Making the Trains Run on Time:
A Cross-Country Analysis of Cost Inefficiency in the Railroad Sector, 1883-1912

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Abstract

The railroad sector at the turn of the twentieth century is often perceived as being inefficient. This paper presents the first cross-country estimates of cost inefficiency using a new data set on aggregate railroad costs, outputs, and input prices from 1883 to 1912. Estimates from a stochastic cost frontier model show that average inefficiency across countries was relatively high from the 1880s to the 1900s. The level of inefficiency changed quite differently across countries. Those who became more efficient tended to have higher labor productivity and those who became less efficient tended to have lower labor productivity. The results have implications for productivity growth and the effects of various ownership and regulatory policies.

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1. **Introduction**

Railroads were a leading sector in most economies at the turn of the twentieth century. Productivity growth was high and average fares or freight charges were generally decreasing. That said the industry is believed to have been fairly inefficient during this period. The costs of operating railroads lines are thought to have been excessive. Inefficient lines were able to survive because they were often shielded from competition. High barriers to entry emanating from the technology of building tracks and operating locomotives made competition difficult, but government policies are also believed to have played a role by limiting the construction of parallel lines and the leasing of track by rival companies.

Efficiency is central to many of the issues concerning railroads in this period. Cost inefficiency implies that a railroad can lower its costs without reducing output or services. If railroads were very inefficient at the turn of the twentieth century then this would imply a managerial failure, a policy failure, or both. Greater efficiency could also provide a source of productivity growth, complementing technological change and greater economies of scale. On the other hand, lower efficiency could act as a drag on productivity and may have offset the gains from technological change and greater scale. Efficiency differences across countries are of further interest because they indicate whether some economies succeeded in spite of the poor performance of their railroads or in part because they had a very efficient railroad sector. Countries also differed in their ownership and regulatory policies, which may have been linked with efficiency.

This paper takes a global view on the measurement of cost inefficiency. It uses a new cross-country data set on railroad costs, outputs, and input prices from 1883 to 1912.

The data span 18 countries or colonies including the Netherlands, Canada, Russia, Switzerland, Sweden, the U.K., Austria-Hungary, Japan, Argentina, Australia, India, the U.S., Belgium, Italy, Germany, Spain, France, and Norway. Cost inefficiency is measured using stochastic frontier models. The main specification uses the 'true fixed effects' model which helps to separate inefficiency from unobserved heterogeneity. The results indicate there was a fairly high level of inefficiency in the world's railroad sector. Average inefficiency was relatively constant from the 1880s to the 1900s but it changed differently across countries over time. For example, Germany, France, and Norway were among the least efficient in the 1880s, but they were the most efficient in the 1900s. Overall countries which had lower inefficiency in the 1900s tended to be those with higher labor productivity throughout the economy.

What explains the changes in costs or inefficiency within and across countries? One contributing factor was the degree of private or state ownership. The trend over this period was towards greater ownership by state authorities. States constructed an increasing number of new railroads and they nationalized an increasing number of privately-owned railroads. The analysis shows that greater state ownership increased costs directly but did not influence efficiency. This suggests that state ownership might have inhibited the adoption of technologies which lowered costs but it did not influence the efficiency by which inputs were combined.

The analysis also considers the effects of well-known regulatory policies. It focuses on inefficiency in the U.S. following the creation of the Inter-State Commerce Commission (ICC). The results suggest that inefficiency increased significantly following the passage of the Inter-State Commerce Act in 1887. This result points to failure of the ICC to promote greater efficiency

This paper is not the first to estimate railroad cost efficiency. Crafts, Mills, and Mulatu (2007) and Crafts, Leunig, and Mulatu (2008) have used the true fixed effects model to estimate cost inefficiency for British railways between 1893 and 1912. Farsi *et. al*. (2005) have used the same methodology to estimate cost inefficiency for Swiss Railroads in the 1980s and 1990s. This study extends the same framework to aggregate data across countries.[2] Analyzing railroad costs at an economy-wide level is conceptually similar to analyzing costs at the level of individual railroad lines. It does require, however, more careful attention to the issue of unobserved heterogeneity because countries differ in so many ways. Several studies have applied stochastic frontier models to economy-wide outcomes, like the performance of educational and health care systems. Greene (2004) was one of the first to estimate technical efficiency in national health care systems using the true random effects model. His approach was to model health care outputs, like life expectancy, using an aggregate production function with inputs like health care spending and average education levels. This paper follows the same approach and assumes there is an aggregate cost function for railroads which depends on ton-miles, passenger miles, wages, and fuel prices.

The paper is organized as follows. Section 2 reviews the methodology of stochastic frontier models. Section 3 discusses the data. Section 4 discuses specification and aggregation issues. Section 5 presents the baseline results. Section 6 considers

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[2] James Foreman-Peck (1987) has estimated inefficiency in the construction of railroads across countries. This paper differs because it studies operational costs.

robustness checks. Section 7 discusses the implications of the estimates. Section 8 concludes.

2. Methodology

Cost inefficiency occurs when firms do not minimize costs with respect to a given output level and input price vector. The input choice of a cost inefficient firm is illustrated in figure 1. The curve *l(q)* defines the set of inputs x and y which yield an output *q*. The firm's costs are *c=wa*, where *a* is the vector of chosen inputs and *w* is the input price vector facing the firm. The firm is inefficient because it could lower its costs to *c'=wb* by choosing the input vector *b*. The degree of inefficiency is equal to the length of the vector *u*, which defines the difference between *c* and *c'*.

There are several methods for estimating cost inefficiency using panel data. One of the most commonly-used is the 'true fixed effects' or the 'true random effects' model. The baseline true fixed effects cost frontier model with multiple outputs is usually specified as a Cobb-Douglass cost function taking the following form:

$$\ln c_{it} = \sum_{k=1}^{K} \beta^k \ln q_{ii}^k + \sum_{j=1}^{J} \gamma^j \ln p_{ii}^j + \alpha_i + u_{it} + v_{it} \qquad (1)$$

where $\ln c_{it}$ is the natural log of costs for unit *i* in year *t*, $\ln q_{it}^k$ is the log of output *k* for unit *i* in year *t*, $\ln p_{it}^j$ is the log of the price of input *j* for unit *i* in year *t*, α_i is a fixed effect for unit *i*, u_{it} is a half-normal random variable with mean 0 and variance σ_u^2, and v_{it} is a normal random variable with mean 0 and variance σ_v^2. The term u_{it} measures the cost inefficiency of unit *i* in year *t* and the second term v_{it} is the error term. Cost inefficiency is estimated for each unit and year using the composite term error term

$\varepsilon_{it} = u_{it} + v_{it}$ and the parameter estimates for σ_u^2 and σ_v^2. The conditional mean for cost inefficiency of unit *i* and year *t* is calculated using the following formula from Jondrow et. al. (1982):

$$E[u_{it} \mid \varepsilon_{it}] = \frac{\sigma\lambda}{1+\lambda^2}\left[\frac{\phi(z)}{1-\Phi(z)} - z\right] \qquad (3)$$

where ϕ is the p.d.f of the standard normal, Φ is the c.d.f. of the standard normal, $\sigma = \sqrt{\sigma_u^2 + \sigma_v^2}$, $\lambda = \frac{\sigma_u}{\sigma_v}$, $z = \frac{\varepsilon_{it}\lambda}{\sigma}$, and $\varepsilon_{it} = u_{it} + v_{it}$.

