, quantifies the contribution of reallocation. It decomposes annual industry-level TFP growth into the following five terms:

$$\sum_{i=1}^{n}\theta_{it-1}\Delta tfp_{it} + \sum_{i=1}^{n}\Delta\theta_{it}(tfp_{it} - TFP_{it}) + \sum_{i=1}^{n}\Delta\theta_{it}\Delta tfp_{it} + \sum_{i=1}^{e}\theta_{it}(tfp_{it} - TFP_{it-1}) - \sum_{i=1}^{x}\theta_{it-1}(tfp_{it-1} - TFP_{it-1}) \qquad (9)$$

where θ_{it} is the market share for firm i in year t, tfp_{it} is the natural log of TFP for firm i in year t, TFP_{it} is the log of total factor productivity averaged over all firms in year t, e is the set of entrants in year t, x is the set of exits in year t, and n is the set of incumbent firms in year t. The second term $\sum_{i=1}^{n}\Delta\theta_{it}(tfp_{it} - TFP_{it})$ captures the effect of increasing the market share of more productive firms. Notice the second term is positive if market share increases for firms that have greater than average productivity. The fourth term $\sum_{i=1}^{e}\theta_{it}(tfp_{it} - TFP_{it-1})$ captures the effect of entry. Notice that industry productivity rises if entering firms are more productive than the average firm. The fifth term $\sum_{i=1}^{x}\theta_{it-1}(tfp_{it-1} - TFP_{it-1})$ captures the effect of exit and has a similar interpretation as the entry effect. The reallocation effect is defined as the sum of the second and fourth terms minus the fifth term. The remaining source of industry TFP growth is called the 'within' effect or the sum of terms one and three. Notice that the first term $\sum_{i=1}^{n}\theta_{it-1}\Delta tfp_{it}$ measures the contribution of within railway TFP growth holding market share constant.

Economists have investigated the relative contribution of reallocation and within-firm TFP growth because it implies different sources of industry TFP growth. For example, industries with lots of turnover and competition tend to have more productivity growth through reallocation (Foster, Haltiwanger, and Krizan 2001). We use the FHK decomposition to study the effect of reallocation on Indian railways TFP growth.

Interestingly, we find that reallocation did not contribute to higher TFP growth in Indian railways. Figure 4 plots industry TFP growth (the black line) and the contribution of reallocation (the grey line). TFP growth was volatile from year to year, but little of the variation was due to reallocation. The implication is that most industry TFP growth was due to within-railway growth in TFP (or term 1 in equation 9). Moreover, the reallocation effect is generally negative. Before 1890, reallocation lowered TFP growth by an average of 1.4 percent per year. Afterwards reallocation continued to lower TFP growth but at a more modest rate of 0.5 percent per year.

Reallocation reduced TFP growth in part because entering railways tended to be less productive than incumbents. Before 1890 entering railways reduced industry productivity growth by an average of 0.4 percent per year. There was a similar effect in the late 1890s when more railways entered. Exiting railways also tended to be less productive than the average railway. Normally the exit of less productive firms raises industry TFP, but in Indian railways the exit effect was muted. The reason is that exits did not mean the end of services on a line, but simply a merger to a larger system.

The greatest retarding factor in reallocation was the shift in market share away from the most productive lines. The East Indian, for example, was among the most productive railways in every year, but its market share declined from 47 percent in 1874 to 25 percent by 1912. The decomposition calculation shows that the average effect of changes in market share among incumbents was to lower industry TFP growth by around 1 percent. Such patterns are a sign that competition was limited in Indian railways. In competitive markets more productive firms usually gain market share by offering lower prices. But, perhaps one should not expect a lot of competition because railways are differentiated by space.

Stepping back from the issue of reallocation, the FHK decomposition points to the importance of within-railway TFP growth. We now investigate what can explain the TFP growth of Indian railway systems. A leading candidate is capacity utilization driven in part by greater demand for railway services.

7.2 Capacity Utilization

Historians and colonial officials alike have argued that Indian railways were built ahead of demand. Traffic was slow in the early decades of railway construction in the 1850s and 1860s and did not pick up until the 1870s or later (Sanyal 1930). In such a context TFP increases could reflect increased capacity utilization. Fishlow (1966) discusses capacity utilization in the case of US railroads and we quote him because he accurately describes how utilization can influence productivity.

"For capital intensive and capital durable sectors faced with indivisibilities, the size of the capital stock is not a good proxy for the annual flow of services it delivers. At their inception, firms will typically be burdened with higher capital-output ratios than current demand seems to dictate, due both to technical considerations and to positive expectations. Only over time will capital services attain a stable relationship with the magnitude of the stock. . . . Because the capital stock has been used as an input, part of the measured productivity gains of railroads. . . derives from this phenomenon of increasing utilization (p. 630)."

Fishlow goes on to calculate the contribution of capacity utilization by assuming a constant capital to labor ratio. He argues that capital utilization can explain between one-sixth and one-third of productivity growth in US Railroads between 1840 and 1910.

Did capacity utilization play a similar role in India as it did in the US? Indian railways were built ahead of demand similar to some US railroads in the West. The capital-output ratio was large initially and there was a lot of room for greater utilization once output grew. On the other hand, Indian railways operated in a different economic environment. The

Indian economy did not grow as rapidly and so the rate of utilization might have increased more slowly.

We measure the contribution of utilization by assessing whether a significant portion of the variation in railway-level TFP is related to train miles run per track mile. We use train miles per track mile as our measure of capacity utilization because track clearly sits idle when trains are not running. Transport economists also use train miles per track mile because it measures economies of density or usage of the fixed network (Oum, Waters, and Yu 1999). Lastly, train miles run per track mile is revealing because railway track is generally constant in quality. Other measures of utilization, like loads per train, are more conflated with technological change.[23]

Figure 5 plots the industry trend in train miles per track mile from 1876 to 1912. 1876 is the first year where train miles run are reported in the official publications. Similar to the industry-level TFP measure, the figure averages train miles across railways using output shares as weights. Train miles per track mile have no upward trend until the mid-1890s, but there is a clear increase in track utilization after 1895. From 1895 to 1912 train miles run per track mile increased by more than 40 percent. To quantify the contribution of utilization to TFP, we modify our Cobb-Douglas production function to include a railway-level measure of track utilization in each year. Unfortunately, the LP estimation cannot be modified to include non-input variables. Hence, we show these results for the OLS and FE models only. Our approach is similar to other works that measure economies of density by including utilization terms directly in the cost or production function (Oum, Waters, and Yu 1999).[24]

Table 8 reports the coefficients on track utilization. Unsurprisingly, greater track utilization increases output. In the Cobb-Douglas FE , for example, the elasticity of track utilization is 0.31. Although significant, the coefficient is not large enough to explain all the TFP growth. Track utilization increased by 50 percent, but industry-level TFP almost doubled in this period.

Calculations of TFP growth net of utilization confirm that capacity utilization is not the major driver of TFP growth. At the bottom of table 8 we report the rate of net TFP growth from 1876 to 1912.[25] We also report the average TFP growth rate without accounting for utilization for comparison. Average annual TFP growth rates are lower, but not substantially. Track utilization accounts for about 15 to 20 percent of TFP growth in

[23]For example, train loads could rise because of more powerful locomotives or because greater demand allowed for more vehicles to be used.

