Working Paper No. 08/05

Efficiency among Private Railway Companies in a weakly Regulated System: The Case of Britain's Railways in 1893-1912

Abay Mulatu
&
Nicholas F. R. Crafts

Department of Economic History
London School of Economics

February 2005

Financial support from the Economic and Social Research Council under grant R000239536 is gratefully acknowledged. We wish to thank Tony Arnold, Dudley Baines, Roy Edwards, Tim Leunig, Sean McCartney and Cees Withagen for helpful advice. We also benefited from discussions at EH590 Seminar, LSE. The usual disclaimer applies.

For further details about this project and additional copies of this, and other papers in the series, go to:

http://www.lse.ac.uk/collection/economichistory/

Department of Economic History
London School of Economics
Houghton Street
London, WC2A 2AE

Tel: +44 (0) 20 7955 7860
Fax: +44 (0) 20 7955 7730

Efficiency among Private Railway Companies in a Weakly Regulated System: The Case of Britain's Railways in 1893-1912

*Abay Mulatu & Nicholas F. R. Crafts**

Abstract

This paper uses a stochastic cost frontier model to investigate the efficiency of Britain's private railways during the period 1893-1912. We find that there was substantial inefficiency in the industry with no sign of reduction over time. Our main conclusion is that principal agent problems were pervasive in railway management at this time. Our results suggest that private ownership per se is not sufficient to promote efficiency in the railway industry; it should be supported by competition for franchises and price-capping regulation as in the 1990s.

1. Introduction

Since the mid-1980s, economists have generally become persuaded that privatization of state-owned enterprises improves their performance and there is a large empirical literature that supports this position (Megginson and Netter, 2001). Exactly how important is the change of ownership per se as opposed to greater competition remains a matter of some debate as does the role of regulation in achieving good results from privatization. In some cases it has been argued that change of ownership is all that matters (Ehrlich et al., 1994) but in the presence of agency problems there are reasons to believe that better results will be achieved if competition is intensified or strong regulatory incentives to productivity improvement are applied (Vickers and Yarrow, 1988) and the

* Corresponding author. Department of Economic History, London School of Economics, Houghton Street, London WC2A 2AE, U.K. E-mail: n.crafts@lse.ac.uk. Tel.: +44 20 7955 6399. Fax: +44 20 7955 7730.

general experience of British privatizations seems to bear this out (Parker, 2004).

In the case of railways there is relatively little scope for competition in the market in a sector that is characterized by substantial elements of natural monopoly and sunk costs such that entry barriers are high and contestability is weak. When railways are privately operated in the modern world, regulation is the order of the day. The privatization of British Rail in the mid-1990s was organised so as to produce competition for the market in the form of bidding for franchises for train-operating companies which were then subject to regulation in the form of price-capping. A separate company (Railtrack) was established to act as track authority to which the operating companies paid access charges and this was also subject to 'RPI – X' regulation with periodic price reviews (Shaw, 2000). Despite many claims to the contrary, careful analysis suggests that, prior to the Hatfield crash in 2000, this combination of competition for the market and price-capping regulation was delivering faster productivity growth and sizeable welfare gains for consumers (Pollitt and Smith, 2002).

In the recent economic history of Britain's railways it has only been possible to observe the performance of either state-owned or highly-regulated private enterprise. There is, however, a considerable amount of data relating to the twenty years or so before the First World War that is available to analyze the performance of privately-owned companies subject only to weak and unsophisticated regulation and exposed to relatively little potential competition. These data can be used to throw light on the likely outcome if British Rail had been privatized as a set of unregulated regional monopolies with uncontested franchises.

In order to do this, we examine efficiency across 15 major British railway companies during the period 1893 to 1912. In this study the methodology for the measurement of efficiency that we employ is the stochastic cost frontier model, a parametric frontier technique as opposed to the non-parametric and deterministic technique of Data Envelopment Analysis (DEA) (see Oum et al. 1992 for a survey of methodologies).[1] The cost function approach as opposed to its dual, the production function, is standard for applications of these techniques to railways (Caves et al. 1981; Kumbhakar, 1988). The results from our investigation can be compared with the findings for the late 1990s period of Affuso et al. (2002) on the performance of the train operating companies and of Kennedy and Smith (2004) on the record of the various divisions of Railtrack.

We address the following questions:

a) How much inefficiency was there in the railway industry in Britain in the late nineteenth and early twentieth centuries

b) How does the performance of the weakly-regulated railway companies of a hundred years ago compare with that of the heavily-regulated railway system of the late twentieth century?

Our answers to these questions will form the basis on which to comment on the design of the recent rail privatization.

The rest of the paper is organized as follows. Section 2 presents the econometric model followed by description of our data in Section 3. Estimation results are presented in Section 4, and are discussed in Section 5. Section 6 concludes.