Estimation of the true-fixed model requires maximum likelihood. The software program LIMDEP allows for relatively easy estimation of these models. The output provides estimates of cost function parameters, their standard errors, and the parameter estimates for σ_u^2 and σ_v^2. The program also combines the estimates of σ_u^2 and σ_v^2 with the composite error term ε_{it} to estimate the conditional mean of inefficiency in each unit and in each year.

The true fixed effects model is an extension of the fixed effects model and the pooled normal half-normal stochastic frontier model. The fixed effects effect model does not include a half-normal random variable u_{it} and instead it defines inefficiency using the estimated fixed effects from the cost function. The pooled normal half normal includes a half-normal random variable u_{it} but it drops the unit fixed effect. The true fixed effects model has two advantages over these two models. First, unlike the fixed effects model, it allows cost inefficiency to be time-varying. This is an important property in this context because there is no reason to believe that the efficiency of railroads remained constant over a thirty-year period. Second, unlike the pooled normal half-normal model, the true fixed effects model includes a unit fixed effect which captures all time-invariant unobservable factors. Ideally the effects of unobserved factors should be separated from inefficiency because some units will operate at higher or lower costs because of factors beyond their control, like topography. Greene (2005) argues that cost inefficiency is generally over-estimated in the fixed effects model and the pooled normal half-normal models because they conflate unobserved heterogeneity with inefficiency. The true fixed effects model can address this problem as long as there is sufficient within-unit variation.

3. Data

Aggregate railroad statistics are available in a number of sources. The main three are *The Statistical Abstract for the Principal and Other Foreign Countries*, *The Statistical Abstract for the Several Colonial and other Possessions of the United Kingdom*, and *the Statistical Abstract for the United Kingdom*, all of which were published by the British Board of Trade in various years starting in the 1870s. They provide data on the length of the network, expenses, revenues, passenger miles, ton miles, train miles, injuries, deaths, and various other characteristics for more than 50 countries or colonies between 1840 and 1912. Moreover, the financial data are always reported in the home currency and in British pounds based on an average exchange rate.

The data in the *Statistical Abstracts* is drawn from publications of annual railway statistics in each country. These volumes marked one of the first attempts to compile and present comparable cross-national data. The information is clearly presented and is easily entered into spreadsheets for statistical analysis. That being said, there are a number of complications which arise in using the data. First, in some cases the *Statistical Abstracts* report total expenses or working expenses, but not both. Working expenses include spending on the operation of railroads, such as labor and fuel, along with maintenance to the track, plant, and equipment. Total expenses are working expenses plus purchases of new capital goods like locomotives. Construction spending on the track and stations is usually provided separately and is never included in either total or working expenses.

Table 1 shows the countries that report both working and total expenses as well as the ratio of working to total expenses in each case. The average ratio of working to total expenses was 0.941 but in most cases working expenses were around 95 or 96% of total expenses. The one outlier is Austria-Hungary where its working expenses average 83% of total expenses. Based on this information it appears that spending on the operation of railroads and maintenance to the track, plant, and equipment represent the vast majority of total expenses.

The focus of this paper will be on working expenses rather than total expenses because most of the debate concerns the operation of railroads, especially the management of labor, coal supplies, and maintenance of the fixed and rolling stock. It is necessary to estimate working expenses for all countries where only total expenses are reported (the raw data can be used for countries where working expenses are reported). One possibility is to multiply total expenses by the average ratio of working to total expenses in table 1. This approach might lead to a biased estimate of working expenses if the ratio of working to total expenses varied systematically with the growth of the network. Higher mileage growth could lead to more spending on new capital goods like locomotives and hence a lower ratio of working to total expenses. A regression of the ratio of working to total expenses in country *i* and year *t* on a fixed effect for country *i* and the growth of railroad miles in country *i* and year *t* shows there is a negative and significant relationship between the ratio of working to total expenses and the growth of railroad miles. The coefficient on mileage growth was relatively similar when country fixed effects are dropped, but it was not statistically significant. This suggests there are unobserved factors across countries that influence the ratio of working to total expenses and that network growth affects the ratio of working to total expenses once these unobserved factors are accounted for. Building on these findings, total expenses were multiplied by the predicted ratio of working to total expenses using the regression without fixed effects.[3] The unobserved country-specific factors will be accounted for with country fixed effects in the stochastic cost function analysis presented later.

Passenger miles and ton miles are the output variables. The *Statistical Abstracts* often report the number of passengers transported, the number of tons of freight transported, the average passenger trip in miles, and the average haul for goods in miles. For most of the countries, passenger miles are calculated by multiplying the number of passengers transported by the average trip in miles. Similarly ton miles are calculated by multiplying tons shipped by the average haul in miles. Unfortunately the average haul or the average trip was not reported in some countries. In these cases a series of steps were performed. First, the *International Historical Statistics* volumes were consulted to check for published series on passenger miles and ton miles (see Mitchell 1988, 1992, 1995, 2003). Second, if necessary the data on average haul and average trip was interpolated

[3] In other words the ratio of working to total expenses in year t equals 0.9444897 - 0.0763076*Mileage Growth in year t.

for missing years and then multiplied by the number of passengers or tons. The average haul and average trip length was strikingly stable in most countries at the turn of the twentieth century. For example, the coefficient of variation for the average trip length in Germany between 1901 and 1912 is 0.01. The coefficient of variation for the average haul is 0.008. The stability of the average trip length and average haul length implies that little error is introduced by interpolating to missing years. The third and final step was to consult the secondary literature for additional estimates of output when the Statistical Abstracts provide no information on average haul or average trip length. In one important case, Crafts, Mills, and Mulatu (2007) provide estimates of ton miles and passenger miles for British railways. These were combined with estimates of passengers and tons shipped on British railways to produce an estimate of the average haul and average trip. These were then applied to Irish railways to get an estimate of UK ton miles and passenger miles.

The production of ton miles and passenger miles requires inputs like labor, fuel, and capital. Per-unit labor, fuel, and capital costs were not reported in the Statistical Abstracts and so it is necessary to use secondary sources for each. Railroads hired workers from all regions of the country and would have paid something similar to the average wage in the country. Williamson (1995) provides estimates of real wages for Norway, Sweden, the Netherlands, Belgium, Spain, Italy, the United States, Argentina, Great Britain, Germany, Australia, and Canada. They are reported in an index form with the real wage in Great Britain in 1905 serving as the base.