[24]Similar to these studies, we assume the natural log of the residual is the log of track utilization plus a variable representing all the other factors including technology.

[25]Net railway TFP (in logs) can be calculated by deducting from output the coefficients on the inputs multiplied by the inputs and the coefficient on track utilization multiplied by track utilization.

most specifications.[26]

7.3 Gauge Diversity

India is one of a large number of countries that had multiple railway gauges within its border. Australia, the US and UK are other well known examples. However, India made little progress in converting to a single gauge by 1913. Elsewhere gauge conversion happened relatively early as in the United States (Puffert 2009). In fact, the diversity of gauges probably increased in India as both the broad gauge network and meter gauge network expanded from 1880 to 1912. While there were few railways that actually changed gauge, railway systems often included a small mileage of narrow gauge lines.[27]

Gauge diversity is often seen as a source of inefficiency because traffic has to be unloaded and reloaded at breaks of gauge. In India, breaks of gauge were costly and undoubtedly lowered TFP, but it is difficult to measure the direct impact of breaks of gauge because such an analysis would require a conversion event or more detailed information on traffic flows than are available. That said, we can explore whether TFP was different across the two gauges. If technology improved on one type of gauge more than another, then greater gauge diversity may have slowed TFP growth.

It is straight forward to measure differences in TFP for broad gauge and meter gauge railways using our estimates.[28] We construct an estimate of broad gauge TFP using equation (7) restricting to the set of broad gauge railways only. We also construct an estimate of meter gauge TFP and mixed gauge using the same method. Figure 6 shows the three TFP indices where 100= the broad gauge TFP in 1874. One evident pattern is that broad gauge railways had higher TFP than meter or mixed gauge railways. The differences were largest in the 1870s and the 1900s. We cannot necessarily conclude that gauges caused the difference in TFP because the choice of gauge was endogenous to environmental and economic factors. Nevertheless the differences are suggestive of some productivity difference. A second evident pattern is that all systems experienced relatively high TFP growth suggesting that one gauge was not more or less amenable to productivity change. Bases on these patterns, we conclude that gauge diversity did not greatly reduce TFP growth on Indian railways.

[26]Other measures of utilization such as tons per train and passengers per train may be conflated with the quality of the capital stock. But we find strong evidence of net TFP growth even after including these additional variables in the production function.

[27]The only major one that we know of is Nagpur-Chattisgarh (later known as Bengal-Nagpur) that changed from meter to standard gauge in the 1880s.

[28]We code a system as broad or meter if more than 90 percent of the mileage is of the same gauge. The others are coded as mixed namely Eastern Bengal, Madras and Southern Mahratta, South Indian and Nizam's railways.

7.4 Technological and Organizational Change

In most industries, technological and organizational changes are the most important drivers of TFP growth. In the late 19^{th} and early 20^{th} century, railway technology improved significantly throughout the world. But, it is unclear whether India participated in this technological advance. The state of technology on Indian railways circa 1900 is summarized in the Robertson Report (1903). The author, Thomas Robertson, argued that Indian railways lagged behind railways in advanced countries like the United States, Canada, and Britain. According to Robertson, Indian railways were using few of the best practice technologies such as automatic vacuum brakes, gas and electrical lighting, high capacity bogie vehicles, and inter-locking signal systems for railway stations. But over the 1900s Indian railways increased their adoption of new technologies and their relative backwardness changed by 1912.

In 1890 only 11 percent of engines and 1 percent of vehicles were fitted with vacuum brakes.[29] By 1912, 81 percent of engines and 47 percent of vehicles were fitted with brakes. Previously one worker had to be present on each engine and vehicle and concurrently pull the brake in order for the train to stop. With such automatic brakes the entire train could be brought to a halt quickly thereby increasing safety. Inter-locking signal systems at stations also improved safety. With this technology signals on the track were locked when a train entered the route and were not unlocked until it passed. Inter-locking signals were widely used on British and US railways. In India they became more common in the 1900s. The average number of stations with inter-locking systems increased from 17 to 55 percent between 1902 and 1912.

The Robertson Report (1903) also emphasized the importance of bogies and high-sided wagons to improve the movement of passenger and freight traffic. Bogies were vehicles where the axles were attached through bearings. High-sided wagons were shorter than conventional vehicles which was useful in crowded yards near stations. The adoption rate for high-sided wagons increased from 6 percent in 1900 to 15.4 percent in 1912, while the adoption of bogie coaches increased over two-fold from 10 percent in 1900 to 25 percent in 1912. In this area, Indian railways were copying the practice of US railroads, where high capacity bogie vehicles were common on routes with heavy traffic (Robertson 1903, p. 80).

A similar change occurred in electrical and gas lighting. In 1900, 40 percent of the rolling stock was lighted by gas. It increased to over 70 percent by 1912. Electrical lighting was largely absent in the early 1900s, but by 1912, 17 percent of the rolling stock was lighted by

[29] All these adoption rates are constructed from information reported in the *Administration Reports* for 1900 and 1912.

electricity. Electrical lighting was supposedly superior to gas because it gave off less heat (Robertson 1903).

Indian railways moved closer to the technology frontier by 1912 in adopting what experts considered best-practice technologies. Similar to other studies of TFP (for example, Rosegrant and Evenson 1992), we assess the correlation between these notable technological changes and our estimates of railway-level TFP in table 10.[30] The technology variables are all measured in terms of adoption rates. For example, bogie coaches refers to the proportion of all coaches with the bogie technology.

Table 9 suggests a subset of the new technologies were correlated with the high TFP levels of the 1900s. In specifications 1 and 2, which do not include railway fixed effects, we find interlocking signal and block stations are positively correlated with TFP. However, the proportion of rolling stock lighted by gas is negatively correlated with TFP. The across railway comparisons for some of these technology variables are problematic because railways were both adopting gas lighting and also transitioning from gas to electric lighting in this period. Interestingly, when we exploit within railway variation, we find positive effects for gas lighting of the rolling stock on TFP.

Many of the coefficients on these technology variables are insignificant individually, but a joint F-test across the four specifications suggests we can strongly reject that they are jointly equal to zero. As opposed to focusing on individual technologies, table 9 suggests these technologies as a whole were in fact correlated with TFP. The adjusted R^2 suggests the major technologies jointly explain about half the TFP variation in this period (specification 1 and 2). We believe this likely underestimates the total contribution of technology because many innovations in railways were not quantified. For example, officials noted the fitting of super-heaters to locomotive engines saved fuel by 15 percent on average. According to the *Administration Report* of 1913-14, super-heaters were a worldwide movement in which Indian railways were participating (p. 24). The same report also described the 'train control system' where a central manager had direct telephone communication with all the station managers instructing them when trains should be pushed or held back. Train control was credited with increasing the capacity of over-crowded track in the early 1910s (p. 22). Such qualitative evidence speaks to the many technological changes occurring in the 1900s.