2. Econometric Model

Following Kumbhakar and Lovell (2000) a standard stochastic cost frontier for the *i*th firm in time *t* can be expressed as

---

[1] The DEA technique is deterministic in the sense that it gives no room for noise in frontier constructions, which is a weakness. On the other hand the DEA has advantage over the stochastic frontier technique because it does not entail any distributional assumptions.

$$E_{it} \geq C(Q_{it}, P_{it}; \beta)e^{v_{ti}} \tag{1}$$

where $E = \sum_m PX$ is expenditure on an *m*-vector of inputs *X*, which have a corresponding *m*-vector of prices *P*; *Q* is an *n*-vector of outputs; $C(Q, P; \beta)e^{v}$ is a cost frontier common to all firms; β is a vector of unknown parameters; and $e^{v_{it}}$ is a firm-specific random component.

Cost inefficiency of firm *i* in year *t* is therefore defined as the ratio of observed cost to minimum feasible cost:

$$CI_{it} = E_{it} \big/ C(Q_{it}, P_{it}; \beta)e^{v_{it}} \tag{2}$$

Since $E > C(Q, P; \beta)e^{v}$ we have $CI \geq 1$.

Assuming a log linear formulation of the cost frontier, the model in (1) can be written as

$$\begin{aligned} \ln(E_{it}) &\geq \ln C(Q_{it}, P_{it}; \beta) + v_{it} \\ &= \ln C(Q_{it}, P_{it}; \beta) + v_{it} + u_{it}, \end{aligned} \tag{3}$$

where *u* is the non-negative cost inefficiency component. Using (2) we also have $CI = e^{u}$.

In specifying the error components and estimating (3) we employ Battesse and Coelli's (1992) stochastic production frontier model and their computer program FRONTIER, which also accommodates a cost frontier model analogue of their production frontier model. In their model v_{it} are as usual assumed to be *iid* $N(0, \sigma_v^2)$; and $u_{it} = u_i e^{(-\eta(t-T))}$, where u_i are assumed to be *iid* as truncations at zero of the $N(\mu, \sigma_u^2)$, η is a parameter to be estimated and *T* is the end year of the time series. This model by Battesse and Coelli is a more general model of a class of models called 'error components stochastic frontier models' in the sense that quite a few of this class of models can be derived as special cases. For example, setting $\eta = 0$ results in the time-invariant model of Battesse, Coelli and Colby (1989). A further restriction of $\mu = 0$ gives the model by Pitt and Lee (1981).

In obtaining the maximum likelihood estimates of the model the variances of the error components are parameterized as: $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \sigma_v^2 / \sigma^2$. So γ represents the proportion of the total variance that is attributable to the inefficiency component. A statistical test of this structural parameter is therefore a test of whether or not the inefficiency effects can be ignored.

We will explore both the simple Cobb-Douglas model and the translog model from which the former can be derived as a special case. The translog function is a flexible specification that does not impose restrictions on substitution possibilities among inputs and allows scale economies to vary over output levels (see, e.g., Christensen and Greene, 1976). The Generalised Translog cost function for *n* outputs and *m* inputs can be written as

$$\begin{aligned} \ln C = \alpha_0 + \sum_j^n \alpha_j \ln Q_j + \sum_k^m \beta_k \ln P_k + 1/2 \sum_j^n \gamma_{jk} \ln Q_j \ln Q_k + \\ 1/2 \sum_j^m \rho_{jk} \ln P_j \ln P_k + \sum_j^m \delta_{jk} \ln Q_j \ln P_k + v + u \end{aligned} \qquad (4)$$

where $\gamma_{jk} = \gamma_{kj}$ and $\rho_{jk} = \rho_{kj}$; *C* is the sum of working expenditures and capital costs; *Q* is passenger/freight train miles and traffic density; and *P* is prices of capital, labour, coal and materials. These are fairly standard output and input variables considered in the literature (see, e.g., Caves et al. 1981). It is typical of applications in railways that 'quality' of output is not considered. The most popular measures of railway output, passenger miles and freight ton-miles (so called 'revenue measures') are not available, hence we resorted to train miles. We are in effect using what is called "available output measures" in the sense of "the level of capacity supplied" (Oum and Yu, 1994, p. 122).[2] Our measure of density is defined as total train miles divided by total route miles. Admittedly such a measure is not perfect since it ignores trainloads.

The Cobb-Douglas model results from setting $\gamma_{jk} = \gamma_k = \rho_{jk} = \rho_{kj} = \delta_{jk} = 0$ in Equation 4, and can be written as

$$\ln C = \alpha_0 + \sum_j^n \alpha_j \ln Q_j + \sum_k^m \beta_k \ln P_k + v + u \qquad (5)$$

The theoretical requirement of linear homogeneity in input prices implies the following restrictions

$\sum_j^m \beta_j = 1$; $\sum_j^m \rho_{jk} = 0$; and $\sum_j^m \delta_{jk} = 0$

In our investigation of cost inefficiency of Britain's railways prior to World War I, we will consider the *time-variant* and the *time-invariant* versions of the cost inefficiency term *u* in each Equation (4) and (5).

