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

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Abstract

While other sectors of the Indian economy enjoyed limited productivity growth under the British Raj, railways were an exception. In this paper, we present new estimates of total factor productivity (TFP) using railway-level data on outputs and inputs from 1874 to 1912. We estimate railway-industry TFP growth and find it to be substantial averaging between 2.0 and 2.6 percent per year from 1874 to 1912. We also find that capacity utilization is secondary in importance, suggesting a key role for technological change. Finally, we show that TFP growth on Indian railways accounted for 13 percent of Indian GDP per capita growth from 1874 to 1912.

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1 Introduction

Railways were the most significant infrastructure development of the 19^{th} century. In most countries, railways reduced trade costs, helped to integrate markets, and increased both trade and travel. The experience of colonial India was no exception. Given the poor state of existing transportation networks, railways completely transformed the infrastructure of the sub-continent by connecting the ports to major industrial and commercial centers in the interior of the country. Despite the documented benefits of Indian railways on price convergence and trade flows (Hurd 1983, Andrabi and Kuelhwein 2010, Donaldson 2010), economic historians have offered a mixed assessment of the sector. Such arguments note that managment was complacent and railways did not lead to rapid economic growth in India (Thorner 1955, 1977, Hurd 2007).

We reassess the performance of Indian railways by presenting new estimates of total factor productivity (TFP) from 1874 to 1912. If Indian railways failed to achieve a higher rate of TFP growth relative to other sectors of the economy or had slower TFP growth than railways in other countries, then this would be evidence for some type of 'failure.' On the other hand, if TFP growth was rapid then railways should be viewed as a success story for the colonial Indian economy. Our approach combines detailed railway-level data with modern econometric techniques and offers a range of TFP estimates based on different methodologies. Previous studies have calculated labor and capital productivity (Christensen 1981, Hurd 2007), but to date none of them account for fuel and capital changes or estimate TFP. Unlike studies relying on aggregate data, our paper is among a small group that uses railway-level data to estimate productivity in the railway sector (see Herranz-Loncán 2006, Crafts, Mulatu and Leunig 2008, Dodgson 2011).

Our panel data covers 32 railways over a 38-year period. These railways jointly account for more than 95 percent of total output in Indian railways. We rely on official reports to construct the necessary variables needed for the productivity analysis: ton miles, passenger miles, track miles, locomotives, vehicles, capital outlay, fuel and number of employees. The analysis begins in 1874 when the output series become usable and ends in 1912. Since the data series change after the War, we restrict our focus in this study to the pre-World War 1 period. Although the data sources are rich in details, they are not without problems. First, the fuel inputs are inconsistently reported over the years as Indian railways transitioned from British coal to Indian coal. Second, the reported capital outlay series are constructed similar to the perpetual inventory method, but annual investment is not converted into constant prices. To address these issues we construct a quality adjusted fuel series and new capital stock series using real investment.

We estimate TFP at the railway-level according to the traditional Index Number method with UK, US and Indian weights for capital, labor and fuel. Next, we calculate TFP as a residual from an estimated production function. There are several methods to estimate the coefficients of a production function. The main concern with using ordinary least squares is the potential correlation between unobserved productivity shocks and input choices. To address such endogeneity problems we present both fixed effects estimates that control for all railway-level time invariant shocks and Levinsohn-Petrin estimates that use intermediate inputs such as fuel to get around the simultaneity problem (Levinsohn and Petrin 2003). Fortunately in our case, the TFP estimates do not differ substantially and offer the same qualitative picture.

Using the railway-level TFP estimates, we calculate annual industry-level TFP using output shares as weights. We find evidence of significant TFP growth in the Indian railway sector regardless of the method. Our preferred estimates suggest TFP growth averaged between 2 and 2.6 percent per year. TFP growth was especially high in the 1900s ranging from 2.3 to 3.4 percent per year.

The performance of Indian railways stands in stark contrast to the rest of the Indian economy in this period. Between 1890 and 1910, the average rate of TFP growth in the Indian economy was close to zero (Broadberry and Gupta 2010). The poor productivity performance of the overall economy is largely driven by agriculture, which accounted for almost 75 percent of the total labor force up to Indian independence in 1947. But, even among the modern sectors productivity growth was significantly higher in railways. For example, labor productivity growth in cotton textiles, an important manufacturing sector, was very low (Clark 1987, Clark and Wolcott 1999). Even more surprising is the peformance relative to other countries. TFP growth was similar to or higher than railways in developed economies like the US, UK, and Spain.

One may be concerned the TFP measures are not picking up evidence of productivity, such as better organization or technical efficiency, but rather reflect greater capacity utilization spurred by an increase in the demand for railway services. Clearly, utilization affects railway TFP because tracks and vehicles sit idle when trains are not running. If greater capacity utilization is not due to improvements in organization methods such as loading and train turn-around times, then one may question if greater utilization should be viewed as 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 85 to 90 percent of the original estimates after accounting for utilization, suggesting capacity utilization is not the sole source of TFP growth.

We believe technological and organizational changes drove a significant portion of the TFP growth on Indian railways. Consistent with this view, we show that a number of best-practice technologies were adopted such as vacuum brakes, electrical lighting and bogie carriages. By 1912 Indian railways had moved closer to the technological frontier. Organizational changes also occurred, including agreements among railways to coordinate the exchange of traffic and rolling stock. Perhaps surprinsingly, the colonial Government of India led the way in promoting better operating practices. Railway performance was an important state objective in the pre-war colonial period (Bogart and Chaudhary 2011a).

The growth in railway TFP had important implications for the development of the Indian economy. As a final exercise we estimate the contribution of railway TFP growth to GDP per capita growth using Crafts (2004) new growth accounting framework. We find railway TFP growth contributed between 0.06 and 0.08 percent per year to Indian GDP per capita from 1874 to 1912. Including railways' additions to the aggregate capital stock raises the total contribution to around 0.1 percent per year or 17 percent of the total increase in GDP per capita.

Following the convention in the literature we also convert our estimates into a social savings (i.e., the percent of national income attributable to railways). We find that Indian railways increased national income by approximately 4 percent between 1874 and 1912. Using a different methodology, Hurd (1983) and Donaldson (2010) find social savings on the order of 10 percent of Indian GDP. Our estimates are smaller in part because we study the impact of railways from 1874 to 1912, whereas they study the impact of railways from the 1850s. We also illustrate the equivalence between TFP growth and the decline in freight charges, a key indicator in their studies.

Our paper complements a long line of studies on Indian railways including McAlpin (1974), Hurd (1975, 2007), Adams and West (1979), Derbyshire (2007), Kerr (2007), and Bogart and Chaudhary (2011a, 2011b). We also contribute to the comparative literature on railway productivity and efficiency (for example, Fishlow 1966, Crafts, Mills, and Mulatu 2007, Herranz-Loncán 2006, Bogart 2010). To our knowledge, this is the first paper to estimate a production function using railway-level data before 1913. Lastly, our research relates to a growing literature on productivity trends in the colonial Indian economy (Clark and Wolcott 1999, Broadberry and Gupta 2010, Roy 2010). In late 19^{th} and early 20^{th} century India, railways were an engine of growth.