Indian railways experienced a number of organizational changes that may have also

[30]We do not augment the production function with these technology variables as we did in section 7.2 because we do not know if these variables are significant and hence it is theoretically ambiguous how one should calculate the residual in the presence of these technology non-inputs. Also the technology adoption data only covers the years from 1900 to 1912. Hence, we have fewer observations than before to estimate our production function.

positively contributed to TFP growth. Perhaps the most notable was the Government takeover of a majority of the private companies controlling the trunk routes. As described in section 2, the initial network was constructed by privately owned British companies backed by a GOI guarantee. Beginning in 1879, the GOI began to takeover the private companies although many of them were allowed to retain operations. In other work, we find this transition to state ownership decreased operating costs, particularly labor costs (Bogart and Chaudhary 2012a).

The link between government ownership and efficiency is perhaps surprising given the broader evidence on state ownership in the literature (see Shleifer 1998, Bogart 2011). As the rail sector became more important for the colonial Government, it appears to have introduced new policies with a stated aim of improving efficiency. For example, the GOI introduced a profit sharing agreement with state railway employees in 1880. The Railway Provident Fund contributed a portion of state railway earnings, disbursing them to employees in proportion to their salary and position. In the 1900s many railways also began providing schools for the children of railway employees or reimbursing fees at neighboring public schools.[31] Such measures suggest railway companies may have been paying efficiency wages to their employees. Unfortunately, the official publications do not provide direct information on wages and other subsidies offered to employees to examine labor compensation issues in more detail.

Finally, the GOI also organized 'railway conferences,' to create exchanges between state railway officials and companies. The first railway conference in 1880 introduced a code of general rules for the working of all lines, including agreements for the interchange of rolling stock, a uniform classification of goods, and accounting standards. Subsequent conferences in the 1880s and 1890s tried to assimilate the construction of rolling stock. A special committee met regularly to adopt standards, arrange experiments, and publish research (Bell 1894, p. 114). Though it is difficult to quantify the effects of these organizational changes, the GOI faced strong incentives to improve performance in this sector. Gross railway revenues as a proportion of total GOI revenues increased from less than 5 percent in the 1870s to just over 30 percent by 1912 (Bogart and Chaudhary 2012b).

[31] This amounted to a small subsidy of 0.24 percent based on the wages of fitters in Lahore working on the North Western Railway and the fees of schools in Punjab. The subsidy may have been larger in other parts of the country where school fees were higher. We were only able to locate wages for fitters in Lahore working on the North Western Railways.

8 Conclusion

Using new data on individual railways, we find strong evidence of TFP growth in Indian railways from 1874 to 1912. Our estimates suggest that TFP growth averaged between 2 and 2.6 percent per year. TFP growth had a large aggregate impact on the Indian economy adding 0.08 percent per year to Indian income per capita, and generating a social savings of around 3.1 percent in 1912.

The performance of Indian railways stands in sharp contrast to the limited productivity growth in agriculture and cotton textiles, another key modern industrial sector of this period. Indian railways also compared favorably to railways in advanced economies such as Britain and the United States, especially in terms of fuel and capital productivity. Although scholars may be right that railways could have done more to generate economic growth in India before World War I, it is hard to criticize the sector based on its productivity performance.

We find there is not any single factor which was the main driver of TFP growth. Technological changes made important contributions, as did greater capacity utilization and organization changes. However, reallocation within the industry played no role and in fact negatively influenced productivity. Gauge diversity also appears to be a secondary factor, although the precise effects still need to be established.

In concluding, we note that the success of Indian railways was short-lived. A number of performance indicators, like ton miles per worker and real freight charges, stagnate or reverse from 1920 to Indian Independence in 1947 (Hurd 2007, Bogart and Chaudhary 2012b). Thus Indian railways acted as 'engines of growth' only during the first era of globalization. Explaining why the productivity growth of Indian railways stopped around 1920 is a key issue for future research.

References

1. Adams, John, and Roberts Craig West. 1979. "Money, Prices, and Economic Development in India 1861-1895." *Journal of Economic History,* 39 (1): 55-68.

2. Andrabi, Tahir and Michael Kuehlwein. 2010. "Railways and Price Convergence in British India." *Journal of Economic History,* 70 (2): 351-377.

3. Bell, Horace. 1894. *Railway Policy of India: With Map of Indian Railway System.* Rivington: Percival.

4. Blundell, Richard, and Stephen R. Bond. 2000. "GMM Estimation with Persistent

Panel Data: An Application to Production Functions." *Econometric Reviews,* 19: 321-40.

5. Bogart, Dan. 2010. "A Global Perspective on Railway Inefficiency and the Rise of State Ownership, 1880-1912." *Explorations in Economic History*, 47 (2): 158-178.

6. Bogart, Dan and Latika Chaudhary. 2012a. "Regulation, Costs, and Ownership: A Historical Perspective from Indian Railways," *American Economic Journal: Economic Policy* 4, no. 1: 28-57.

7. Bogart, Dan and Latika Chaudhary. 2012b. "Railways in Colonial India: An Economic Achievement?" Available at SSRN: http://ssrn.com/abstract=2073256.

8. Broadberry, Stephen and Bishnupriya Gupta. 2010. "The Historical Roots of India's Service-Led Development: A Sectoral Analysis of Anglo-Indian Productivity Differences, 1870-2000." *Explorations in Economic History,* 47 (3): 264-278.

9. British Board of Trade. 1880-1912. *The Statistical Abstract of British India.*

10. Bureau of Railway News and Statistics. 1913 and 1916. Railway statistics of the United States of America. Chicago: R. R. Donnelley and Sons.

11. Caves, Douglas W., Laurits R. Christensen, and Joseph A. Swanson. 1980. "Productivity in U.S. Railroads, 1951-1974." *Bell Journal of Economics,* 11 (1): 166-181.

12. Christensen, R.O. 1981. "The State and Indian Railway Performance, 1870-1920. Part I. Financial Efficiency and Standards of Service." *Journal of Transport History*, 2 (2): 1-15.

13. Clark, Greg. 1987. "Why Isn't the Whole World Developed? Lessons from the Cotton Mills." *Journal of Economic History*, 47 (1): 141-173.

14. Clark, Greg and Susan Wolcott. 1999. "Why Nations Fail: Managerial Decisions and Performance in Indian Cotton Textiles, 1890-1938." *Journal of Economic History*, 59 (2): 397-423.

15. Crafts, Nicholas. 2004. "Steam as a General Purpose Technology: A Growth Accounting Perspective." *Economic Journal,* 114 (495): 338-351.

16. Crafts, Nicholas, Terence C. Mills, Abay Mulatu. 2007. "Total factor productivity growth on Britain's railways, 1852–1912: A reappraisal of the evidence." *Explorations in Economic History*, 44 (4): 608–634.

17. Crafts, Nicolas, Timothy Leunig, and Abay Mulatu. 2008. "Were British railway companies well managed in the early twentieth century?" *Economic History Review,* 61 (1): 842–866.

18. Derbyshire, Ian. 1987. "Economic Change and the Railways in Northern India, 1860-1914." Modern Asian Studies, 21 (3): 521-545.

19. Derbyshire, Ian. 2007. "Private and State Enterprise: Financing and Managing the Railways of Colonial North India, 1859-1914." In *27 Down: New Departures in Indian Railway Studies,* ed. Ian Kerr. New Delhi: Orient Longman

20. Dirección General de Ferrocarriles. 1913. Estadística de los ferrocarriles en explotación. Buenos Aires.

21. Dodgson, John. 2011. "New, disaggregated, British railway total factor productivity growth estimates, 1875 to 1912." *Economic History Review,* 64 (2): 621-643.