It is, of course, possible that results from the estimation of these models will partly reflect differences in the nature of the business and operating environment across companies. Where data permit, a second-stage analysis to investigate such possibilities (e.g. are there systematic effects of being a 'commuter line' as opposed to specializing in mineral

---

[2] Oum and Yu (1994, p. 122) argue that the use of "available output may be justified in measuring managerial efficiency when government controls the railways in terms of what to supply". In any case, their experiments with the two alternative measures of output show that "overall the two sets of efficiency indices are comparable"(p. 129).

traffic?) would be appropriate. Unfortunately we have data on only 15 companies which precludes formal analysis of this kind.[3]

3. Data

Our sample consists of a panel of 15 railway companies over the period 1893-1912.[4] Data on various measures of cost, output and traffic density are obtained from the *Railway Returns*, published, annually, by the Board of Trade. Specifically, the *Returns* provide data on total working expenditures, capital costs (calculated as the sum of all payments on capital), passenger/train miles and length of lines.

Data on input prices, i.e. wages, coal prices and price of iron and steel are constructed on the basis of information from various sources. With respect to the cost of capital we use a uniform rate of 6% for each railway in all the periods. This figure is comparable to what one would find by dividing total expenditure on capital by total capital stock (book value). Iron and steel price data are formed on the basis information on f.o.b price and transportation rates from the *Iron and Coal Trades' Review* (ICTR) and information on shortest distances to the then two main sources of iron and steel: north of England (Stockton – On Tees) and South Wales (Cardiff). Regarding coal prices, the cost per ton of coal consumed in locomotive power is considered. Such information is available from the public record office (PRO RAIL 414 595) for 14 of the 15 companies under consideration. Following Dodgson (1993), estimates for the Taff Vale railway company and some missing data for the South Eastern railway company are obtained on the basis of a regression of

[3] We will nonetheless conduct a simple analysis of (rank) correlation between the inefficiency scores and revenue shares of the various services.
[4] The sample represents the first 14 and the twenty-third in terms of train miles, of Britain's rail companies in 1912 (i.e. Dodgson's (1993) sample of companies plus one more company).

cost per ton of locomotive coal for the companies with available information on fuel cost per train-mile.

We construct our wage data on the basis of information from *Earnings and Hours Enquiry*, which provides regional wage data reported by railway companies for two periods: 1886 and 1891. This same source gives a second set of wage data for Bricklayers reported for various localities for the period 1870-1906. The procedure employed to obtain regional railway wages is extrapolation of the reported railway wages of 1886 and 1891 using our calculated rates of changes of the Bricklayers' wages up to 1906. For the years after 1906, we used the Board of Trade figures for average weekly earnings in 20 British railway companies as index to further extrapolate the extrapolated rail-wage figures. (The Board of Trade figures are reported in Munby and Watson, 1978, p. 58). All monetary figures are converted to 1900 price levels using the Board of Trade Wholesale Price Index (Mitchell, 1988). Some descriptive statistics of our data are presented in Table 1.

<Insert Table 1 about here >

4. Estimation Results

Estimation results of the stochastic frontier translog cost function are presented in Table 2. The two sets of results pertain to the two versions of the model: the time-variant and the time-invariant, respectively. In both versions, the data for the period 1893-1912 are pooled. We only have a cross-section of 15 companies which would make it impossible to follow the common practice in the literature, that is to estimate a frontier function for each year and analyze efficiency over time. However, in the first version of the model we are allowing cost inefficiency to vary systematically over time. The basic assumption here is that there is no shift of the frontier itself during the period and that the railway companies are comparable over the sample period. This assumption is not entirely plausible since there was modest TFP growth in the railways (Crafts et al. 2004). We will therefore explore our data by splitting our sample into two in order to address this issue.

<Insert Table 2 about here >

We note that in both versions of our model most of the parameter estimates of the cost frontier function are insignificant at conventional levels of significance. This is not surprising in view of the large number of regressors which, aside from the terms involving the output variables, show little variation resulting in huge multicolinearity (Christensen and Greene, 1976, p. 662; Kumbhakar and Lovell, 2000, p. 144). We also note however that in stochastic frontier analyses it is the disturbance terms that are the main focus, and the parameters of the cost function are often "of secondary interest" (Greene, 2000, p. 395).

Coming to these crucial parameters of the two error components we see that there are considerable differences between the two versions. In the second version none of the variance parameters are significant. In the first version, on the contrary, each of these parameters is significant. This estimate of the structural parameter of γ is significant and shows that about 91% of the total variance of the composite disturbance term is attributable to the inefficiency component. The log-likelihood ratio test statistic of this parameter is 394.8 (the last row of Table 3). The statistic has a mixed chi-squared distribution with 2 degrees of freedom with a critical value of 8.273 for the probability value of 1%.[5] So the statistic is significant meaning that the inefficiency effects cannot be ignored. In conducting a formal test of the null hypothesis that $\eta = 0$, we can again

[5] Critical values of this mixed chi-squared distribution are provided in Table 1 of Kodde and Palm (1986).

use the log-likelihood ratio test. The test statistic, which has a mixed chi-squared distribution with 14 degrees of freedom, is the log-likelihood ratio, λ = -2[394.9 - 484.7] = 179.6. This is clearly significant at any level of conventional significance and hence the null hypothesis is once again rejected. This means that the time-variant version of the model is to be preferred. The estimate of –0.02 for the parameter η implies that the inefficiency terms u_i are monotonically increasing functions of time.