For the rest of the countries in the sample individual sources were consulted. Gregory (1992) provides a wage index for Russian railroad workers and a retail price index from 1885 to 1912. Allen (2001) provides real wages for building laborers in Paris up to 1911. Studer (2008) provides real wages for Switzerland from the mid-1800s to 1913. Mesch (1984) provides real wages for Austria starting in 1891. Nominal wages for India are available in the *Statistical Abstracts for British India* starting in 1884. The real wage was estimated by dividing the nominal wage series by the Indian consumer price index published in Global Financial Data.[4] Finally nominal wages for agricultural workers in Japan from 1885 to 1913 were provided by David Jacks, Peter Lindert, and Salvadore Puente through the Global Price and Income History Group.[5] Like India, real wages in Japan were estimated by dividing the nominal wages by the Japanese consumer price index published in Global Financial Data.

To ensure compatibility with Williamson's data, the real wage series for Russia, Austria, Japan, and India were all converted into 1905 British pounds using exchange rates and then divided by the real wage for agricultural workers in Britain in 1905.[6] Allen's (2001) Paris real wage series was divided by Allen's estimate of the real wage in London in 1905 to obtain a real wage index for France relative to Great Britain in 1905. Studer provides the ratio between Swiss and British wages in 1905, which is used to construct the real wage for Switzerland relative to Britain in 1905.

Coal was the main source of fuel for railroads. Coal prices are available for many countries in the *Returns Relating to the Production and Consumption of Coal* published by the British Board of trade. The reports list the price of coal in shillings per metric ton for the U.K., Russia, Sweden, Germany, Belgium, France, Spain, Austria, Hungary,

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[4] See https://www.globalfinancialdata.com
[5] See http://gpih.ucdavis.edu/.
[6] Wages for agricultural workers in Britain come from Mitchell (1988). The British consumer price index comes from Global Financial data.

Japan, the U.S., India, Canada, Australia, and New Zealand.[7] Coal Prices for other countries were obtained from different sources. Dutch coal prices are provided by Arthur van Riel through the Global Price and Income History Group. Norwegian coal prices were provided by Ola Grytten. Swiss coal prices are published in Siegenthaler (1996). Italian coal prices are published in Cianci (1933). Finally, coal prices for Argentine railroads are published in the annual bulletin, *Estadistica de Los Ferrocarriles en Explotacion*.

Capital-goods are the remaining input that needs to be considered. Here the data sources are more limited. Collins and Williamson (2001) provide comparable data on capital prices in Australia, Canada, Germany, Italy, Japan, Norway, Sweden, the U.K., and the U.S., but to my knowledge there is no similar data for the other countries in the sample. The lack of coverage on capital prices is less problematic than it might first appear. Construction costs and spending on new locomotives are already excluded from working expenses and so the prices of these capital goods do not need to be considered. Nevertheless it is necessary to examine the estimates of inefficiency when capital prices are included in the model. In the analysis below, efficiency will be estimated for countries where capital prices are available and then these results will be compared with the baseline estimates of inefficiency when capital prices are excluded. As we shall see later, the estimates of inefficiency are largely unaffected.

4. Specification and Aggregation Issues

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[7] In most countries, coal prices are the pit's mouth (i.e. wholesale) but in a few cases they are reported as market prices.

There are a three specification and aggregation issues that need to be discussed before analyzing the results. First, the data set on railroad expenses and outputs spans 30 years for some countries. As a result there are likely to be time-varying unobservable factors which influence costs besides output, input prices, and inefficiency. The main type of time-varying unobservable factor would be technological change. Year fixed-effects provide one way of controlling for technological changes and other factors that are common to all countries. However year fixed effects absorb precious degrees of freedom because there are few cross-sectional units relative to time-units. Instead the models below include the year and the square of the year. The quadratic time trend allows the cost frontier to evolve in flexible manner without sacrificing too many degrees of freedom.

Second, theory requires that cost functions must be homogenous of degree one in prices. In the Cobb-Douglass specification this implies that the coefficients on the price variables sum to one. Imposing this restriction implies that the Cobb-Douglass stochastic cost function for railroads can be transformed to the following:

$$\ln\left(\frac{c_{it}}{p_{it}^{labor}}\right) = \alpha_i + \beta^{tm} \ln tonmi_{it} + \beta^{pm} \ln passmi_{it} + \gamma^{coal} \ln\left(\frac{p_{it}^{coal}}{p_{it}^{labor}}\right) + u_{it} + v_{it} \qquad (3)$$

The left hand side variable is now the log of real working expenses divided by real wages and on the right-hand side there is a country fixed effect α_i, variables for the log of ton miles and passenger miles, a variable for the log of real coal prices divided by real wages, a variable for inefficiency u_{it}, and lastly the error term v_{it}. Once the parameters are estimated the coefficient γ^{labor} can be recovered by subtracting γ^{coal} from one.

Third, in this paper, the stochastic cost function is estimated at the country-industry level rather than the firm-level.[8] In order for aggregation to make sense there needs to be a common aggregate production function for railroad services in each country. Differences in total costs would then reflect differences in output levels, input prices, and the efficiency of the representative railroad.[9] The assumption of a common production function is not unreasonable in this setting. Steam-driven locomotives were dominant in the industry before World War I. Moreover most countries imported locomotives and iron or steel rails from a small number of countries like Britain, Germany, France, or the United States. The main technological differences were the gauges of railroad track. Some countries primarily used the standard gauge width of 4 ft. 8.5 inches, but others operated with broader gauges exceeding 5 ft. Gauges might have affected costs, but their influence was likely to be fixed over the period from 1883 to 1912. Therefore, the effects of gauges should be captured by the inclusion of a country fixed effect.

5. Baseline Results

This section presents the estimates of cost inefficiency for railroads in several countries between 1883 and 1912. Table 2 reports summary statistics for the key variables. Working expenses and coal prices were deflated by a consumer price index in

[8] There is a large literature which analyzes stochastic frontier models at the industry country-level. See Afonso and St. Aubyn (2005) or Greene (2004) for two examples.

[9] The interpretation of scale economies is somewhat different in the aggregate country-level analysis as opposed to the firm-level. If the estimates show that a 1% increase in ton miles or passenger miles results in a less than 1% increase in costs, then this would be evidence for industry-level economies of scale. Such cases are usually indicative of externalities. As railroad firms increase their output then by some channel, like technological change or regulatory influence, they reduce the costs of other railroads as well.

each country with base 1905 and then converted into 1905 British pounds.[10] They are reported as the log of real working expenses and the log of real coal prices. The log of real wages is the natural log of the real wages indices from Williamson (1995) and those assembled for other countries. The bottom panel of table 2 reports the standard deviation between countries using the means of each country. It also reports the average of the standard deviation within countries. Most of the variation in real working expenses, output, wages, and coal prices is between countries, but as the figures show there is also significant variation within countries. For most variables at least 20% of the variation is due to within-country variation. This implies that there is likely to be enough variation to separate efficiency from unobserved heterogeneity using country fixed effects.