22. Donaldson, Dave. 2010. "Railways of the Raj: Estimating the Impact of Transportation Infrastructure," Working paper.

23. Feinstein, Charles. 1988. "Transport and Communications" in Feinstein, Charles and Sidney Pollard, eds. Studies in Capital Formation in the United Kingdom, 1750-1920. Oxford: Clarendon.

24. Fishlow, Albert. 1965. *American Railroads and the Transformation of the Ante-bellum Economy* . Cambridge, MA: Harvard University Press.

25. Fishlow, Albert. 1966. "Productivity and Technological Change in the Railroad Sector, 1840-1910" in *Output, Employment, and Productivity in the United States after 1800.* Ed. Dorothy S. Brady. New York: National Bureau of Economic Research.

26. Robert Fogel. 1970. *Railroads and American Economic Growth: Essays in Econometric History* . Baltimore: Johns Hopkins Press.

27. Government of India. 1880. *Report of the Indian Famine Commission.* London: Her Majesty's Stationery Office.

28. Government of India. 1896-1922. *Prices and Wages in India.* Calcutta. Superintendent Government Printing.

29. Government of India. 1882-1912. *Administration Report on the Railways in India.* Calcutta: Superintendent Government Printing.

30. Government of India. 1860-1881. *Report to the Secretary of State for India in Council on Railways in India.* Calcutta: Superintendent Government Printing.

31. Green, Allan. 1986. "Growth and Productivity Change in the Canadian Railway Sector, 1871-1926" in Stanley L. Engerman and Robert E. Gallman, eds. Long-Term Factors in American Economic Growth. New York: National Bureau of Economic Research.

32. Griliches, Zvi and Mareisse Jacques. 1998. "Production Functions: The Search for Identification" in *Econometrics and Economic Theory in the Twentieth Century: The Ragnar Prisch Centennial Symposium*, pp. 169-203. Cambridge: Cambridge University Press.

33. Gupta, Bishnupriya. 2011. "Wages, unions and labour productivity: evidence from Indian cotton mills." *Economic History Review* 65 (S 1): 76-98.

34. House of Commons, Great Britain. 1913. *Coal Tables.* British Parliamentary Papers 1913 CCLXXXV. London: Her Majesty's Stationery Office.

35. Hurd, John II. 1975. "Railways and the Expansion of Markets in India 1861-1921." *Explorations in Economic History,* 12 (3): 263-288.

36. Hurd, John II. 1983. "Railways" in ch. 8 of the Cambridge Economic History of India, vol. 2:1757-1970. Eds. D. Kumar and M. Desai. London: Cambridge University Press.

37. Hurd, John II. 2007. "A Huge Railway System But No Sustained Economic Development: The Company Perspective, 1884-1939: Some Hypotheses." In *27 Down: New Departures in Indian Railway Studies.* ed. Ian Kerr. New Delhi: Orient Longman.

38. Kerr, Ian. 1983. "Constructing railways in India–an estimate of the numbers employed, 1850-80. *Indian Economic and Social History Review,* 20 (3): 317-341.

39. Kerr, Ian. 2007. *Engines of Change: The Railroads that Made India.* Westport: Praeger.

40. Levinsohn, James and Amil Petrin. 2003. "Estimating Production Functions using Inputs to Control for Unobservables. *Review of Economic Studies,* 70 (2): 317-342.

41. Herranz-Loncán, Alfonso. 2006. "Railroad Impact in Backward Economies: Spain, 1850-1913." *Journal of Economic History,* 66 (4): 853-881.

42. Herranz-Loncán, Alfonso, 2011. "The contribution of railways to economic growth in Latin America before 1914: a growth accounting approach," MPRA Paper 33578, University Library of Munich, Germany.

43. Maddison, Angus. 2003. *The World Economy: Historical Statistics.* Paris: Development Centre, OECD.

44. McAlpin, Michelle Burge. 1974. "Railroads, Prices and Peasant Rationality: India, 1860-1900." *Journal of Economic History,* 34 (3): 662-84.

45. Morris, David Morris and Cylde Dudley. 1975. "Selected Railway Statistics for the Indian Subcontinent." *ARTHA VIJÑANA*, 15 (3): 1-128.

46. Olley, G. Steven, and Ariel Pakes. 1996. "The Dynamics of Productivity in the Telecommunications Equipment Industry." *Econometrica,* 64 (6): 1263-98.

47. Oum, Toe Hoon, W. G. Waters II, and Chunyan Yu. 1999. "A Survey of Productivity and Efficiency Measurement in Rail Transport." *Journal of Transport Economics and Policy,* 33 (1): 9–42.

48. Puffert, Douglas, J. 2009. *Tracks across Continents, Paths through History: The Economic Dynamics of Standardization in Railway Gauge*. Chicago: University of Chicago Press.

49. Roberston, Thomas. 1903. *Report on the Administration and Working of Indian Railways.* London: Darling & Son.

50. Rosegrant, Mark W. and Robert E. Evenson. 1992. "Agricultural Productivity and Sources of Growth in South Asia." *American Journal of Agricultural Economics* 74(3): 757-761.

51. Roy, Tirthankar. 2010. *The Economic History of India 1857-1947.* New Delhi: Oxford University Press.

52. Sanyal, Nalinksha. 1930. *Development of Indian Railways.* Calcutta: University of Calcutta.

53. Shleifer, Andrei. 1998. "State versus Private Ownership." *Journal of Economic Perspectives,* 12 (4): 133-150.

54. Sivasubramonian, S. 2000. *The National Income of India in the Twentieth Century.* New Delhi: Oxford University Press.

55. Syverson, Chad. 2011. "What Determines Productivity?," *Journal of Economic Literature*, American Economic Association, vol. 49(2), pages 326-65.

56. Summerhill, W. R. 2005. "Big Social Savings in a Small Laggard Economy: Railroad-Led Growth in Brazil." The Journal of Economic History, 65: 72-102.

57. Thorner, Daniel. 1955. "The Pattern of Railway Development in India." *Far Eastern Quarterly*, XIV: 201-6.

58. Thorner, Daniel. 1977. *Investment in Empire: British Railways and Steam Shipping Enterprise in India 1825-1949.* Philadelphia: University of Pennsylvania Press.

59. Van Biesebroeck, Johannes. 2008. "The Sensitivity of Productivity Estimates: Revisting Three Important Debates." *Journal of Business and Economic Statistics*, 26 (3): 311-328.