The inefficiency scores estimated by each of the two versions of the model are presented in Table 3. The last row of Table 3 refers to the time-invariant version of the model, and the rest refer to the time-variant version of the model. In the latter, mean inefficiency is shown to have risen from about 36% in 1893 to about 59% in 1912. The spread of the inefficiency scores is substantial. At about 66% the Lancashire and Yorkshire railway company is shown to be the most cost inefficient in 1893; while the Glasgow & Southwest railway company is shown to be the least inefficient with a score of about 3%.

<Insert Table 3 about here >

The imprecise coefficient estimates of the translog cost function reported in Table 2, while not too uncommon in the literature (see e.g. Affuso et al. 2002) might suggest trading-off the benefit of flexibility of such a function against the statistically significant coefficient estimates that the simpler models might produce. To that end we have explored the log-linear Cobb-Douglas model specified in Equation (5). Estimation results of the time-variant and the time-invariant versions of the stochastic frontier Cobb-Douglas cost function and the corresponding estimates of inefficiency scores are presented in the appendix in Tables A.1 and A.2, respectively. We see that in both versions of the model almost all the coefficient estimates have the expected signs and are significant.

Focusing on the parameters of the two components of the disturbance term we note that once again the time-variant version of the model is to be preferred judging by the significance of the variance parameters and the log-likelihood ratio statistic, λ = -2[419.17- 460.8] = 83.26. This statistic has a mixed chi-squared distribution with 14 degrees of freedom with a critical value of 28.485 for a probability value of 1%. So the hypothesis that the time variation of the inefficiency can be ignored is rejected. About 94% of the variance in the combined disturbance term is accounted for by the inefficiency term. The inefficiency scores reported in Table A.2 show a similar increase in the mean inefficiency from about 35% in 1893 to about 68% in 1912. A statistical test of whether or not we can reject the restriction imposed by the Cobb-Douglas model can be based on the log-likelihood ratio test. The test statistic λ = -2[460.8-484.7] = 47.8. This statistic has a chi-squared distribution with 21 degrees of freedom and the critical value for the probability value of 1% is 38.304. The restrictions can therefore be rejected.

In view of the relatively long time series we are examining and the fact that the parameter η (which captures the evolution of the inefficiency scores over time) is a monotonic function of time, we have further explored our data by splitting the sample into two sub samples, 1893-1902 and 1903-1912. The estimation results of the translog functions for each sub sample are presented in the appendix in Tables A.3 and A.4, respectively. Table A.5 displays the corresponding cost inefficiency scores. The Cobb-Douglas counterparts of all these results are presented in the appendix in Tables A6-A8. Our investigation of the sub samples does not reveal any dramatic changes in the results from the ones we obtained for the entire sample. The only noticeable change is that the parameter η is positive (although insignificant) in the sub sample 1893-1912 (in the tarnslog model) implying that cost inefficiency declined over time. As before the Cobb-Douglas specifications produce relatively sharper coefficient estimates. But unlike before, the restrictions imposed by the Cobb-Douglas model cannot be rejected at conventional levels of significance.[6]

As a crude second-stage analysis relating the inefficiency scores with the differing nature of the business, we looked at the rank correlation between the inefficiency scores and the revenue shares of different services in the companies. We found weak positive rank correlation between the inefficiency scores in 1893 and the share of passenger revenue in total receipts in the same year (r = 0.25) or the average of 1893-1912 (r = 0.23) and weak inverse rank correlation between the inefficiency scores in 1893 and the share of mineral revenue in total receipts in the same year (r = -0.23) or the average of 1893-1912 (r = -0.14).

In sum, a consistent picture emerges from all these various estimations which have delivered robust results. First, the railways exhibit substantial cost inefficiency. Second, the spread of performance across the companies was very marked. Third, things did not get better over time. Obviously, our results may reflect unobserved heterogeneity across these railway companies. Nevertheless, the inefficiency scores are big and the trends in inefficiency are adverse so it would seem implausible to rely on this as an alibi.

5. Discussion

Our evidence suggests that inefficiency in the British railway industry prior to World War I was pervasive, persistent and pronounced. Our results are in sharp contrast with those that have emerged from

[6] The test procedure is once again based on the likelihood ratio statistic. We refrain from reporting the detailed test results here to avoid clutter.

similar analyses of the recently-privatized railways for the period 1995 to 2000.

Affuso et al. (2002) undertook a comprehensive Data Envelopment Analysis of 25 train-operating companies.[7] They found that the average DEA score rose from 0.698 in 1995 to 0.877 in 2000 “associated with an impressive reduction in real operating costs” (2002, p. 16). Nine of the eleven companies with an initial score of less than 0.7 improved by at least 0.1 in the three years from 1997 to 2000. Kennedy and Smith (2003) found that the average net efficiency score in their DEA analysis of the divisions of Railtrack rose from 0.881 in 1995/6 to 0.923 in 1999/00. They note that firm-wide productivity was growing at 6.8 per cent per year pre-Hatfield.