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. Private British companies backed by a Government of India (GOI) guarantee managed the initial construction and operation of the lines. Beginning in the 1870s, the GOI began to construct new lines and in the 1880s a hybrid GOI owned but privately operated structure emerged. The Princely States were also involved in railways with many of them outsourcing the construction and operations to private companies. The public-private partnership model was the dominant organization form till the 1920s when complete nationalization was gradually introduced.

The initial network was constructed on a broad 5 feet 6 inches gauge 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. These lines often served as feeder lines connecting to the main trunk route. A few narrow gauge (2 inches) lines were also constructed connecting to different hill stations. While economic and military concerns dictated route placement in the earlier decades (Thorner 1955), social concerns following the devastating famines of the 1870s lead to the construction of some protective famine lines in the 1880s. There were also several mergers in the late 19^{th} century and early 20^{th} century between the trunk lines and other lines operating in the area. Figure 1 displays the rail network as of 1909.

Our sample of railways includes all the major standard and meter gauge railways operating between 1874 and 1912. Table 1 lists each railway in the sample noting its gauge, entry and exit date. The exits 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 initial 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 fourteen railways began operations after 1874 but ceased to operate by 1912 because of mergers. Other than a few exceptions, these lines were often of smaller size compared to the principal trunk lines to which they merged. Because we are interested in industry-level TFP, we include information on all lines in our dataset even if they subsequently merge.

In the literature, railway companies are viewed with some skepticism. Hurd (2007) argues that railways missed opportunities for development and that management was often complacent. The critique of railways fits into a larger view that the colonial Indian economy failed to achieve growth. However, railway performance has not been assessed by a clear metric. 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. We now turn to a discussion of a new data set, which we use to address TFP.

3 Data

We construct a new data set of Indian railways from 1874 to 1912 using *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, locomotives, vehicles, fuel, labor, and the value of capital starting in 1874.

Similar to the transportation literature, we use ton miles and passenger miles to measure output.[1] The TFP analysis requires a single output measure and the convention is to use a weighted average of ton miles and passenger miles. Following Caves, Christensen, and Swanson (1980) we define the weights using the cost elasticity of ton miles and passenger miles. Based on an earlier study (Bogart and Chaudhary 2011a) that calculates cost elasticity estimates, we assign a weight of 0.56 to ton miles and a weight of 0.44 to passenger miles. As a robustness check we also use the annual revenue shares for each railway as weights.

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. 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 an Indian coal, Kurhurbaree coal (the main fuel source of the East Indian Railway).

From 1890 to 1901, we have information on total fuel consumption in tons and total fuel consumption in tons of Kurhurbaree coal for each railway. The *Reports* do not discuss how fuel is converted into tons of Kurhurbaree coal, but they give BTU conversion rates

[1]Passenger miles are only reported for private railways between 1874 and 1879. To construct passenger miles for state railways in these years, we multiply total passengers that are reported 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.

for more than 20 different types of coal and wood. Between 1897 and 1901 the *Reports* become more detailed and give the conversion rate from Indian coal, foreign coal, and wood to Kurhurbaree coal for each railway.

We extend the data on the quality adjusted fuel series from 1890 to 1901 to the other years. 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 Kurhurbaree 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. In these years, we apply the BTU conversion rates based on the fuel description and calculate fuel consumption in tons of Kurhurbaree coal.[2]

The years from 1882 to 1889 are the most challenging because we only have information on the total tons of fuel consumed without any information on the type of fuel. While there are notes describing the fuel type, they do not give the precise breakdown. 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 the detailed information on fuel type.[3] 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 yield an estimate of the tons of Kurhurbaree coal consumed by each railway.[4]

We measure capital in two ways. First, we use the number of track miles, locomotive engines, and vehicles (i.e., wagons and carriages) as three separate capital inputs. But, there are a few potential problems with this approach. Track miles were built on different gauges, and engines and wagons differed in terms of design. Our baseline model does not adjust for quality because there is no obvious procedure to account for these differences. While we can control for time-invariant differences using fixed effects in the productivity estimates, quality still remains an issue. The second problem is that track miles, locomotive engines, and vehicles represent most but not all the capital inputs. Capital also included stations,

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

[3]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 Kurhurbaree coal. If they consumed only Indian coal, their adjustment factor would be between 0.8 and 1 depending on the variety used. If they consumed only Kuruhbaree coal, their adjustment factor would naturally be one. Since the other Indian varieties were inferior to Kuruharbaree coal, their adjustment factor would be less than one.

[4]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 Kurhurbaree 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.

warehouses, bridges, and stores of other equipment. Our second approach addresses the breadth issue by providing a comprehensive measure of capital.

The *Reports* state total capital outlay by each railway in each year, which includes the cumulative value of all past investments (i.e., new track, vehicles, etc.) minus retirements.[5] To construct an estimate of nominal investment less depreciation, we begin by taking the yearly difference in the capital outlay series.[6] We then construct a real investment series by multiplying nominal investment with a capital price deflator. 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.

Unskilled labor and British capital were the key inputs in railway construction (Kerr 1983). We use Feinstein's (1988, p. 470-471) capital price series on railway rolling stock, ships, and vehicles from 1850 to 1912 as a measure of British capital import prices.[7] For labor we use information on average monthly wages for unskilled agricultural workers between 1874 and 1912 as reported in the *Prices and Wages in India* (Government of India 1896, 1922).[8] For each railway we average the wages across the relevant regions traversed by the railway. Finally, we rely on Kerr's (1983) estimates of labor costs in railway construction to guide our choice of weights. We use 0.55 as the weight for wages and 0.45 as the weight for British railway capital imports.[9]

Table 2 summarizes all the variables used in the productivity analysis. The average railway transported 296 million ton miles and 330 million passenger miles, but there was tremendous variation across railways and over time as captured by the standard deviation. 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 959 miles of track, 210 locomotive engines, and 4717 vehicles. The average capital stock was 147 million rupees or around 11 million pounds sterling using exchange rates in the late 1800s.

The bottom of table 2 presents partial productivity estimates disaggregated by time-

[5]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. While we are sympathetic to the issues they highlight, we do not believe the measurement error is large enough to render the series unusable. The types of issues they raise can also be addressed by including year and railway fixed effects in the estimation procedure.

[6]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

[7]We convert the series into rupees using the market exchange rate.

[8]The wage data between 1850 and 1874 is not consistently available for all the regions. The available evidence from the United Provinces suggests nominal wages rose in this period. We apply the United Provinces wage growth rate to all regions.

[9]Based on our constructed series, we believe the capital series reported in the official publications probably under states the capital stock. For example, based on our estimates the East Indian railway had 15 percent more capital by 1881 than the reported capital outlay. The main reason is that labor and railway capital goods were less expensive in the 1850s when the East Indian built its railway.

period. There was a large increase in both output 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 engines, miles and vehicles 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 some TFP growth in Indian railways.

There are other outcomes worth noting. Freight represented about two thirds of total revenues in Indian railways throughout the period from 1874 to 1912. Thus there was stability in the composition between freight and passenger traffic. There was also stability in the composition of passenger traffic. The lowest class passengers (i.e., third or fourth) represented around 85 percent of passenger revenues throughout the period.

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.[10] 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 revenues 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:

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

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

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.

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.[11] 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. We report results using the aggregate Indian, British and US weights.