Table 3 reports the parameter estimates for the stochastic cost function. In brief, the parameter estimates imply there were economies of scale at the industry-level and that labor inputs had a larger impact on working expenses than fuel inputs.[11] The year and year squared variables also imply that all else equal working expense increased slightly from 1883 to 1912.

The main findings are the cross-country estimates of inefficiency which are calculated using the formula for the conditional mean of the inefficiency term in equation (3). The top panel of table 4 reports the average inefficiency by country in three separate periods 1883-1892, 1893-1902, and 1903-1912 using the estimates from the true fixed effects model. Countries are ordered from the most efficient to the least efficient in 1903 to 1912. In the early period some countries are dropped because data is not available.

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[10] The consumer prices indices for each country are provided in Global Financial Data. Canadian consumer prices are from Minns and MacKinnon (2006).

[11] In the true fixed effects model economies of scale are estimated to be 1.85. In the same model, a 1% increase in wages raised working expenses by 0.62% while a 1% increase in coal prices raised working expenses by 0.38%.

The results indicate there was a relatively high level of inefficiency in the world's railroad sector. The estimates imply that working expenses could have been reduced by as much as 7.5% if the average country eliminated all its inefficiency in the 1880s. A similar conclusion holds for the 1890s and 1900s. If these figures are compared to modern studies they imply that average inefficiency was about the same in the railroad sector in the early twentieth century compared to the late twentieth century.[12]

The second main conclusion is that the level of inefficiency and the rankings across countries differed substantially over the thirty years from 1883 to 1912. India had the most efficient railroad sector from 1883 to 1892. Its average cost inefficiency in this 10-year period was only 0.042, which is below the average of 0.075. The rest of the top five in terms of efficiency were the Netherlands (0.05), Switzerland (0.052), Russia (0.054), and Austria-Hungary (0.062). The U.K., Canada, Belgium, the U.S., and Germany were in a middle group. Their cost inefficiency ranged from 0.067 to 0.091. The most inefficient countries in the 1883 to 1892 period were Spain, France, Germany, and Norway. All four had cost inefficiencies ranging from 0.099 to 0.114.

The rankings change quite significantly in the period from 1893 to 1902. Canada went from the middle to being the most efficient. From 1893 to 1912 cost inefficiency in Canada went down from 0.07 to 0.057. Norway, Sweden, and Russia formed the rest of the top four with cost inefficiencies ranging from 0.065 to 0.066. The decrease in Norway's inefficiency was particularly large going from 0.114 to 0.065. A large number of countries are in the middle group with cost inefficiencies ranging from 0.07 to 0.08. Among the most notable were France and Germany whose inefficiencies declined

[12] Farsi et. al. (2005) estimate the mean cost inefficiency for Swiss Railroads in the 1980s and 1990s to be 0.063 using a similar model as the one used here.

significantly in these years. The Netherlands and India were the least efficient in the years from 1893 to 1902. Both fell from the ranks of the most efficient because they experienced a substantial rise in inefficiency over this period.

The rankings of countries changed once again from 1903 to 1912. France, Norway, and Germany were in the top three with cost inefficiencies less than 0.06. Both Germany and France moved to the top because of a significant decline in inefficiency. Spain, the United States, Italy, and Belgium were the next four with cost inefficiencies between 0.06 and 0.07. All of them had their cost inefficiencies decrease in the 1900s compared to the 1890s. Argentina, Australia, Austria-Hungary, and the UK were in a third group with cost inefficiencies ranging from 0.071 to 0.077. The rankings of Austria-Hungary and the U.K. changed little over 1890s and 1900s because cost inefficiency was relatively stable in these countries. Japan, India, Sweden, Russia, Canada, Switzerland, and the Netherlands were the most inefficient in this period. Their cost inefficiencies ranged from 0.089 to 0.117. Most of these countries either became more inefficient or they changed little from 1903 to 1912.

The inefficiency estimates suggest a number of immediate conclusions. First, there was a tendency for the most productive economies to have greater railroad efficiency in the 1900s and the least productive economies to have lower railroad efficiency in the 1900s. For example, France, Germany, and the United States all had relatively high labor productivity by World War I and they were in the top five in terms of cost efficiency for railroads. On the other end of the spectrum, India, Russia, and Japan generally had lower labor productivity and they were in the bottom seven in terms of cost efficiency for railroads. These findings suggest that greater efficiency of railroads was related to greater economic performance in the broader economy.

The efficiency estimates for U.K. railways be compared with those made by Crafts, Mills, and Mulatu (2007) and Crafts, Leunig, and Mulatu (2008). They find that the mean cost inefficiency of British railway lines averaged 0.071 from 1893 to 1912. The estimates here show that the average cost inefficiency of UK railways was 0.077 from 1893 to 1912. The similarity between the estimates is encouraging because they are derived using different samples but with a similar technique: the true fixed effects model. Efficiency on U.K. railways can be compared with the U.S. and Germany, its main economic rivals in this period. Figure 2 shows the ratio of cost inefficiency in the U.S. relative to the U.K. and the ratio of cost inefficiency in Germany relative to the U.K. The U.S. and Germany were both less efficient than the U.K. in the 1880s, but starting in the mid-1890s cost inefficiency for U.S. and Germany railroads decreased relative to U.K. railways. By World War I railways in the U.K. were less efficient than in the U.S. and Germany. Broadberry (2006) has documented similar trends in U.K., U.S., and German labor productivity in the service sector.

6 Robustness Checks

This section further examines the robustness of the results by comparing different specifications. To begin it is useful to compare the true fixed effects model with the fixed effects model and the pooled normal half-normal models. In the fixed effects model, the half normal random variable for efficiency is dropped and cost inefficiency is measured using the country fixed effects. Define $\min\{\hat{\alpha}_i\}_{i=1}^{N}$ as the lowest estimated fixed effect among the *N* countries. Cost inefficiency for country i is defined as $\hat{\alpha}_i - \min\{\hat{\alpha}_i\}_{i=1}^{N}$. The pooled normal half normal model is identical to the true fixed effects model except it does not include the country fixed effect.

The cross-country estimates of cost inefficiency are quite different in the fixed effects model and the pooled normal half-normal models discussed earlier. Table 5 shows the summary statistics for cost inefficiency in the three models. The average inefficiency in the fixed effects model is 1.24. In the pooled normal half-normal model average inefficiency is 0.194 and in the true fixed effects model it is 0.079. The three models also yield different estimates of relative inefficiency across countries. Table 6 shows there is little correlation between the average inefficiency for countries in the true fixed effects model and inefficiency for countries in the fixed effects model. There is a positive, but insignificant, correlation between inefficiency in the true fixed effects model and the pooled normal half-normal model.