These modern studies find much lower inefficiency scores than we estimate for the distant past together with a clear tendency for organizational slack to fall over time and substantial progress by the initial laggards. This is perhaps not surprising given the enormous difference in the regulatory environment between the two eras. The RPI – X regime of regulation in place after 1996 was intended to stimulate productivity growth by setting *X* factors that reflected scope for cost reduction in an environment which allowed for yardstick comparisons between train-operating companies. Competition for franchises saw train-operating companies committing themselves to sharply decreasing subsidies over time with franchises to be contestable again after 7 years in most cases (Shaw, 2000, pp. 107-9).

In contrast, the key features of the regulatory situation a hundred years ago were as follows. First, incumbent companies did not have to compete for franchise renewal and were not involved in bidding to

[7] They also supplement their DEA with the ‘corrected least squares stochastic frontier’ technique.

operate with lower subsidies. Second, charges for freight traffic were capped under the Railway and Canal Traffic Act of 1894. By 1899 it had become clear that this amounted to a price freeze (Cain, 1988). As costs increased after 1900, this led to pressure on profits but this was modest in the low inflation era of the Gold Standard. Third, the Cheap Trains Act of 1883 imposed strong tax incentives to keep fares for 3rd-class passengers below 1d per mile and required some workmen's trains to be run at reduced fares (Lee, 1946). There was no parallel to the concept of a periodic price review or price caps based on scope for productivity improvement.

Thus the regulatory regime in Edwardian Britain appears to have offered much weaker incentives to productivity improvement than that of the late 1990s. There was little but shareholder power to energize sleepy management but the diffuse structure of shareholding in these large joint-stock companies mitigated against this while hostile takeovers were unknown in this era (Hannah, 1974). These were privately-owned firms with significant agency problems, as Cain (1988) points out.

Vickers and Yarrow (1988) were sceptical of the case for privatization of British rail, mindful of failures to establish effective competition or regulation in a number of early privatizations. As it turned out, their message that rail privatization would need to be accompanied by an appropriate regulatory regime was largely heeded and our comparison between the two eras suggests that this was important in improving rail efficiency post-privatization. Change of ownership on its own might have achieved much less. This is not to suggest that the privatization of British Rail was perfectly designed or implemented. There are many reasons to doubt that, not least the question of the appropriate degree of vertical integration of the industry. Nevertheless, privatization succeeded in precluding a return to the wasteful practices of Edwardian days and its design deserves some credit for that.

6. Conclusions

Our analysis of the performance of the major private railway companies operating in Britain in the late nineteenth and early twentieth century has revealed that in most cases costs were much higher than the efficient level. Notwithstanding the obvious caveats relating to differences in the operating environment, an average excess cost of 59 per cent in 1912 (Table 3) surely confirms Cain's judgement that 'there was waste and inefficiency in the railway system' (1988, p.120). This verdict is strengthened by our finding that inefficiency was increasing rather than decreasing in the early twentieth century.

The performance of the private railway companies of late Victorian and Edwardian Britain does not compare favourably with that of the privatized railway industry of the late 1990s which achieved rapid improvements in efficiency under the auspices of demanding franchise contracts and RPI – X regulation. The British railway system of a century ago was privately-owned but weakly-regulated with high barriers to entry and no mechanism to provide competition for the market. The performance of the railway companies in that environment strongly suggests that private ownership per se is not the key to efficient operation but needs to be complemented with competitive pressure and well-designed regulation.

References

Affuso, L. Angeriz, A. and Pollitt, M.G. (2002), 'Measuring the efficiency of Britain's' Privatised Train Operating Companies', Regulation Initiative Discussion Paper Series, Number 48, London Business School.

Battese, G.E., Coelli, T.J. and Colby, T.C. (1989), 'Estimation of Frontier Production Functions and the Efficiencies of Indian Farms Using Panel Data From ICRISAT's Village Level Studies', *Journal of Quantitative Economics*, 5, 327-48.

Battese, G.E. and Coelli, T.J. (1992), 'Frontier Production Functions, Technical Efficiency and Panel Data: With Application to Paddy Farmers in India', *Journal of Productivity Analysis*, 3, 153-69.

Cain, P.J. (1988), 'Railways 1870-1914: the Maturity of the Private System', in M.J. Freeman and D.H. Aldcroft (eds.), *Transport in Victorian Britain*. Manchester: Manchester University Press, 92-133.

Caves, D.W., Christensen, L.R. and Swanson, J.A. (1981), 'Productivity Growth, Scale Economies and Capacity Utilization in US Railroads, 1955-1974' *American Economic Review*, 71, 994-1002.

Christensen, L.R. and Greene, W.H. (1976), 'Economies of Scale in US Electric Power Generation', *Journal of Political Economy*, 84, 655-76.

Crafts, N.F.R., Mills, T.C. and Mulatu A. (2005), 'Total Factor Productivity Growth on Britain's Railways, 1852-1912: A Reappraisal of the Evidence', London School of Economics, Department of Economic History Working Papers, Large Scale Technological Change 07/05.

Dodgson, J.S. (1993), 'British Railway Cost Functions and Productivity

Growth, 1900-1912', *Explorations in Economic History*, 30, 158-181.