Figure 1: Map of Indian Railways, 1909

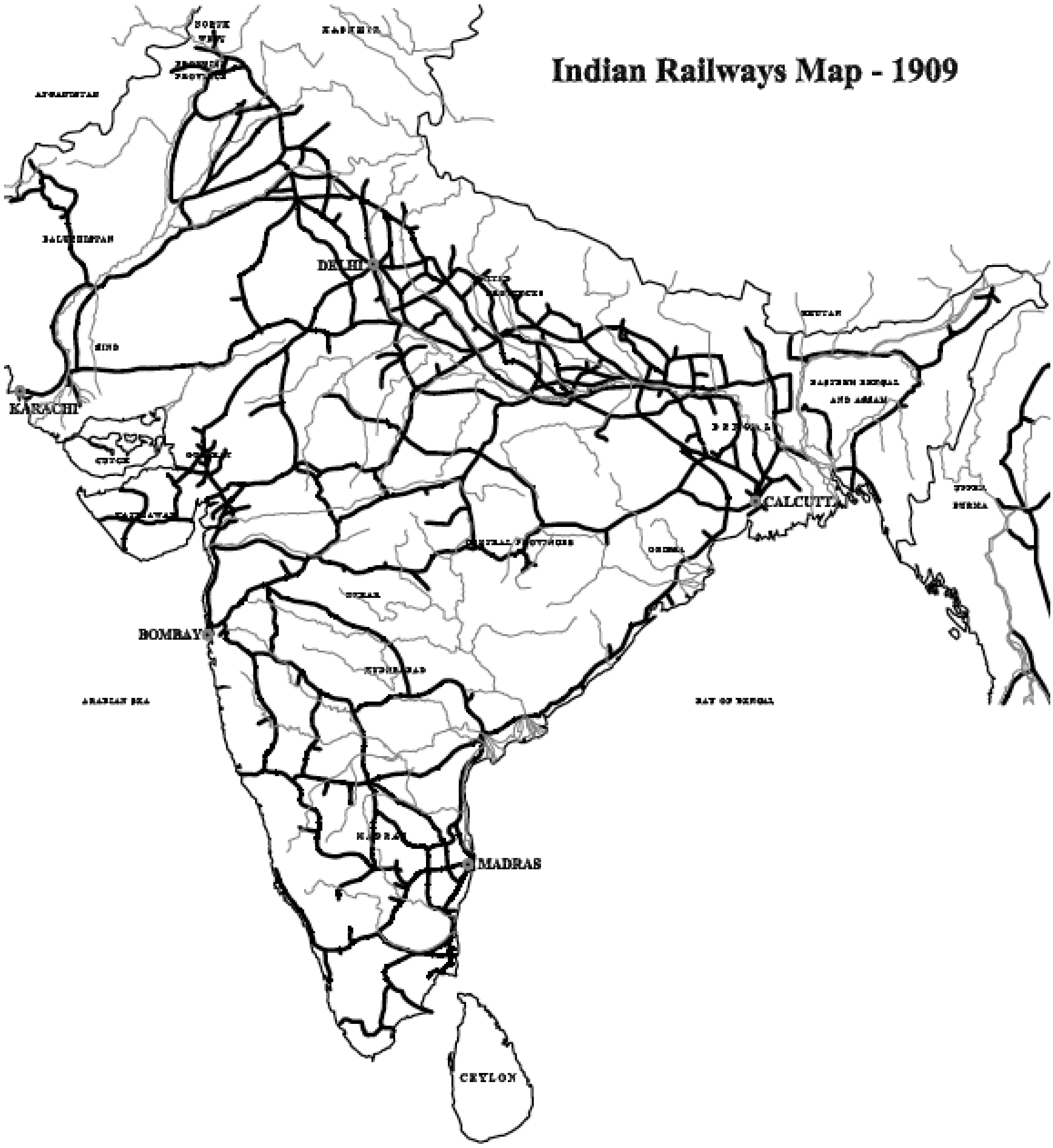

Figure 2: TFP Index (1874=100)