The different estimates of inefficiency across the three models are not necessarily a cause for concern. Most scholars who compare the true fixed effects model with the pooled normal half-normal or the fixed effects model find that the latter two usually yield estimates of inefficiency that are implausibly large (see Greene 2005). This appears to be the case here as the fixed effects model implies that the average country could reduce its costs by 245% if all inefficiencies were eliminated! The average inefficiency in the pooled normal half-normal model is more reasonable, but it is still quite large. The estimates of inefficiency from the true fixed effects model should be preferred. There is no reason to believe that the cost inefficiency of railroads was constant within countries and so the fixed effects model is too restrictive. The pooled normal half normal model is also too restrictive because it assumes there is no correlation between unobserved heterogeneity and efficiency. Such an assumption seems implausible given that countries operated in vastly different geographic and economic environments.

Some inefficiency studies add railroad density as another explanatory variable in the cost function. Density is measured by the number of miles traveled by trains divided by total route miles. It captures the frequency by which trains traveled over the same route. Density was not included in the baseline specification because the *Statistical Abstracts* did not provide information on train miles in Russia, India, or Spain. In addition train miles are not available for all years where there is data on expenses, passengers, and tons shipped. In total 127 of the 419 observations would be lost if density were included.

As it turns out, the results are largely unchanged when the log of density is added to the true fixed effects model. The top panel of table 7 reports summary statistics for the cost inefficiency estimates when the log of density is added. It also reports summary statistics for the baseline true fixed effects model discussed in the previous section. The distribution of the inefficiency estimates look very similar between the two models. The mean and the standard deviation are nearly the same. The bottom panel also shows the correlation coefficient between the cost inefficiency estimates in both models is very high, implying no practical differences in the rankings. The estimates from the model suggest density and passenger miles are capturing the same thing. When both are included the coefficients are nearly identical and are insignificant. An increase in the frequency of trains is essentially synonymous with higher passenger miles.

The stochastic cost functions estimated in the previous section only included labor and fuel prices. Capital prices were not included because there is limited data available and it is not obvious that working expenses should depend on the price of capital goods. That said, the failure to incorporate capital prices might bias the inefficiency estimates. To investigate this issue the true fixed effects model is re-estimated after dropping 227 of the 419 observations where capital prices are unavailable. The top panel of table 7 shows summary statistics for the cost inefficiency estimates when the log of real capital prices is incorporated in the model.[13] The mean and the standard deviation of inefficiency are substantially lower in the capital-price augmented model. However the correlation of the cost inefficiency estimates between the true fixed effects model with capital prices and the baseline true fixed effects model is quite high (ρ=0.85). These findings imply that the rankings of inefficiency across countries are not too sensitive to the omission of capital prices. The levels of inefficiency, on the other hand, are more sensitive to the omission of capital prices.

The baseline model imposed the assumption that the cost function was homogenous of degree one in prices. This is defensible on theoretical grounds because a doubling of input prices should double working expenses all else equal. Nevertheless it is useful to consider whether the results are sensitive when this assumption is dropped. Table 7 shows summary statistics for a true fixed effects model which does not impose the homogeneity assumption. The distribution of the inefficiency estimates is relatively similar with the mean and standard deviation being lower in the true fixed effects model that does not impose homogeneity. The correlation coefficient between the models is not

[13] The assumption that the cost function is homogenous of degree 1 is maintained. The right-hand side price variables are the log of capital prices divided by real wages and the log of real coal prices divided by real wages.

as high as before but it is still quite large. This suggests that the rankings of inefficiency across countries is relatively insensitive to the assumption that the cost function must be homogenous of degree one.

All the previous estimates are based on the Cobb-Douglass specification. The translog cost function is preferred in some applications because it is more flexible. Unfortunately it was not possible to estimate inefficiency in the translog model with country fixed effects. The estimated variance of u_{it} degenerated to zero making it impossible to separate inefficiency from the fixed effect.

Overall the additional specifications suggest that the rankings of inefficiency across countries in the baseline true fixed effects model are robust. The level of inefficiency is perhaps more sensitive, suggesting that conclusions about the degree of inefficiency differences across countries or the degree of change over time are more speculative. The final section discusses the implications of the baseline inefficiency estimates for the performance of the railroad sector within and across countries.

7. Implications

The new cross-country estimates of railroad inefficiency have implications for productivity growth and the effects of ownership and regulatory policies. This section briefly discusses these issues. Generally speaking, productivity growth is due to increases in scale, technological change, and improvements in efficiency. Kumbhaker and Lovell (2000, p. 293) provide a formula for the decomposition of annual total factor productivity growth $\dot{tfp}$.

$$\dot{tfp} = (1 - \partial \ln c / \partial \ln q)\dot{q} - \dot{c} - \dot{u} \qquad (4)$$

The first term is 1 minus the elasticity of cost with respect to output multiplied by the annual growth of output. It captures productivity growth due to greater scale. The second term measures annual technical change which is equivalent to a downward shift in the cost frontier. The third measures the annual change in efficiency. It represents a movement towards the cost frontier or a movement along the cost frontier towards the cost-minimizing bundle of inputs.

Earlier we saw that average cost inefficiency across countries was relatively constant over time. From 1883 to 1892 the average cost inefficiency was 0.075, from 1893 to 1902 it was 0.076, and from 1903 to 1912 it was 0.079. These figures imply that greater efficiency did not contribute to higher total factor productivity throughout the world's railroad sector. Instead the estimates suggest that one of the main factors was increasing scale. The data show that the average annual growth rate of ton miles and passenger miles were both 6%. The estimates imply that the elasticity of costs with respect to output (ton miles and passenger miles) is 0.54. By formula (6) greater scale contributed 2.8% to annual productivity growth.

An analysis of the average contribution of efficiency to productivity growth masks a diversity of experiences across countries and within time periods. This can be illustrated in the cases of the U.S., France, Canada, and the U.K. The top two panels of table 8 list TFP and TFP growth in 1890 1900, and 1910.[14] TFP growth was rapid in the U.S. in the 1890s but far less so in the 1900s. TFP growth was high in Canada in both the 1890s and the 1900s. France had relatively high TFP growth in the 1890s but less in the 1900s. Lastly the UK had relatively low TFP growth in both the 1890s and 1900s.

[14] For estimates of TFP growth in British railways see Crafts, Mills, and Mulatu (2007), for U.S. railroads see Fishlow (1966), for Canadian railroads see Green (1986), and for French Railroads see Caron (1983).

Indices for cost inefficiency are listed in the bottom panel of table 8 for these same countries in 1890, 1900, and 1910. Also listed is the implied contribution to annual TFP growth from the annual percentage change in efficiency. Greater inefficiency contributed to productivity growth in U.S. railroads during the 1890s, but not in the 1900s. The story appears to be similar for Canada and France in the 1890s as greater efficiency contributed to productivity growth. The situation reversed in dramatically Canada in the 1900s. when a sharp decrease in efficiency acted as a drag on productivity growth. In the U.K. greater inefficiency slowed productivity growth in the 1890s, but it appears to have contributed to higher productivity growth in the 1900s. In these four countries the net contribution of efficiency changes to productivity growth was positive. Moreover in periods where efficiency increased productivity growth tended to increase and in periods where efficiency decreased productivity growth tended to slow down. Thus efficiency clearly mattered for productivity growth even if its net contribution was small.