In general, our data are better suited to a parametric estimation of TFP.[12] 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:

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

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:

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

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. Following this approach the estimating equation in the Cobb Douglas model is:

$$y_{it} = \alpha_0 + \alpha_l l_{it} + \alpha_k k_{it} + \alpha_m m_{it} + \varphi_i + \delta_t + \varepsilon_{it} \quad (6)$$

[11] 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.

[12] 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.

where φ_i is a railway system fixed effect and δ_t is a year fixed effect. The log of TFP is again calculated as a residual except with railway and year fixed effects. The railway fixed effect is interpreted as the time-invariant component of TFP. Numerous factors, like location, are captured by this term. The year fixed effects are interpreted as time-varying productivity shocks that are common to all railways. Anything from global technological changes to trade shocks are included here. The fixed effects (FE) model allows for a correlation between inputs and the fixed effects, but assumes independence between inputs and the error term. In other words, FE cannot control for any time varying unobserved productivity shocks at the railway level that may bias the coefficients on α_l, α_k, and α_m.

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.[13] The Levinsohn and Petrin estimator relies on intermediate inputs such as 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). Thus, we use these different approaches namely IN, FE and Levinsohn-Petrin, to generate railway level TFP estimates for each year. We then calculate the log of industry TFP 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:

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

5 Results

We discuss the results in four separate sub-sections. The first section reviews the input coefficients on capital, labor and fuel across the different estimation techniques described above. Section 5.2 presents the results on industry-level TFP and sections 5.3 and 5.4 examine capacity utilization and technological change to better understand the sources of TFP growth.

[13] 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.

5.1 Input Coefficient Estimates

Table 3 presents the coefficient estimates on capital, labor and fuel across the different methods. Specification (1) is the standard OLS model, a Cobb Douglas production function augmented by year FE, where miles, engines and vehicles enter as separate capital inputs. Since OLS is likely to be biased, we report these coefficients for comparison only. Specification (2) adds railway fixed effects (FE) to the model. Other than engines, all the remaining input coefficients have a positive sign and are significant at the 5 percent level. Fuel has the highest estimated output elasticity followed by vehicles, miles, and labor. The elasticity of engines is indistinguishable from zero. Adding all the coefficients yields an estimate for scale economies of 1.06, but the hypothesis of constant returns to scale cannot be statistically rejected. Specification (3) uses the revenue-weighted output measure as a robustness check and the coefficients are not significantly different from those reported in specification (2), our standard cost weighted output.

One disadvantage of using the number of capital units as in specification (1) to (3) is these measures just count the number of miles, vehicles and engines without taking into account any quality changes. This is of particular concern in our setting because the quality of locomotive engines was continuously changing. Such changes can generate an upward or downward bias on the individual capital coefficients depending on whether the existing capital stock was replaced by lower or higher quality units. Specifications (4) to (6) address these concerns using the capital series we constructed from annual real investment. Specification (4) is the standard OLS, specification (5) includes railway FE and specification (6) reports the Levinsohn and Petrin (LP) estimates that control for simultaneity. While the coefficients on labor are similar across the different methods, the coefficients on capital and fuel are quite different. Similar to the original Levinsohn and Petrin (2003) study, we find the LP estimates on capital are higher than OLS (or even the FE in our case) 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. In general, the FE estimates are in-between the OLS and LP estimates.

Across the different methods, we find no evidence of significant economies of scale. Scale economies are small and statistically indistinguishable from zero in all the specifications other than OLS. Many Indian railway systems more than doubled in terms of mileage, employment and vehicles 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 for railway consolidation was also favorable because the colonial Government of India actively promoted railway mergers. However, consolidation and internal growth did not increase productive efficiency since economies of scale were limited.

In terms of TFP, the estimates are broadly similar across the specifications and methods. Table 4 reports the correlation coefficients between the railway-level TFP estimates. There is a high correlation between the models with multiple or single capital inputs. The LP estimates are also highly correlated with the IN estimates. While the TFP railway-level estimates are similar across methods, we do find some differences in TFP growth rates. This is to be expected since each method assigns a different weight to labor, capital, and fuel. We now turn to a discussion of industry-level TFP growth and its implications.

5.2 Industry TFP

Industry-level TFP growth is one of the best indicators of improving performance in the Indian railway sector. This measure summarizes railway-level TFP growth and any changes in market structure affecting productivity. Table 5 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 OLS model with multiple capital inputs yields the most conservative estimate of TFP growth: an average rate of 1.17 percent per year from 1874 to 1912. Since OLS is likely to be biased, we give less weight to this estimate.

The methods that control for potential endogeneity between input choices and unobserved productivity shocks all imply a larger average annual rate of TFP growth as do the IN methods. The FE estimation using the single capital measure shows an average annual TFP growth rate of 1.99 percent while the LP generates an average annual rate of 2.55 percent. Similar to the IN methods, LP also shows a high rate of growth because both methods assign a similar elasticity to fuel. Depending on the choice of methods, the estimates range from 1.2 to 2.7 percent, but the more credibly identified models such as FE and LP suggest a tighter range from 2 to 2.6 percent. At the very least, all the estimates show TFP growth was positive and rapid in the Indian railways sector between 1874 and 1912.

Figure 2 plots the various TFP indices across the three capital input estimation models and figure 3 plots the TFP indices across the single capital estimation models. The TFP indices are standardized to 100 in 1874. Despite some differences in the growth rates, the graphs illustrate 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 some estimates suggest killed almost 10 million people between 1876 and 1878. Famine deaths were particularly severe in 1877 when railways were involved in moving grain between regions. In general railways were influenced by the macroeconomic 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. The 1900s were a golden age for Indian railways. Under-pinned by high TFP growth, there was a boom in profits along with substantial reductions in freight rates.

The TFP growth rate in Indian railways is especially impressive compared to other sectors and the overall economy. The literature is generally quite pessimistic about India's economic progress in the late 19^{th} and early 20^{th} century. The annual growth rate of output per worker in agriculture averaged 0.4 percent in the late 19^{th} century and 0 percent in the 20^{th} century up to independence in 1947. TFP growth rates for the overall economy were close to zero in most of the colonial period driven largely by the poor performance of agriculture (Broadberry and Gupta 2010). Even among the modern sectors, Clark and Wolcott (1999) argue there was very little labor productivity growth in Indian cotton textiles compared to around 2 percent per year in railways (table 2).

Indian railways also look impressive by international standards. Table 6 compares average annual rates of TFP growth for railways in India, Britain, Spain, Canada, and the US. The methodology and time period are also summarized. Strikingly, Indian railways had higher TFP growth than US railways (2.1 percent) and British railways (0.8 percent) using the Index Number approach. Canadian railways enjoyed exceptionally high TFP growth beating both the US and India. Our production function estimates generate a slightly higher TFP growth rate of 2.0 percent compared to 1.5 percent for Spanish railways estimated using a variable cost function. Thus, Indian performance in the railway sector matched and in some cases even surpassed the performance in advanced countries. Compared to other sectors of the Indian economy and world standards, railways were the productivity star of the Indian economy.

5.3 TFP Growth or Capacity Utilization?

Given the striking performance of Indian railways, one may be concerned whether the increase in TFP reflects true productivity gains such as improvements in organizational and technical efficiency, or whether they reflect increased 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). An increase in utilization after the 1870s could have impacted productivity.