Ehrlich, I., Gallais-Hamonno, G., Liu, Z. and Lutter, R. (1994), 'Productivity Growth and Firm Ownership: an Analytical and Empirical Investigation', *Journal of Political Economy*, 102, 1006-1038

Greene, W.H. (2000), *Econometric Analysis*, Prentice-Hall, Inc.: Upper Saddle River NJ.

Hannah, L. (1974), 'Takeover Bids in Britain before 1950: an Exercise in Business Pre-History', *Business History*, 16, 65-77.

Kennedy, J. and Smith, S.J. (2003), 'Assessing the Efficient Cost of Sustaining Britain's Rail Network: Perspective Based on Zonal Comparison', Judge Institute of Management, University of Cambridge, DAE Working Paper No. 0317.

Kodde, D.A. and Palm, F.C. (1986), 'Wald Criteria for Jointly Testing Equality and Inequality Restrictions', *Econometrica*, 54 (5), 1243-48.

Kumbhakar, S. C. (1988), 'On the Estimation of Technical and Allocative Inefficiency Using Frontier Functions: The case of US Class I Railroads', *International Economic Review*, 23, 283-306.

Kumbhakar, S. C. and Lovell, C.A. (2000), *Stochastic Frontier Analysis*. Cambridge: Cambridge University Press.

Lee, C. E. (1946), *Passenger Class Distinctions*. London: the Railway Gazette.

Megginson, W. L. and Netter, J. M. (2001), "From State to Market: a Survey of Empirical Studies on Privatization", *Journal of Economic Literature*, 39, 321-389.

Munby, D. L. and Watson, A. H. (1978), *Inland Transport Statistics: Great Britain 1900- 1970*. Oxford: Clarendon Press.

Mitchell, B.R. (1988), '*British Historical Statistics*'. Cambridge:

Cambridge University Press.

Oum, T.H., Tretheway, M. and Waters, W. (1992), 'Concepts, Methods and Purposes of Productivity Measurement in Transportation', *Transportation Research*, 26A, 493-505.

Parker, D. (2004), "The UK's Privatisation Experiment: the Passage of Time Permits a Sober Assessment", CESIFO Working Paper No. 1126.

Pollitt, M. G. and Smith, A. S. J. (2002), "The Restructuring and Privatisation of British Rail: Was It Really That Bad ?", *Fiscal Studies*, 23, 463-502.

Pitt, M.M. and Lee, L.F. (1981), 'Measurement and Sources of Technical Inefficiency in the Indonesian Weaving Industry', *Journal of Development Economics*, 9, 43-64.

Shaw, J. (2000), *Competition, Regulation and the Privatisation of British Rail*. Aldershot: Ashgate.

Vickers, J. and Yarrow, G. (1988), *Privatization: an Economic Analysis*. London: MIT Press.

Table 1 Mean and standard deviations (in parenthesis), 1893-1912[1]

Railway company	Total cost (m £)	Passenger train miles (m)	Freight train miles (m)	Wage (*s* weekly)	Coal prices (*s* per ton)	Iron & Steel prices (*s* per ton)
Great Eastern	5.6	13.0	8.0	25.0	10.7	108.3
	(0.7)	(0.8)	(0.7)	(1.6)	(1.3)	(21.2)
Great Northern	5.3	12.0	10.3	25.0	9.8	108.1
	(0.6)	(1.0)	(1.0)	(1.6)	(1.4)	(21.2)
Great Western	11.8	25.8	20.3	24.4	11.0	108.0
	(2.0)	(4.7)	(1.3)	(1.1)	(1.9)	(21.2)
London, Brighton and Chatham	5.7	12.0	5.8	24.8	8.6	108.0
	(0.7)	(1.0)	(0.6)	(1.0)	(1.2)	(21.2)
London & North Western	3.3	9.1	1.9	25.9	10.3	108.3
	(0.3)	(1.0)	(0.1)	(1.4)	(0.6)	(21.2)
London & South Western	14.2	26.9	19.6	23.9	9.3	108.0
	(1.6)	(3.0)	(1.8)	(1.0)	(1.8)	(21.2)
Lancashire & Yorkshire	5.0	13.4	4.4	25.9	15.8	108.2
	(0.6)	(1.8)	(0.3)	(1.4)	(2.6)	(21.2)
Manchester, Sheffield and Leeds (Great Central, after 1897)	3.7	6.1	7.5	24.8	8.9	108.0
	(1.0)	(2.2)	(1.0)	(1.0)	(1.4)	(21.2)
Midland	11.7	20.3	26.1	23.9	8.9	108.0
	(1.7)	(2.6)	(1.6)	(1.0)	(1.2)	(21.2)
North Eastern	9.2	15.2	14.0	24.8	9.6	107.8
	(1.2)	(1.7)	(2.3)	(1.0)	(1.3)	(21.2)
South Eastern (+ Chatham, after 1899)	4.3	10.3	2.7	25.9	10.2	108.5
	(1.2)	(2.7)	(0.6)	(1.4)	(0.7)	(21.2)
Taff Vale	0.9	0.8	1.6	24.4	10.7	107.7
	(0.1)	(0.3)	(0.1)	(1.1)	(0.8)	(21.2)
Caledonian	4.5	9.4	7.1	26.4	7.1	108.0
	(0.5)	(0.9)	(0.4)	(1.4)	(1.6)	(21.2)
Glasgow and South Western	1.7	4.1	2.8	23.1	7.8	108.4
	(0.2)	(0.5)	(0.1)	(1.0)	(1.7)	(21.2)
North British	4.4	9.1	8.5	23.1	7.3	108.3
	(0.6)	(0.6)	(0.4)	(1.0)	(1.5)	(21.2)
All companies	6.1	12.5	9.4	24.7	9.7	108.1
	(3.9)	(7.3)	(7.3)	(1.5)	(2.5)	(20.7)

[1] A uniform 6% cost of capital is applied for all companies in each year.
Source: see text.