7.1 Efficiency and State Ownership

State ownership of railroads was increasing in many countries in the late 19th and early 20th centuries. States constructed an increasing number of railroads and in most cases operated them through the state bureaucracy. States also nationalized many privately-owned railroads by buying their shares or compensating the owners for their assets. Afterwards the state operated the nationalized railroads itself or it would lease them to private companies.[15]

The effects of state ownership on efficiency have long been a topic of interest. The degree to which state ownership increased or decreased efficiency has not yet been

[15] See Bogart (2008) for details on the patterns of private and state ownership from 1865 to 1913.

established in the literature however. One possibility is that state railroads had inflated pay rolls or they hired managers without qualifications. Following nationalizations the state might have also replaced good managers with political cronies. Both of these hypotheses would suggest that greater state ownership should increase inefficiency. State ownership could have also limited the adoption of new technologies. In this case, state ownership greater state ownership would have raised overall costs without necessarily changing efficiency.

The effects of greater state ownership can be analyzed in the stochastic frontier framework by adding a variable for the degree of state ownership. Drawing on data from Statistical Abstracts it is possible to measure the fraction of miles owned by private companies as opposed to the state in each country and year. There is also data on the fraction of miles nationalized in each country and year (see Bogart 2008). The fraction of miles owned by companies and the fraction nationalized can be included in the cost function as explanatory variables and they can be included as determinants of inefficiency. Let z_{it} be a vector containing variables for private versus state ownership. The true fixed effects cost function can be specified as follows:

$$\ln\left(\frac{c_{it}}{p_{it}^{labor}}\right) = \alpha_i + \beta^{tm} \ln tonmi_{it} + \beta^{pm} \ln passmi_{it} + \gamma^{coal} \ln\left(\frac{p_{it}^{coal}}{p_{it}^{labor}}\right) + \delta_1 z_{it} + u_{it} + v_{it} \quad (5)$$

where δ_1 is the coefficient on the ownership variables z_{it} in the cost function and u_{it} is a truncated normal random variable with mean equal to a constant plus $\delta_2 z_{it}$ and a variance equal to σ_u^2. This specification is very flexible in that it allows ownership to affect costs directly or indirectly through inefficiency.

Table 9 reports the results for the coefficients on the ownership variables only. The first specification includes only the fraction of miles owned by private companies in each country and year in the model. The results show that a higher fraction of miles owned by private companies had a direct effect on costs, but not on efficiency. The coefficient estimate for the cost function variable implies that a country which shifted from all state ownership to all private ownership would experience a 26% reduction in costs. This same country would experience no change in its efficiency however. These results suggest that private ownership influenced the adoption technologies which lowered costs, but they did not influence how inefficiently inputs were combined.

The second specification includes the fraction of miles nationalized in each country and year. Here the results imply that nationalizations had no direct effect on costs and no effect on efficiency. These results imply that aggregate costs increased when states constructed more railroads but not when states nationalized private railroads. The ambiguous effects of nationalizations can be seen by studying changes in efficiency following the major nationalizations in Japan (1906-07), Switzerland (1902-03), India (1892), and Belgium (1898). Figure 3 plots inefficiency in the four years before and after nationalizations in these four countries. There is some evidence that inefficiency increased in Switzerland and India following nationalizations. In Belgium inefficiency appears to have decreased following nationalization. In Japan there is no discernible change.

7.2 U.S. Railroad Efficiency and the Inter-state Commerce Act

There were major regulatory changes in some countries around the turn of the century. Like ownership, regulation could have had an effect on costs and efficiency. As yet there is no cross-country index for railroad regulations but it is possible to examine changes in efficiency following well-known laws. The Inter-state Commerce Act of 1887 tried to eliminate collusion and price discrimination among railroads in the U.S. by creating the Inter-State Commerce Commission (ICC). Further legislation like the Elkins Act of 1903 is sometimes believed to have weakened the limits on collusion by protecting railroad companies from demands for rebates by large shippers.

Figure 4 plots cost inefficiency for U.S. railroads from 1883 to 1912. Following the passage of the Interstate Commerce Act in 1887 cost inefficiency increased significantly. Inefficiency remained high until after 1900 when it returned to its previous level. The evidence provides some indications that the Interstate Commerce Act may have raised inefficiency!

7. Conclusion

This paper provides the first cross-country estimates of cost inefficiency in the railroad sector at the turn of the twentieth century. Estimates from a stochastic cost frontier model show that inefficiency was fairly large in many countries. Average inefficiency remained constant from the 1880s to the early 1900s but there was significant variation across countries. The railroad sector in some countries like France, Germany, and Norway were among the least efficient in the 1880s but they eventually became the most efficient in the 1900s. Changes in efficiency influenced productivity growth but not always positively so. Greater inefficiency acted as drag on productivity growth in some countries and in others lower inefficiency enhanced productivity growth. Preliminary analysis suggests that costs increased when state ownership increased, but efficiency was unaffected. Major regulatory changes, like the Inter-State Commerce Act also had an effect by raising inefficiency. A more complete examination of the connections between efficiency and ownership or regulatory policies remains a task for future research.

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Table 1: Working to Total Expenses for Selected Countries

Country	Average ratio of working to total expenses
Norway	0.952
Sweden	0.944
Belgium	0.984
France	0.974
Italy	0.914
Japan	0.95
Germany	0.972
India	0.972
Austria-Hungary	0.835
Algeria-Tunis	0.955
Overall Average	0.941
N	182

Sources: see text.

Table 2: Summary Statistics for the main variables

Variable	mean	st. dev.	min	max
log real working expenses	16.111	1.58	12.106	19.593
log passenger miles	21.484	1.503	17.271	24.226
log ton miles	21.918	1.869	16.977	26.265
log real coal prices	2.252	0.453	1.138	3.604
log real wages	4.169	0.633	-1.344	5.347
log (real working expenses/wages)	12.13	1.748	8.551	16.508
log (real coal prices/wages)	-1.73	1.258	-3.555	3.598
N	491			

	Standard Deviation			
Variable	overall	Between	Within	Fraction of Variation Within
log real working expenses	1.58	1.428	0.322	0.204
log passenger miles	1.503	1.347	0.368	0.245
log ton miles	1.869	1.713	0.381	0.204
log real coal prices	0.453	0.507	0.134	0.295
log real wages	0.633	0.658	0.094	0.148
log (real working expenses/wages)	1.748	1.744	0.279	0.159
log (real coal prices/wages)	1.258	1.441	0.144	0.115

Sources: see text.