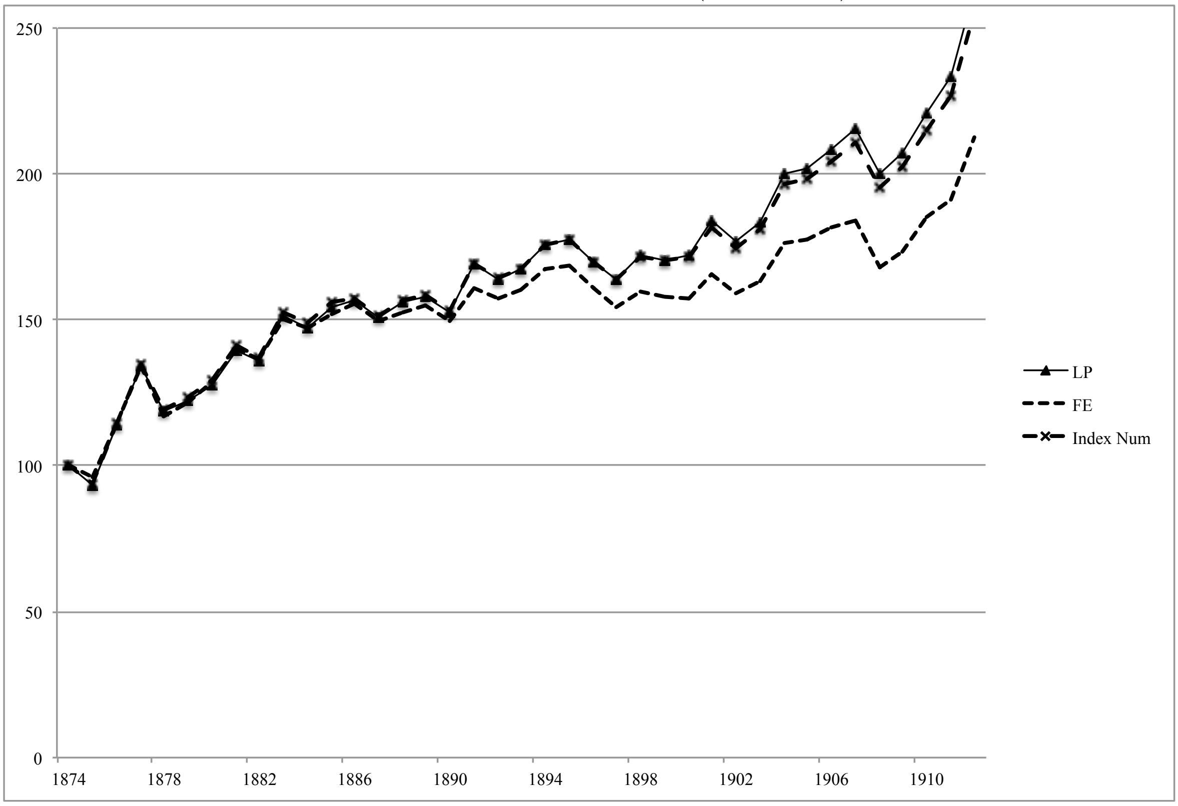

Figure 3: TFP and Freight Rates

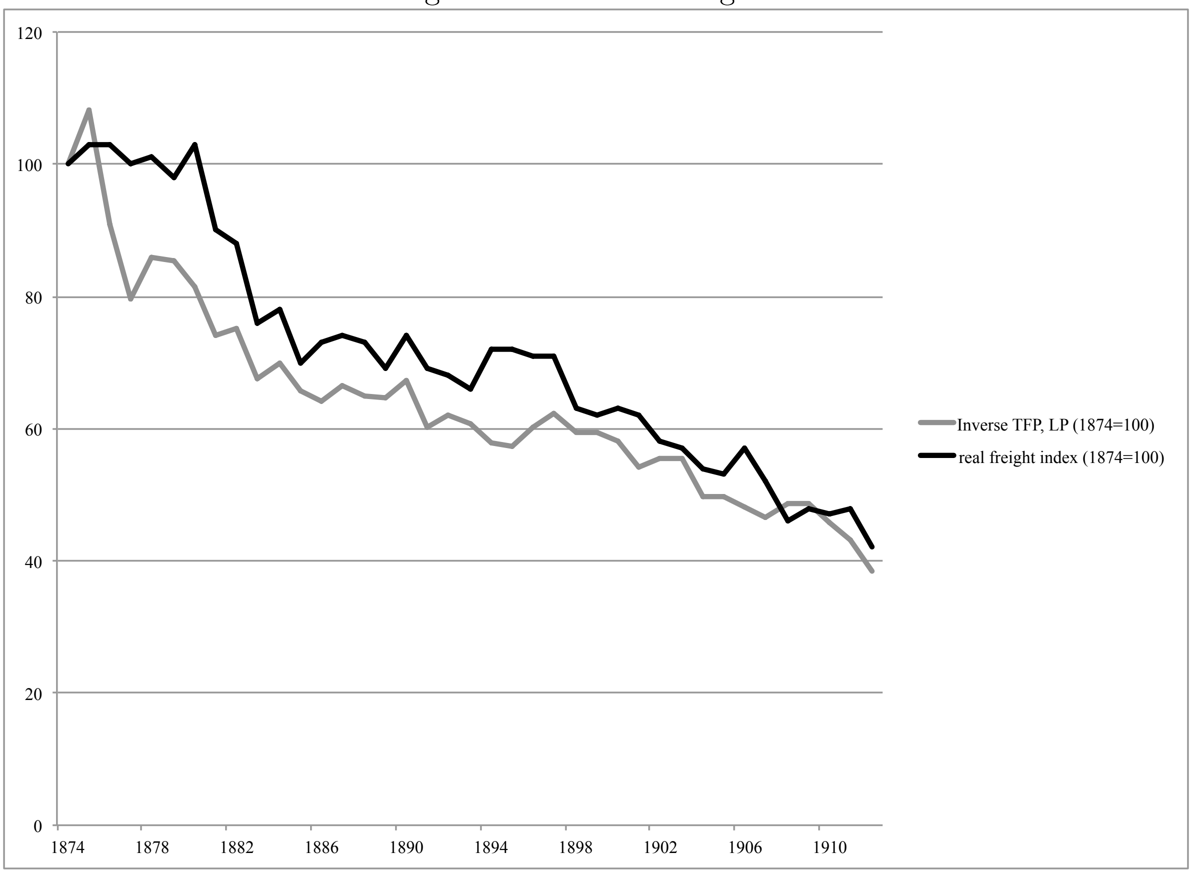

Figure 4: Role of Reallocation in TFP Growth

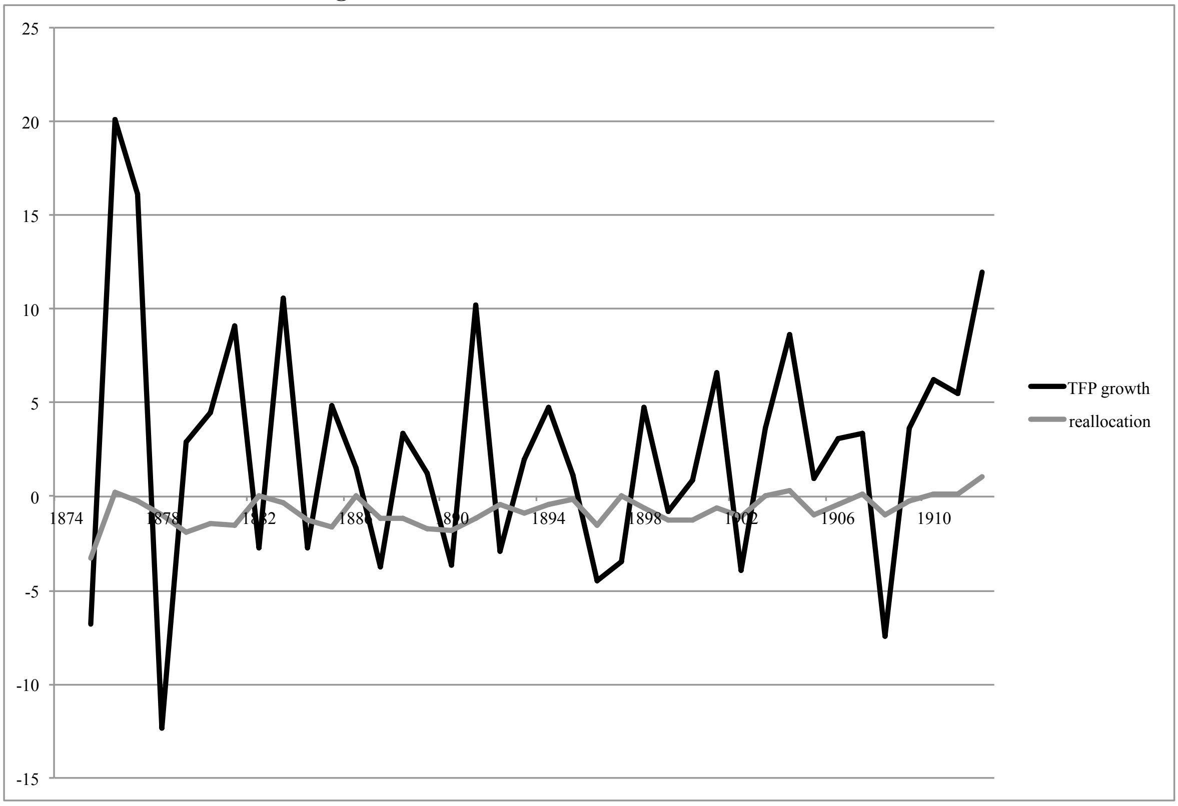

Figure 5: Capacity Utilization - Train Miles Run per Track Mile

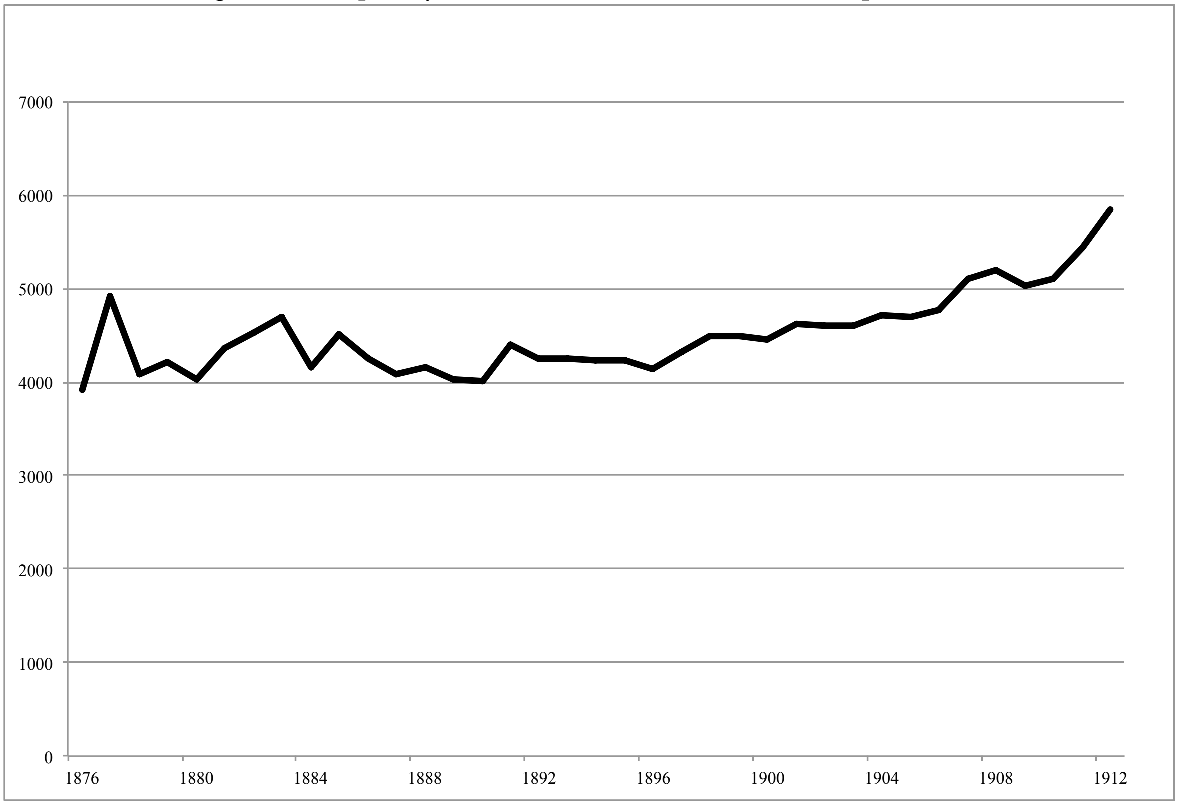

Figure 6: TFP on Broad and Meter Gauge Railways

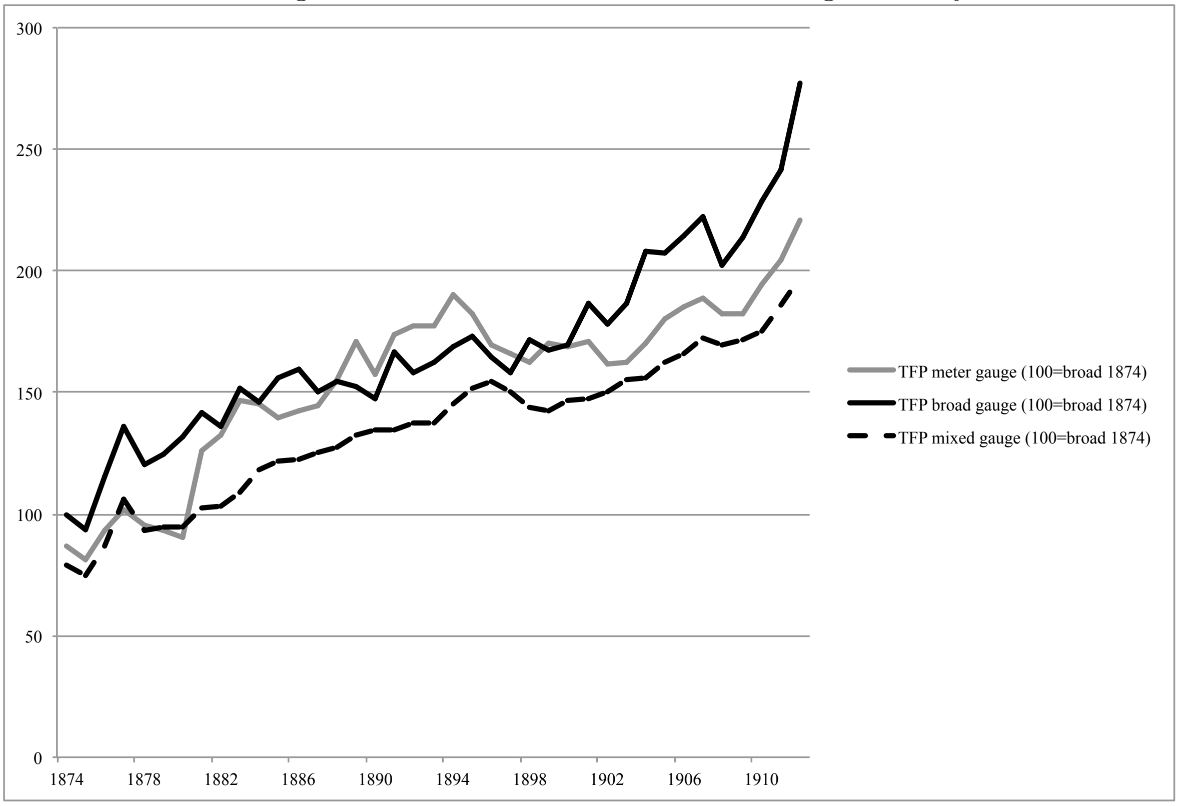

Table 1: Summary Statistics

Variable	Obs	Mean	Std. Dev	Min	Max
Ton miles (millions)	738	294	531	0.12	5,470
Passenger miles (millions)	738	328	388	0.00	2,240
Output (cost weights)	738	309	458	0.16	4,040
Labor	738	15,742	18,091	37	96,542
Fuel (Kurharbaree coal, thousands)	738	80	117	0.18	755
Miles	738	955	841	6	4,917
Capital (in millions of 1912 rupees)	738	138	160	0.4	816

	Annual Growth Rate (in %)				