Table 2. Regression estimates of the translog cost frontier model, 1893-1912

	Time variant cost inefficiency		Time-invariant cost inefficiency	
Coefficient	*Estimate*	*t-ratio*	*Estimate*	*t-ratio*
α_0	13.217	13.153	13.778	13.780
α_P	-1.040	-1.611	-1.824	-1.839
α_F	0.326	0.879	0.534	0.539
α_D	0.413	0.489	-0.873	-0.877
β_K	0.667	0.440	-2.656	-1.537
β_L	-1.516	-1.698	-1.248	-1.252
β_C	1.294	1.573	4.753	4.758
β_M	0.555	0.613	0.151	0.152
γ_{PP}	0.032	3.009	0.037	0.053
γ_{PF}	-0.006	-0.621	-0.012	-0.017
γ_{PD}	-0.015	-1.464	-0.026	-0.029
γ_{FF}	0.021	1.914	0.040	0.069
γ_{FD}	0.011	1.083	0.017	0.024
γ_{DD}	-0.002	-0.157	-0.017	-0.023
ρ_{KK}	0.132	0.570	1.120	0.389
ρ_{KL}	0.173	1.263	0.788	0.468
ρ_{KC}	0.026	0.191	0.082	0.049
ρ_{KM}	-0.067	-0.531	0.250	0.152
ρ_{LL}	-0.071	-0.701	-0.473	-0.485
ρ_{LC}	-0.232	-3.749	-0.227	-0.231
ρ_{LM}	0.131	1.918	-0.088	-0.092
ρ_{CC}	0.142	1.618	0.181	0.189
ρ_{CM}	0.064	0.733	-0.036	-0.038
ρ_{MM}	-0.128	-2.107	-0.126	-0.134
δ_{PK}	0.112	1.666	-0.047	-0.034
δ_{PL}	0.013	0.138	0.186	0.237
δ_{PC}	0.122	2.599	-0.249	-0.312
δ_{PM}	-0.018	-0.577	0.162	0.215
δ_{FK}	0.047	0.565	0.083	0.061
δ_{FL}	0.057	0.879	-0.062	-0.078
δ_{FC}	-0.103	-2.430	-0.006	-0.007
δ_{FM}	-0.001	-0.032	-0.016	-0.020
δ_{DK}	0.096	0.698	-0.192	-0.123
δ_{DL}	0.031	0.276	0.247	0.275

Time variant cost inefficiency			Time-invariant cost inefficiency	
Coefficient	*Estimate*	*t-ratio*	*Estimate*	*t-ratio*
δ_{DC}	-0.034	-0.545	0.044	0.049
δ_{DM}	-0.093	-1.784	-0.099	-0.111
Observations	300		300	
Log-Likelihood function	484.7		394.9	
σ^2	0.016	7.307	0.015	0.031
γ	0.913	45.393	0.749	0.751
μ	0.244	4.504	0.012	0.012
η	-0.020	-6.170	0	
LR[1]	394.8		346.3	

Note: *P* = passenger train miles; *F* = freight train miles; *D* = density; *K* = capital; *L* = labour; *C* = coal; *M* = materials.

[1] LR represents the log-likelihood ratio test of the null-hypothesis that the structural parameter γ can be ignored (see text for details).