Table 3: Parameter Estimates for the True Fixed Effects Stochastic Cost Function

Variable	Coefficient (Standard Error)
ln ton miles	0.519
	(0.044)*
ln passenger miles	0.022
	(0.0577)
ln(real coal prices/real wages)	0.384
	(0.042)*
Year	-0.6495
	(0.3693)*
year squared	0.000173
	(.9747D-04)*
Constant	609.42
	(350.248)*
country fixed effects	Yes
N	419
log likelihood	297.3555
sigma squared v	0.01132
sigma squared u	0.00947

Sources: see text.

Table 4: Cost Inefficiency Estimates by Country, 1883-1912

	cost inefficiency		
country	1883-1892	1893-1902	1903-1912
france	0.104	0.07	0.054
norway	0.114	0.065	0.057
germany	0.091	0.071	0.058
spain	0.099	0.078	0.06
united states	0.09	0.08	0.061
italy		0.094	0.063
belgium	0.085	0.074	0.066
argentina			0.071
australia			0.076
Austria-Hungary	0.062	0.074	0.076
uk	0.067	0.078	0.077
japan		0.072	0.089
india	0.042	0.095	0.093
sweden		0.066	0.094
russia in europe	0.054	0.066	0.099
canada	0.07	0.057	0.1
switzerland	0.052	0.07	0.11
Netherlands	0.05	0.106	0.117
average	0.075	0.076	0.079
	Rankings		
	1883-1892	1893-1902	1903-1912
france	12	6	1
norway	13	2	2
germany	10	7	3
spain	11	12	4
united states	9	13	5
italy		14	6
belgium	8	10	7
argentina			8
australia			9
Austria-Hungary	5	9	10
uk	6	11	11
japan		8	12
india	1	15	13
sweden		3	14
russia in europe	4	4	15
canada	7	1	16
switzerland	3	5	17
Netherlands	2	16	18

Sources: see text.

Table 5: Summary statistics of Cost inefficiency across the Models

Statistics	FE	Half Normal	True FE
Mean	1.24	0.194	0.079
standard deviation	0.911	0.06	0.027
Min	0	0.088	0.028
Max	3.621	0.451	0.215

Table 6: The Correlation between Inefficiency Estimates in the tree models

Models	True FE	FE	Normal Half-Normal
True FE	1		
FE	-0.15	1	
Normal Half-Normal	0.29	0.307	1

Sources: see text.

Table 7: Summary Statistics for Alternative Specifications

Statistics	True FE Baseline	True FE w/ density	True FE w/ pk	True FE w/o homogeneity d.1
Mean	0.079	0.077	0.029	0.049
standard deviation	0.027	0.025	0.005	0.0145
Min	0.028	0.03	0.0169	0.02
Max	0.215	0.163	0.045	0.168

Models	Correlation with True FE model
True FE w/ density	0.97
True FE w/ pk	0.85
True FE w/o homogeneity d.1	0.78

Sources: see text.

Table 8: Cost Inefficiency and TFP in Canada, US, UK, and France

TFP Levels	Canada	US	UK	France
1890	34	45	84	51
1900	66	92	90	73
1910	100	100	100	100
TFP growth (%)	Canada	US	UK	France
1900-1890	6.86	7.41	0.69	3.65
1910-1990	4.24	0.84	1.06	3.2
Cost inefficiency Levels	Canada	US	UK	France
1890	76	186	85	117
1900	60	107	114	95
1910	100	100	100	100
Implied annual tfp growth from efficiency (%)				
1900-1890	2.34	5.38	-2.98	2.06
1910-1990	-5.24	0.67	1.3	-0.51
net contribution of efficiency across all 4 countries				3.02
total productivity growth across all 4 countries				27.95

Sources: see text.

Table 9: Private Ownership, State Ownership, Costs, and Efficiency

Ownership Variables in cost function	(1) Coefficient (Standard error)	(2) Coefficient (Standard error)
Fraction of miles owned by private companies	-0.259 (0.1084)*	
Fraction of Miles Nationalized		-0.0092 (0.0886)
Ownership Variables in the mean of inefficiency		
Fraction of miles owned by private companies	-0.0431 (0.2222)	
Fraction of Miles Nationalized		-0.0972 (281.894)
n	419	419
log likelihood	306.3351	302.7031
sigma squared v	0.00949	0.01365
sigma squared u	0.01555	0.01087

Sources: see text.