	1874-1912	1874-79	1880-89	1890-99	1900-12
Output/Labor	***2.05%***	1.4%	2.1%	0.9%	3.2%
Output/Fuel	***0.91%***	2.9%	2.2%	-1.3%	0.9%
Output/Capital (in rupees)	***3.30%***	6.0%	2.2%	2.0%	4.2%
Output/Miles	***2.40%***	3.7%	0.1%	1.3%	4.6%

Source: *Administration Reports on Railways in India,* 1874 to 1912.

Table 2: Coefficient Estimates

	OLS	FE	LP
(in logs)			
Labor	0.3382***	0.1737*	0.2958***
	[0.112]	[0.090]	[0.079]
Fuel	0.6198***	0.3618***	0.1500
	[0.104]	[0.095]	[0.247]
Capital	0.0910	0.5003***	0.5100**
	[0.108]	[0.101]	[0.221]
Year FE	Yes	Yes	No
Railways FE	No	Yes	No
Obs.	738	738	738
Adj R^2	0.972	0.989	
Scale Economies	1.049	1.036	0.956
F-stat	3.11	0.41	0.85 (chi2)
P-value	0.086	0.527	0.772

Robust standard errors clustered at the railway level in brackets in specifications 1 and 2.
Bootstrapped standard errors in specification 3.