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 take a different approach to measuring the contribution of utilization to TFP than Fishlow. The goal of the exercise is to assess the extent of the correlation between utilization and TFP, and whether a significant portion of the variation in TFP is related to utilization. We do not attempt to attribute a direct causal mechanism between the two. In this exercise, we quantify capacity utilization using micro-data on train miles run per track mile. Track clearly sits idle when trains are not running and so it is a good measure of capacity utilization. Train miles run per track mile is also ideal because railway track is generally constant in quality; otherwise utilization would be conflated with technological change.

Figure 4 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. Our approach is similar to other works that measure economies of density by including utilization terms directly in the cost function (Oum, Waters, and Yu 1999).[14]

[14]Similar to these studies, we assume the natural log of the residual is the log of track utilization plus a

Table 7 reports the coefficients on track utilization across the different models. Unsurprisingly, greater track utilization increases output. In the Cobb-Douglas FE (specification 5), for example, the elasticity of track utilization is 0.52. 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.

Calcluations of TFP growth net of utilization also confirms that capacity utilization is not the major driver of TFP growth. At the bottom of table 7 we report the rate of net TFP growth from 1876 to 1912.[15] We also report the average TFP growth rate without accounting for utilization for comparison (from table 5). Average annual TFP growth rates are lower, but not substantially. Track utilization accounts for about 10 to 15 percent of TFP growth in most specifications.[16] Thus, a substantial portion of the TFP growth appears to be unrelated to capacity utilization.

5.4 TFP, Organization and Technological Change

In this period, there were several technological and organization changes that were probably correlated with TFP growth. The state of technology on Indian railways c1900 is summarized in the Roberston Report (1903). The author, Thomas Roberston, argued that Indian railways lagged behind railways in advanced countries like the United States, Canada, and Britain. At this time, Indian railways were using few of the best practice technologies of this period 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.[17] By 1912, 81 percent of engines and 47 percent of vehicles were fitted with brakes. With such automatic brakes the entire train could be brought to a halt quickly thereby increasing safety. Previously one worker had to be present on each engine and vehicle and concurrently pull the brake in order for the train to stop. Inter-locking signal systems at stations also improved safety. The average number of stations with inter-locking systems increased from 17 to 55 percent between 1902 and 1912.

The Roberston 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

variable representing all the other factors including technology.

[15]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.

[16]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.

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

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 before the Report to 15.4 percent in 1912, while the adoption of bogie coaches increased over two-fold from 9.9 percent in 1900 to 25.3 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 (Roberston 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 electricity. Needless to say it was quite uncomfortable for railway passengers to travel at night without lighting. Electrical lighting was superior to gas because it gave off less heat (Robertson 1903).

There also appear to have been other technologies, which may have contributed to TFP growth but are not easily quantified. For example, officials noted the fitting of super-heaters to locomotive engines that were estimated to save fuel by 15 percent. 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).

Indian railways moved closer to the technology frontier by 1912. That said, it is difficult to empirically quantify the impact of technological changes on TFP. Hence, we hesitate to attribute a causal relationship between the evidence on technology adoption and higher TFP. Nonetheless it is clear Indian railways experienced technological change in the late 19^{th} and early 20^{th} century.

Indian railways also experienced a number of organizational changes. Perhaps the most notable was the GOI takeover of a majority of the private railways. 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 under state ownership. By 1912 the GOI had taken over all the former private companies and formed an extensive ownership stake in the railways sector. The transition to state ownership had the effect of lowering operating costs, particularly labor costs. The unique objectives of the Government combined with an improved regulatory environment made state ownership relatively effective in the Indian case (Bogart and Chaudhary 2011a).

The colonial Government also introduced other organizational changes in this period. 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. The Government 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). Thus, the period of high TFP growth was also one of major organizational and technological changes.

6 Railways and the Indian Economy

In this final section we examine the implications of TFP growth for the Indian economy using the modified growth accounting framework proposed by Crafts (2004). In this framework the growth of income per capita is divided into a contribution from the railways sector and the non-rail 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 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 is equal to the first and third terms. The idea is that railways made a contribution to economic growth through TFP and through additions to the capital stock, which embodied new railway technology.[18]

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

The results are summarized in table 8 for the FE, single capital estimate of TFP growth (our median estimate) and the LP estimate (our higher, but arguably best estimate). The growth in TFP between 1874 and 1912 contributed between 0.06 and 0.08 percent per year

[18] It is also worth noting that the embodied technology component is more controversial because it assumes that in the absence of railways the capital investment in the railway sector would not have occurred.

to income per capita. The growth in railway capital contributed 0.02 percent per year. The total contribution of railways (without any correction for spillovers) is between 0.08 and 0.1 percent per year. Although it appears small, consider that 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 13 or 17 percent of the total income per capita growth.

The calculations make clear the importance of TFP growth. It accounts for more than half of the estimated growth contribution of railways between 1874 and 1912. The effects can be compared with railways in Britain and Spain, where Crafts (2004) and Herranz-Loncán (2006) have made the same calculation. Table 8 shows that railways contributed more to income per capita growth in India than Britain or Spain. Interestingly all three countries realized similar growth contributions from higher TFP, but they had different TFP growth rates. The reason is that railways differed in their share of total output. Indian and Spanish railways were small, while British railways were larger. This suggests railways could have had a larger impact on the Indian economy if the sector had more than a 3 percent share in gross output. Even as late as 1913, railways had not yet penetrated much of the Indian economy.

As in the pioneering works of Fogel (1970) and Fishlow (1965), most economic historians have measured the developmental effect of railways using the social savings methodology. Our calculations are converted into a similar estimate by compounding average annual TFP growth (0.06 or 0.08 percent). The calculations imply that higher railway TFP increased national income by between 2.3 and 3 percent between 1874 and 1912. Incorporating the effects of embodied capital raises the social savings further. Railway capital increased at an average annual rate of 1.67 percent from 1874 to 1912. Multiplying the capital stock growth rate by the share of railway profits in national income implies an annual increase in income of 0.033 percent. Compounded the growth rate from capital over 38 years yields an additional gain in national income of 1.3 percent. Thus the total social savings from 1874 to 1912 is between 3.6 and 4.3 percent.

While our examination of Indian railways emphasizes TFP growth, other studies emphasize the gains from lower trade costs. Drawing on differences between rail freight rates and those for bullock carts during the mid-19^{th} century, Hurd (1983) argued that freight rates would have been 80 to 90 percent higher in the absence of railways. 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.

Hurd and Dondaldson find large social savings on the order of 9 to 10 percent of Indian GDP in 1900 or 1930. Our estimates of the social savings are smaller, but we focus on a more narrow time period from 1874 to 1912. Thus we omit the effects of the introduction of railways in the 1850s and 1860s. We also miss the TFP contribution of railways from 1913 to 1930 when Donaldson's study ends. The railway sector increased in size relative to GDP between 1913 and 1930, which would further magnify the effects of railway TFP growth.