Figure 1: An Illustration of Cost Inefficiency

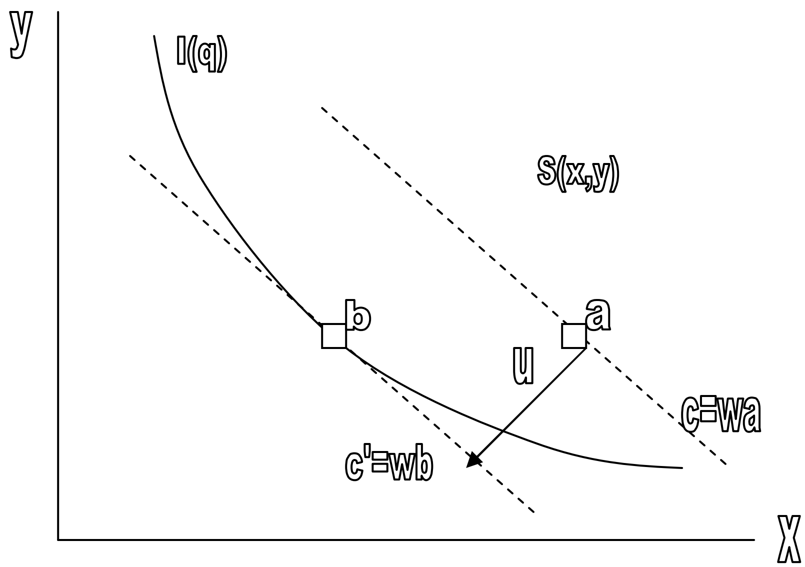
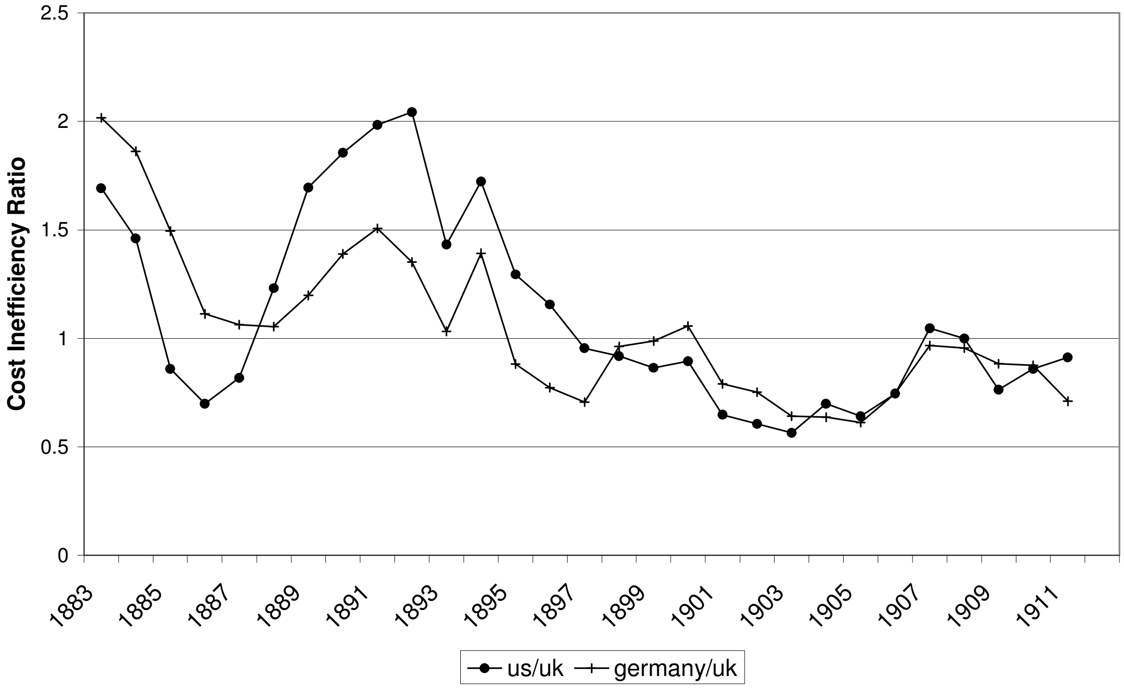
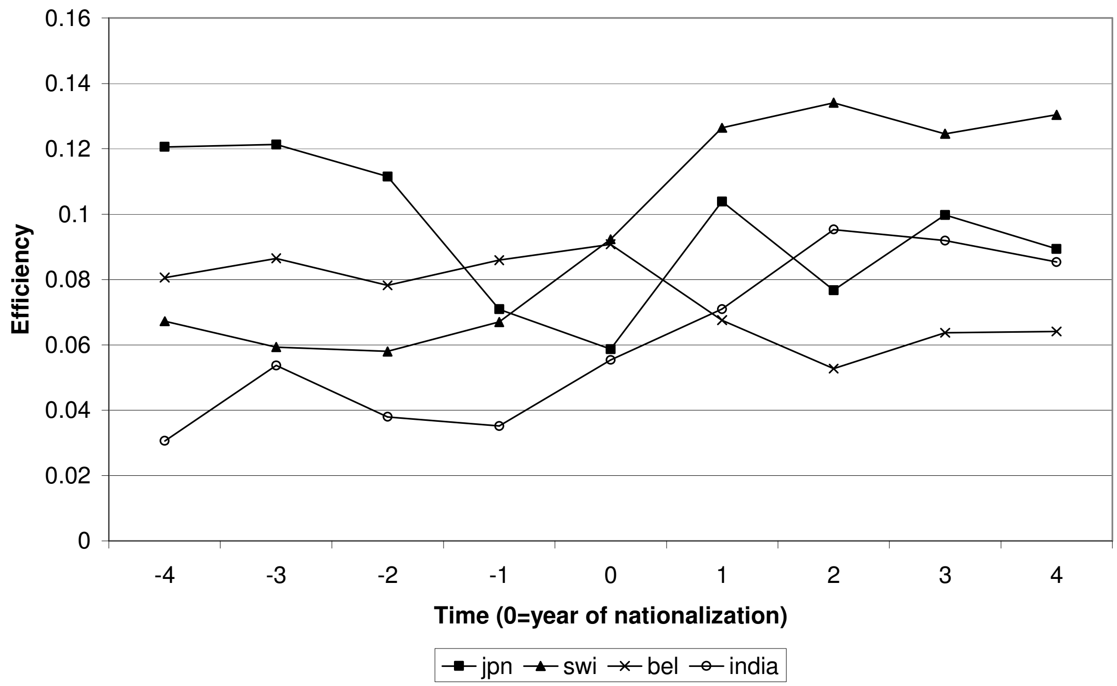


Figure 2: Cost Inefficiency Ratios US/UK and Germany/UK



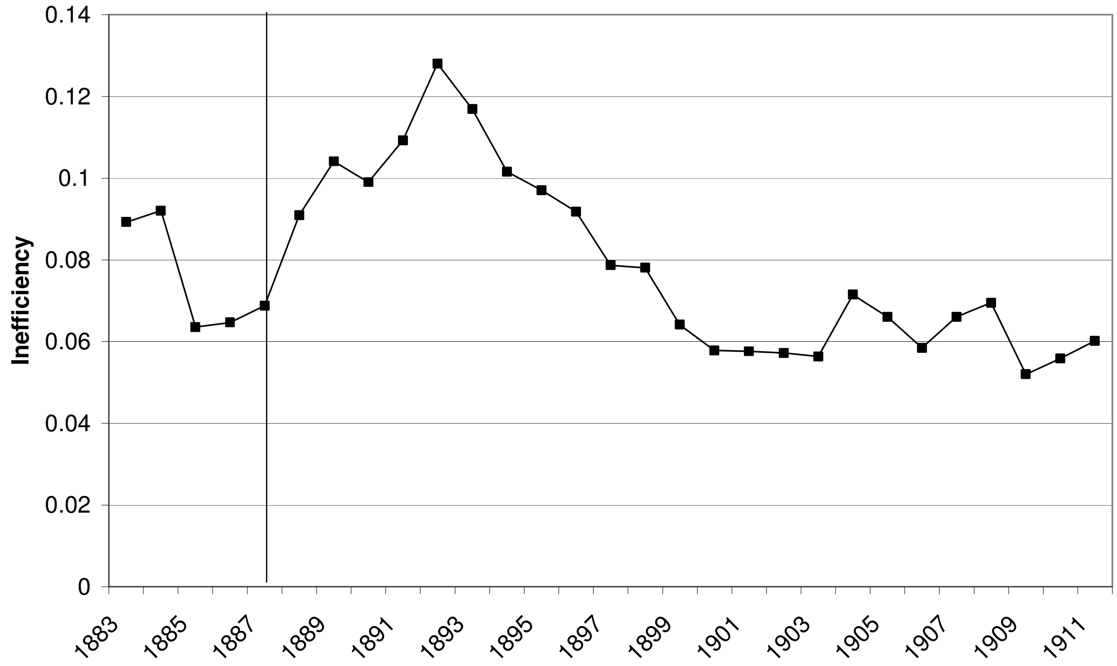
Sources: see text.

Figure 3: Efficiency Before and After Major Nationalizations



Sources: see text.

Figure 4: Cost Inefficiency on US Railroads, 1883-1912



Sources: the vertical bar represents the passage of the Inter-State Commerce Act in 1887.