*** p<0.01, ** p<0.05, * p<0.1

Table 3: Correlation Coefficients Across TFP Models

	OLS	FE	LP	IN (Indian W.)
OLS	1			
FE	0.88	1		
LP	0.75	0.93	1	
IN (Indian W.)	0.79	0.96	0.99	1

Table 4: Estimates of TFP Growth Rates

	Annual Growth Rate (in %)				
	1874-1912	1874-79	1880-89	1890-99	1900-12
OLS	**1.10**	1.82	2.39	-0.58	1.14
FE	**2.00**	3.96	2.47	0.21	2.29
Levinsohn and Petrin	**2.58**	4.05	2.63	0.76	3.38
Index Number	**2.50**	4.32	2.52	0.71	3.17

Table 5: Railway TFP Growth Across Countries

Country	Years	Estimation Method	TFP Growth
India	1874-1912	Production Function (LP)	2.58
India	1874-1912	Index Number	2.50
US	1870-1910	Index Number	2.10
Britain	1874-1912	Index Number	0.80
Spain	1870-1913	Cost Function	1.50

Sources: For the US see Fishlow (1966), for Britain see Crafts, Mills, and Mulatu (2009), for Canada see Green (1986), for Spain see Herranz-Loncán (2006).

Table 6: Indian Productivity Levels in International Perspective

	Railways-1913						Cotton Textiles - 1910	
	Partial Productivity Index (India = 100)							
	Y/L	Y/Fuel	Y/Miles	Y/ Locomotives	Y/Vehicles	Log of TFP (India = 100)	Labor Efficiency Index (India = 100)	Hourly Output per Spindle (India = 100)
India	100	100	100	100	100	100	100	100
US	437	46	171	161	103	114	530	107
Canada	367	66	93	151	96	108		
Belgium	159	46	226	33	35	110		
France	137	50	73	45	37	97	222	
UK	81	32	116	27	18	96	408	130
Argentina	115	74	38	56	70	89		
Brazil	56	30	14	22	43	70		
Japan	104	63	117	54	65	100	106	112
Russia	163	163	169	81	83	111	220	
Austria	122		130	56	63		248	87
Germany	126		142	42	38		256	
Norway	141		30	29	30			
Sweden	126		38	39	35			
Switzerland	96		72	32	51		280	

Notes: Output is measured using the revenue weighted average of ton miles and passengers miles c.1913, labor is measured in number of employees, fuel in tons of coal or equivalent, miles are the number of track miles, locomotives and vehicles are the numbers of each. The log of TFP is calculated is .35*(Y/L)+.15*(Y/Fuel)+.5*(Y/Miles), where the partial productivity measures are drawn from the previous columns.

Sources: India, fuel is from Indian Admin Report (1913-14), p. 470-471; all other Railroad Statistics of the United States or RUS (1916) p. 143. US: fuel and employees, Fishlow (1966) p. 613, 620; ton miles, pass miles, revs, miles RUS (1913), p. 81,87; RUS (1916), p. 40, 43. Canada: fuel Green (1986), p.807; locomotives RUS (1916), p. 48; all other RUS (1913), p. 122. Argentina: all estadistica ferrocarriles en explotacion (1913). Russia: fuel Coal Tables (BPP 1913 Vol 285), p. 48; all other RUS (1916) p. 140. Brazil: RUS (1916), p. 141. Summerhill. France: fuel Coal Tables (BPP 1913 Vol 285), p. 48; all other RUS (1916) p. 135. UK: fuel Coal Tables (BPP 1913 Vol 285), p. 48; employees RUS (1913), p. 123; all other RUS (1916) p. 133. Belgium: fuel Coal Tables (BPP 1913 Vol 285), p. 48; all other RUS (1916) p. 136. Japan: fuel Coal Tables (BPP 1913 Vol 285), p. 48; locomotives and vehicles RUS (1916) p. 142; all other RUS (1913) p. 131. Germany: RUS (1916), p. 134. Switzerland: RUS (1916), p. 137. Austria: RUS (1916), p. 138. Norway: RUS (1916), p. 139. Sweden: RUS (1916), p. 139.

Labor efficiency index is calculated from Clark (1988), table 3, machinery per worker (in loom equivalents). Output per spindle is also from Clark (1988), table 5.

Table 7: Contribution of Indian Railways to Annual GDP per-capita Growth

	India 1874-1912	India 1874-1912
Railway Capital Stock Growth / Worker	3.1	3.1
Railway Profits Share in National Income	0.015	0.015
Railway Capital Contribution	0.05	0.05
Railway TFP Growth (in percent)	2	2.58
Railway Share in National Output	0.03	0.03
Railway TFP Contribution (in percent)	0.06	0.08
Total Railway Contribution w/o Spillovers	0.11	0.13
(as % of GDP per capita growth)	18.33	21.67
TFP Estimation method	FE	LP

Source: See text for details on sources.

Notes: The growth of railway capital per capita is calculated using the total capital of all railways in the sample in 1874 divided by the population of India in 1870 and the total capital of all railways in the sample in 1912 divided by the population in 1913. Railway capital per person was 15.19 in 1912 and 4.77 in 1874. Also note the growth of capital was 3.59% and the growth of population was 0.48% over the same period.

Table 8: Capacity Utilization or TFP?

	OLS	FE
(in logs)		
Train Miles Run/	0.1785	0.3134*
Track Mile	[0.108]	[0.156]
Obs	717	717
Year FE	Yes	Yes
Railways FE	No	Yes
TFP Growth Rate Net of Utilization	**0.84**	**1.72**
TFP Growth Rate Gross of Utilization	**1.04**	**2.08**

Robust standard errors clustered at the railway level in brackets. *** p<0.01, ** p<0.05, * p<0.1. Regressions include capital (in rupees), labor and fuel as in Table 2.

Data covers years 1876-1912 because information on train miles is unavailable for 1874-75

Table 9: Correlates of TFP - Is it Technology?

	TFP - FE	TFP - LP	TFP - FE	TFP - LP
Proportion of				
Engine Brakes (Vacuum)	-0.0488	0.1027	-0.1132	0.0216
	[0.130]	[0.143]	[0.094]	[0.095]
Vehicle Brakes (Vacuum)	-0.1427	-0.2323	0.2443	0.2454
	[0.282]	[0.274]	[0.174]	[0.207]
Rolling Stock Gas Lighting	-0.4735***	-0.3844***	0.2133**	0.3107**
	[0.107]	[0.126]	[0.085]	[0.110]
Rolling Stock Electric Lighting	0.0098	0.1717	0.1303	0.1564
	[0.101]	[0.121]	[0.124]	[0.120]
Interlocking Signal Stations	0.4976*	0.8103**	0.1022	0.1381
	[0.245]	[0.290]	[0.111]	[0.123]
Block Signal Stations	0.1967	0.3251**	-0.0286	-0.0987
	[0.133]	[0.145]	[0.087]	[0.112]
Bogie Coaches	0.3202	0.2316	0.0961	0.3337
	[0.358]	[0.340]	[0.264]	[0.319]
Bogie Wagons	-0.2135	0.2759	-0.1072	-0.1224
	[0.355]	[0.470]	[0.151]	[0.193]
High Sided Wagons	0.0450	0.0132	0.1914	0.0759
	[0.210]	[0.247]	[0.181]	[0.220]
Railway FE	No	No	Yes	Yes
Obs.	226	226	226	226
Adj R^2	0.405	0.441	0.864	0.875

Data only covers years 1900 to 1912. Robust standard errors clustered at the railway level in brackets. *** p<0.01, ** p<0.05, * p<0.1.