Within the time-period 1874 to 1912 there is an interesting connection between trade costs and TFP. Figure 5 shows an index for real average freight revenue per ton mile, a close proxy to real freight charges.[19] The inverse of our single capital FE TFP index is also plotted for comparison. The two series exhibit highly similar trends. By 1912 real freight rates were 42 percent of their level in 1874. The inverse of TFP in 1912 was 47 percent of the level in 1874. This implies that a social savings calculation based on decreasing real freight charges from 1874 to 1912 would yield very similar estimates as an approach based on TFP growth.

A broader implication concerns the connection between TFP and trade costs. Greater TFP contributes to lower trade costs because it lowers railway operating costs. Without lower costs railways could not charge lower freight rates and still maintain or increase their profits. On the other hand, by lowering trade costs railways increase their traffic flow. Thus they can exploit economies of scale or better utilize their capital which raises TFP. The key point is that TFP growth and the dramatic reduction in freight rates that occurred in India and across the world between 1870 and 1913 were reinforcing processes. Without TFP growth railway freight rates would have stagnated in India, much like they did in Britain when TFP growth slowed in the early 1900s (Crafts, Leunig, and Mulatu 2008).

7 Conclusion

Using new data on individual railways, we find strong evidence of TFP growth in Indian railways from 1874 to 1912. Our best estimates suggest that TFP growth averaged between 2 and 2.6 percent per year. The performance of Indian railways is in marked contrast to the stagnant productivity growth in the overall Indian economy and other modern sectors such as cotton textiles. Indian railways compare favorably to railways in the advanced economies of this period such as Britain and the United States.

We also find that the observed TFP growth is not driven purely by an increase in capacity

[19]Dividing revenue P*Q by output Q yields an estimate of the average price. Freight rates often differ by time of purchase and commodity. Thus, there is no single market price even for the same trip. Like other series, the index is an output weighted average of the real revenue per ton mile across all railways in each year. We use the Indian consumer price index from Department of Statistics, Commercial Intelligence Department listed in Global Financial Database to deflate revenues.

utilization. After accounting for the increase in train miles run per track net TFP growth remains large. The evidence suggests Indian railways adopted several new technologies between 1900 and 1912 bringing them closer to the world technology frontier. Lastly, TFP growth and capital accumulation in railways had a large aggregate impact on the Indian economy. Railways added 0.1 percent per year to Indian income per capita, accounting for 16 percent of the total increase in GDP per capita. As a final remark, it is important to 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 2011b). Thus Indian railways acted as 'engines of growth' largely during the first era of globalization.

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Figure 1: Map of Indian Railways, 1909

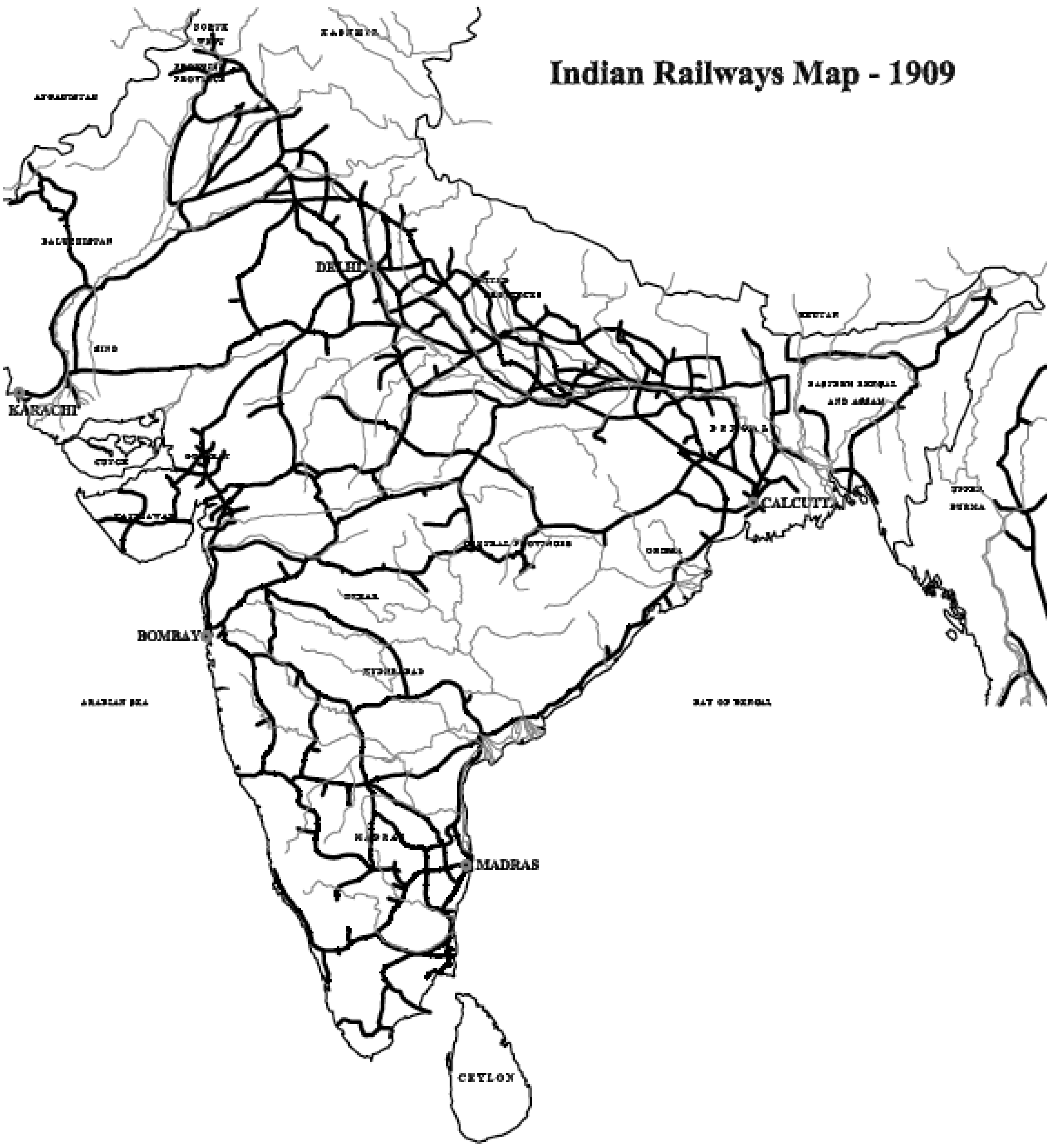

Figure 2: TFP Index (Three Capital Inputs, 1874=100)

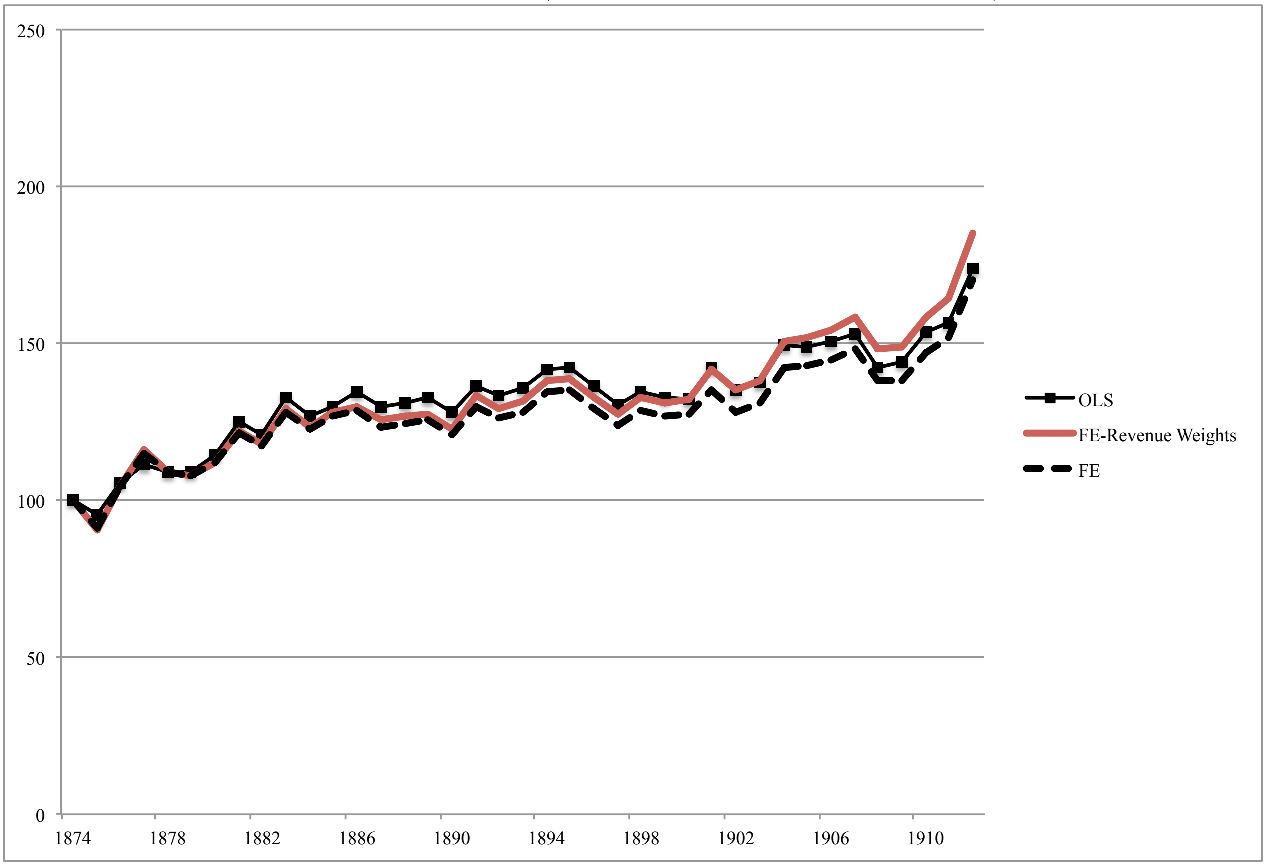

Figure 3: TFP Index (Single Capital, 1874=100)

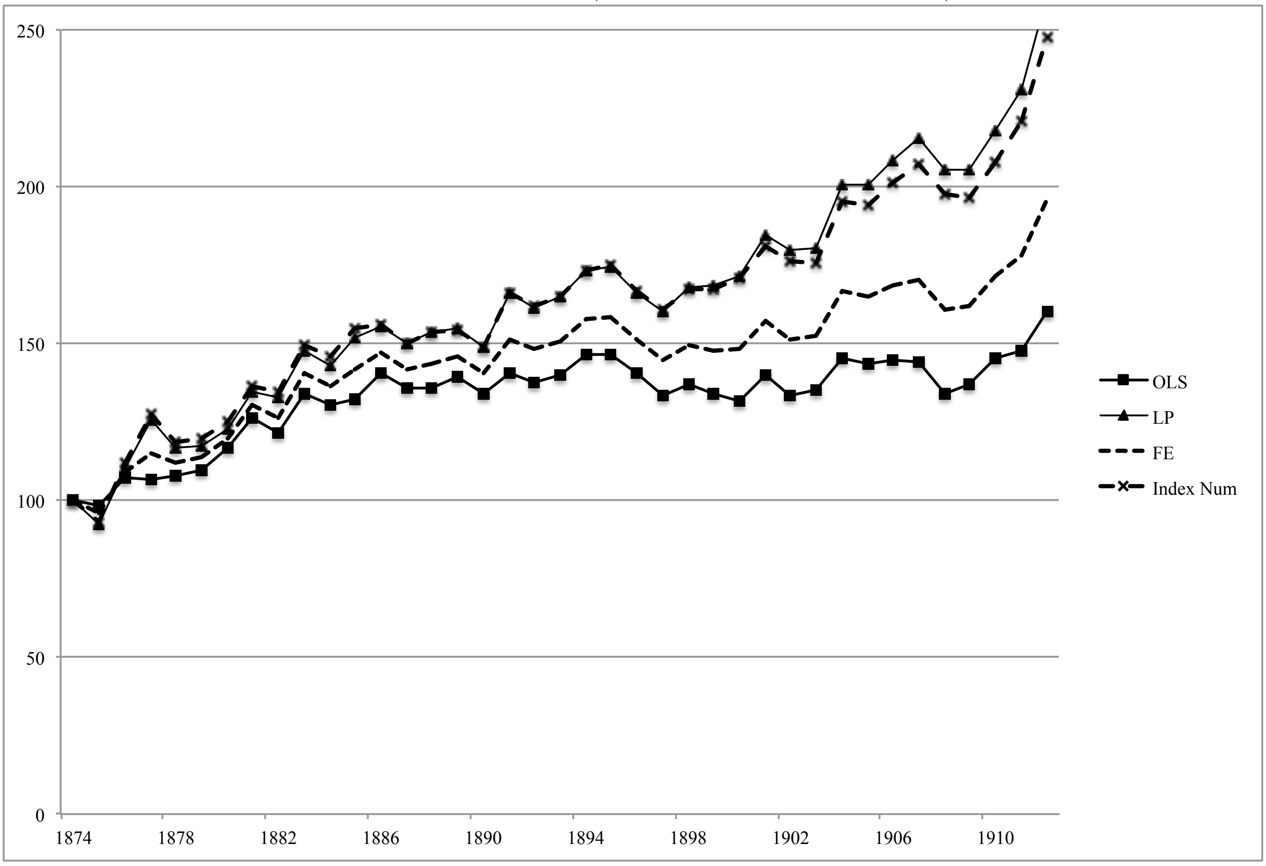

Figure 4: Capacity Utilization - Train Miles Run per Track Mile

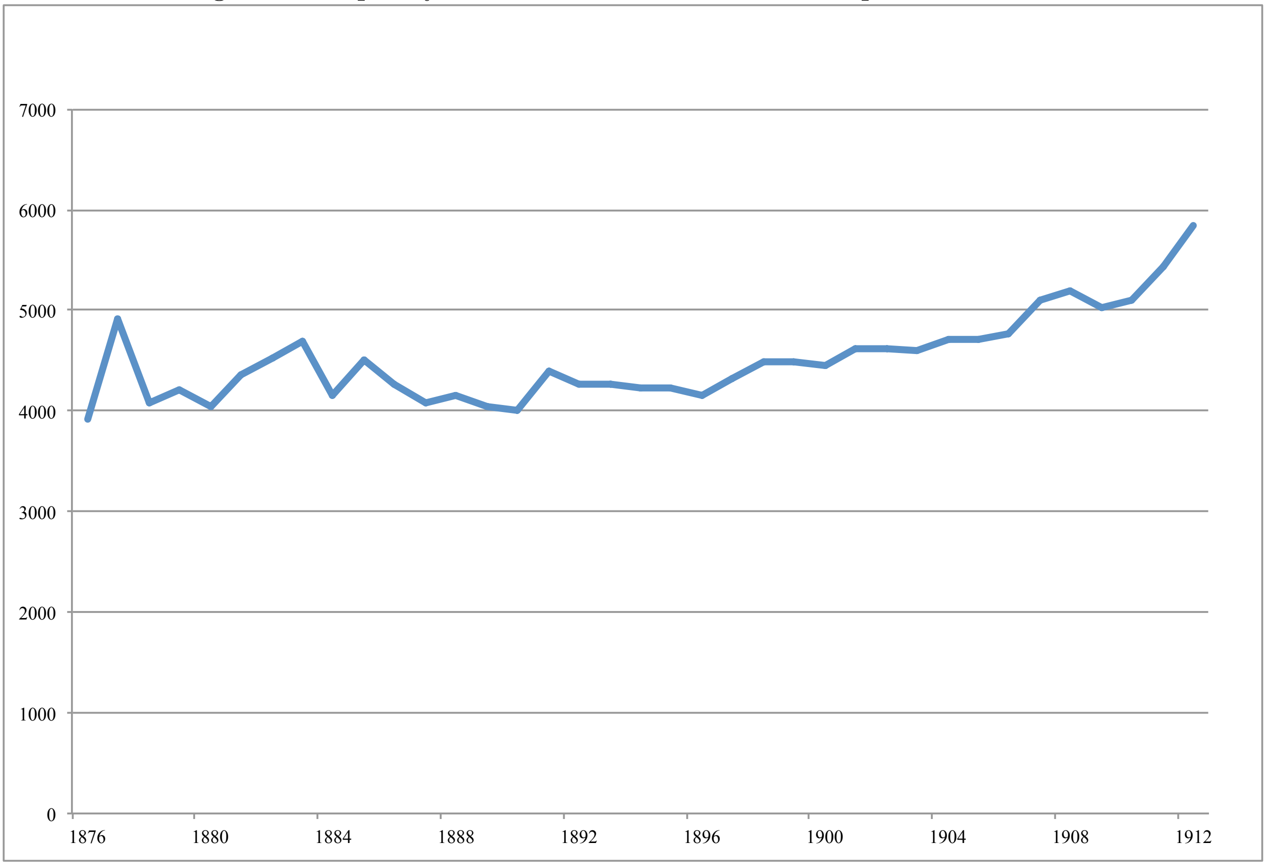

Figure 5: TFP and Freight Rates

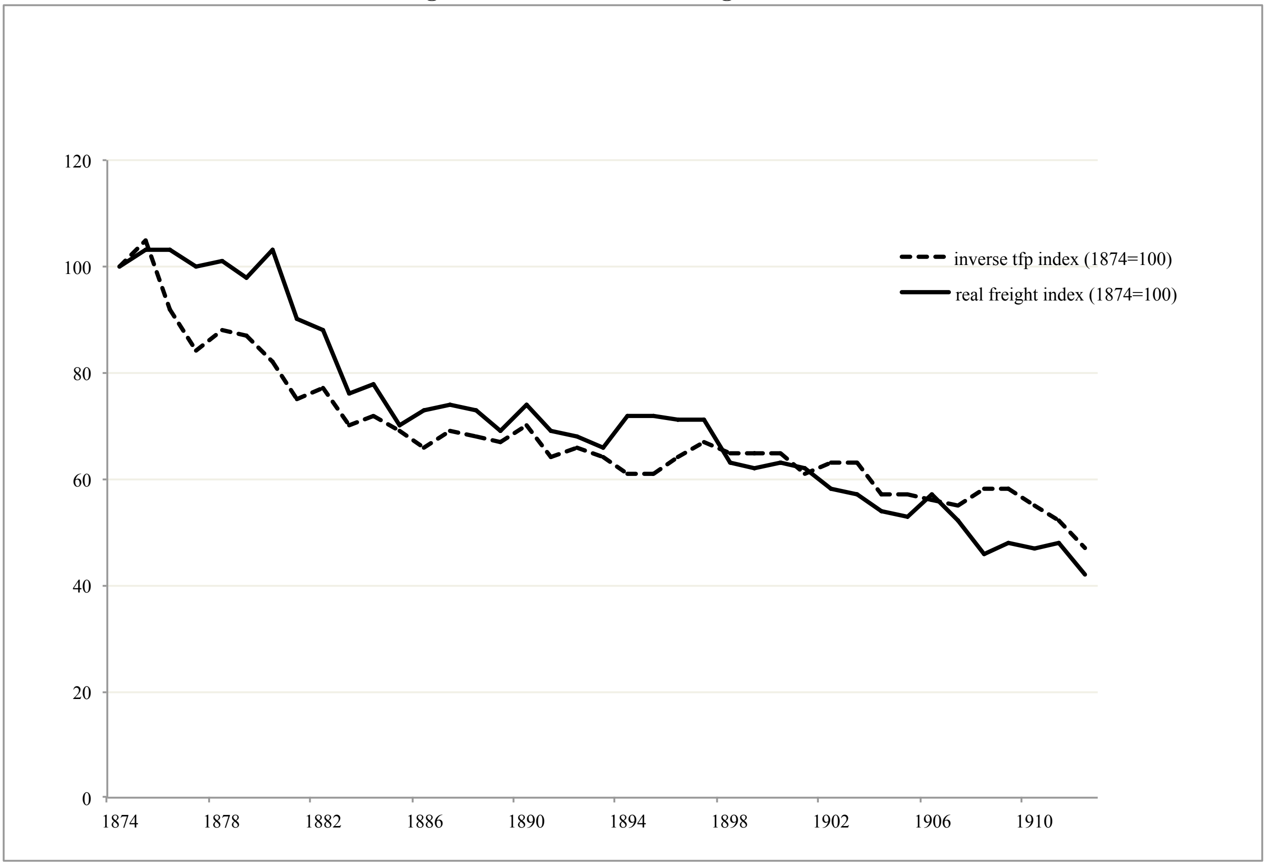

Table 1: Railways in Sample

Railway name	Gauge	Enry	Exit
Great Indian Peninsula	standard	pre-74	n.a.
East Indian	standard	pre-74	n.a.
Madras	standard	pre-74	n.a.
Bombay, Baroda and Central India	standard	pre-74	n.a.
Northwestern (Sind, Punjab and Delhi pre-1885)	standard	pre-74	n.a.
South Indian	meter	pre-74	n.a.
Eastern Bengal	mixed	pre-74	n.a.
Oudh and Rohilkhand	standard	pre-74	n.a.
Rajputana Malwa	meter	pre-74	n.a.
Nizam	mixed	1878	n.a.
Bengal and Northwestern	meter	1884	n.a.
Burma	meter	1878	n.a.
Bengal Nagpur	broad	1880	n.a.
Mysore and Southern Mahratta	meter	1882	1908
Assam Bengal	meter	1896	n.a.
Bhavnagar-Gondal-Junagad-Porbandar	meter	1882	n.a.
East Coast	standard	1894	1901
Udaipur Chittoor	meter	1900	n.a.
Rohilkhand and Kumaon	meter	1885	n.a.
Jodhpore-Bikaneer	meter	1886	n.a.
Dhond-Manmad	meter	1879	1881
Wardha Coal	standard	1879	1891
Indian Midland	standard	1888	1901
Punjab Northern	standard	1875	1886
Indus Valley	standard	1879	1886
Calcutta and Southeastern	standard	pre-1874	1884
Dacca	meter	1885	1887
Bengal Central	standard	1897	1905
Muttra Hathras	meter	1879	1886
Holkar and Sindia-Neemuch	meter	1875	1881
Tirhoot	meter	1876	1889
Northern Bengal	meter	1878	1887

See text for details

Table 2: Summary Statistics

Variable	Obs	Mean	Std. Dev	Min	Max
Ton miles (millions)	732	296	532	0	5,467
Passenger miles (millions)	732	330	388	2	2,214
Output (cost weights)	732	319	478	2	4,463
Labor	732	15,867	18,104	135	96,542
Fuel (Kurharbaree coal, thousands)	732	80	116	0	755
Miles	732	959	828	28	4,737
Engines	732	210	234	2	1,151
Vehicles	732	4,717	4,751	61	26,845
Capital (in millions rupees)	732	147	172	1	1,029

	Annual Growth Rate (in %)				
	1874-1912	1874-79	1880-89	1890-99	1900-12
Output/Labor	**2.04%**	1.4%	2.0%	1.0%	3.1%
Output/Fuel	**0.91%**	3.0%	2.1%	-1.2%	0.9%
Output/Capital (in rupees)	**3.02%**	4.6%	2.2%	2.0%	3.8%
Output/Miles	**2.44%**	3.7%	0.1%	1.3%	4.7%
Output/Engines	**2.51%**	2.6%	1.0%	2.4%	3.7%
Output/Vehicles	**1.70%**	0.9%	0.5%	1.9%	2.8%

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

Table 3: Coefficient Estimates

	Three Capital Inputs			Single Capital		
	OLS	FE	FE (rev wgts.)	OLS	FE	LP
(in logs)						
Miles	0.1386	0.2577**	0.2334**			
	[0.0960]	[0.1086]	[0.1035]			
Vehicles	0.0142	0.3157**	0.2887**			
	[0.1358]	[0.1273]	[0.1299]			
Engines	0.2335*	-0.0288	0.0081			
	[0.1288]	[0.0919]	[0.1050]			
Labor	0.1790*	0.1969**	0.1876**	0.3199***	0.2611***	0.2493***
	[0.1054]	[0.0957]	[0.0897]	[0.112]	[0.087]	[0.0958]
Fuel	0.5196***	0.3204***	0.2993***	0.5804***	0.3394***	0.1800
	[0.1077]	[0.0803]	[0.0900]	[0.119]	[0.095]	[0.2158]
Capital (rupees)				0.1267	0.3873***	0.4800**
				[0.099]	[0.125]	[0.2344]
Year FE	Yes	Yes	Yes	Yes	Yes	No
Railways FE	No	Yes	Yes	No	Yes	No
Obs.	732	732	732	732	732	732
Adj R2	0.97	0.99	0.99	0.97	0.99	
Scale Economies	1.085	1.062	1.062	1.027	0.988	0.909
F-stat	4.09	0.80	0.06	0.85	0.04	1.14 (chi2)
P-value	0.052	0.378	0.808	0.363	0.849	0.285

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

Robust standard errors clustered at the railway level in regressions 1 to 5.

Bootstrapped standard errors in regression 6 - LP.

Table 4: Correlation Coefficients Across TFP Models

	Three Capital Inputs			Single Capital			
	OLS	FE	FE (R)	OLS	FE	LP	IN
OLS	1						
FE	0.80	1					
FE (Rev W.)	0.77	0.97	1				
Single Capital OLS	0.94	0.70	0.68	1			
Single Capital FE	0.73	0.79	0.77	0.81	1		
LP	0.55	0.80	0.79	0.61	0.94	1	
IN (Indian W.)	0.61	0.71	0.71	0.68	0.98	0.94	1

Table 5: Estimates of TFP Growth Rates

	Annual Growth Rate (in %)				
	1874-1912	1874-79	1880-89	1890-99	1900-12
Three Capital Inputs					
OLS	**1.17**	1.91	1.74	-0.21	1.53
FE	**1.41**	1.55	1.51	0.09	2.3
FE, revenue weighted output	**1.66**	1.48	1.63	0.42	2.71
Single Capital (in rupees)					
OLS	**1.24**	1.85	2.42	-0.39	1.39
FE	**1.99**	2.89	2.59	0.34	2.47
Levinsohn and Petrin	**2.55**	3.21	2.81	0.85	3.42
Index Number, Indian weights	**2.41**	3.64	2.59	0.80	3.06
Index Number, UK weights	**2.68**	4.03	2.60	1.08	3.47
Index Number, US weights	**2.46**	3.58	2.57	0.86	3.19

Table 6: Railway TFP Growth Across Countries

Country	Years	Estimation Method	TFP Growth
India	1874-1912	Prod Fn. (FE, single K)	2.0
India	1874-1912	Index Number	2.4
US	1870-1910	Index Number	2.1
Britain	1874-1912	Index Number	0.8
Canada	1875-1910	Index Number	5.5
Spain	1870-1913	Cost Function	1.5

Sources: US - Fishlow (1966), Britain - Crafts, Mills and Mulatu (2007), Canada - Green (1986), Spain - Herranz-Loncán (2006).

Table 7: Capacity Utilization or TFP?

	OLS	FE	FE (revenue weighted)	Single Capital OLS	Single Capital FE
(in logs)					
Train Miles Run/ Track Mile	0.8750***	0.6819***	0.6397***	0.2709**	0.5245***
	[0.079]	[0.075]	[0.079]	[0.117]	[0.071]
Obs	710	710	710	710	710
Year FE	Yes	Yes	Yes	Yes	Yes
Railways FE	No	Yes	Yes	No	Yes
Net TFP Growth Rate	0.98	1.19	1.47	1.14	1.73
TFP Growth Rate (Table 5)	1.17	1.41	1.66	1.24	1.99

Robust standard errors clustered at the railway system in brackets.
*** p<0.01, ** p<0.05, * p<0.1
All the regressions include capital, labor and fuel as in table 3.

Table 8: Contribution of Indian Railways to Annual GDP per-capita Growth

	India 1874-1912	India 1874-1912	Britain 1870-1910	Spain 1891-1913
Railway Capital Stock Growth / Worker	1.46	1.46	0.4	-0.11
Railway Profits Share in National Income	0.015	0.015	0.027	0.014
Railway Capital Contribution	0.02	0.02	0.01	-0.001
Railway TFP Growth	1.99	2.55	1	2.28
Railway Share in National Output	0.03	0.03	0.06	0.025
Railway TFP Contribution	0.06	0.08	0.06	0.06
Total Railway Contribution w/o Spillovers	0.08	0.1	0.07	0.06
(as % of GDP per capita growth)	13.33	16.67	8.5	6.1
TFP Estimation method	FE	LP	IN	Cost Func.

Sources: For Britain see Crafts (2004), p. 346. For Spain see Herranz-Loncán (2006), p. 858.