Table 3. Relative cost inefficiency scores in Britain's railway companies

Year	Great Eastern	Great Northern	Great Western	Lanca-shire &York-shire	London, Brighton, & South Coast	London & North Western	London & South Western	M+S+L (after 1897, Great Central)	Midland	North Eastern	South Eastern (+ Chatham after 1899)	Taff Vale	Cale-donian	Glasgow + SW	North British	Mean
1893	1.277	1.259	1.308	1.662	1.492	1.641	1.320	1.317	1.541	1.492	1.553	1.229	1.194	1.025	1.151	1.364
1894	1.284	1.264	1.315	1.679	1.504	1.658	1.328	1.325	1.555	1.504	1.567	1.234	1.198	1.025	1.155	1.373
1895	1.290	1.271	1.323	1.697	1.517	1.675	1.335	1.332	1.569	1.517	1.582	1.239	1.203	1.026	1.158	1.382
1896	1.297	1.277	1.331	1.716	1.530	1.693	1.343	1.340	1.584	1.530	1.597	1.245	1.207	1.026	1.162	1.392
1897	1.304	1.283	1.338	1.735	1.544	1.711	1.352	1.348	1.599	1.543	1.612	1.250	1.212	1.027	1.165	1.402
1898	1.311	1.290	1.346	1.754	1.557	1.730	1.360	1.357	1.614	1.557	1.628	1.256	1.217	1.027	1.169	1.412
1899	1.319	1.297	1.355	1.775	1.572	1.750	1.369	1.365	1.630	1.572	1.645	1.262	1.222	1.028	1.173	1.422
1900	1.326	1.304	1.363	1.796	1.586	1.770	1.378	1.374	1.646	1.586	1.662	1.268	1.227	1.029	1.177	1.433
1901	1.334	1.311	1.372	1.818	1.601	1.791	1.387	1.383	1.663	1.601	1.679	1.274	1.232	1.029	1.181	1.444
1902	1.342	1.318	1.381	1.840	1.617	1.812	1.396	1.392	1.681	1.617	1.697	1.280	1.237	1.030	1.185	1.455
1903	1.350	1.326	1.390	1.863	1.633	1.835	1.406	1.402	1.699	1.633	1.716	1.287	1.243	1.030	1.189	1.467
1904	1.358	1.333	1.399	1.887	1.650	1.858	1.415	1.412	1.718	1.649	1.735	1.294	1.248	1.031	1.193	1.479
1905	1.367	1.341	1.409	1.912	1.667	1.882	1.426	1.422	1.737	1.667	1.754	1.300	1.254	1.032	1.197	1.491
1906	1.376	1.349	1.419	1.938	1.684	1.906	1.436	1.432	1.757	1.684	1.775	1.308	1.260	1.032	1.202	1.504
1907	1.385	1.358	1.429	1.964	1.702	1.932	1.447	1.443	1.777	1.702	1.796	1.315	1.266	1.033	1.206	1.517
1908	1.394	1.366	1.440	1.992	1.721	1.958	1.458	1.453	1.798	1.721	1.818	1.322	1.272	1.034	1.211	1.530
1909	1.403	1.375	1.451	2.020	1.740	1.985	1.469	1.465	1.820	1.740	1.840	1.330	1.278	1.035	1.216	1.544
1910	1.413	1.384	1.462	2.050	1.760	2.013	1.481	1.476	1.843	1.760	1.863	1.338	1.285	1.035	1.221	1.559
1911	1.423	1.393	1.473	2.080	1.781	2.043	1.493	1.488	1.866	1.781	1.887	1.346	1.291	1.036	1.226	1.574
1912	1.434	1.403	1.485	2.112	1.802	2.073	1.505	1.500	1.890	1.802	1.912	1.354	1.298	1.037	1.231	1.589
1893-1912	1.027	1.008	1.018	1.292	1.139	1.239	1.046	1.183	1.202	1.227	1.203	1.179	1.012	1.005	1.037	1.121

Table A.1. Regression estimates of the Cobb-Douglas cost frontier model, 1893-1912

	Time variant cost inefficiency		Time-invariant cost inefficiency	
Coefficient	*Estimate*	*t-ratio*	*Estimate*	*t-ratio*
α_0	4.865	7.603	0.799	1.422
α_P	0.388	16.151	0.582	24.682
α_F	0.397	16.885	0.321	9.895
α_D	-0.229	-4.041	-0.545	-9.556
β_K	0.538	4.554	-0.327	-3.367
β_L	0.375	3.363	1.218	13.529
β_C	0.059	2.170	0.021	0.784
β_M	0.027	1.002	0.088	3.501
Observations	300		300	
Log-Likelihood function	460.8		419.7	
σ^2	0.030	4.418	0.073	1.365
γ	0.940	64.154	0.963	34.902
μ	0.335	3.755	0.228	1.461
η	-0.028	-6.866	468.8	
LR	550.9		391.7	

Note: *P* = passenger train miles; *F* = freight train miles; *D* = density; *K* = capital; *L* = labour; *C* = coal; *M* = materials.

Table A.2. Relative inefficiency scores in Britain's railway companies (with the Cobb-Douglas model)

Year	Great Eastern	Great Northern	Great Western	Lanca-shire &York-shire	London, Brighton, & South Coast	London and North Western	London & South Western	M+S+L (after 1897, Great Central)	Midland	North Eastern	South Eastern (+ Chatham after 1899)	Taff Vale	Caled o-nian	Glasgow + S. W	North British	Mean
1893	1.270	1.233	1.352	1.597	1.492	1.669	1.338	1.250	1.509	1.479	1.546	1.184	1.198	1.011	1.129	1.350
1894	1.279	1.240	1.364	1.618	1.509	1.693	1.349	1.258	1.526	1.495	1.565	1.189	1.204	1.012	1.133	1.362
1895	1.288	1.248	1.376	1.640	1.527	1.718	1.360	1.266	1.544	1.512	1.585	1.195	1.210	1.012	1.137	1.375
1896	1.297	1.255	1.388	1.663	1.545	1.745	1.372	1.274	1.563	1.530	1.606	1.201	1.216	1.012	1.141	1.387
1897	1.306	1.263	1.401	1.687	1.564	1.772	1.384	1.283	1.583	1.549	1.628	1.207	1.223	1.013	1.146	1.401
1898	1.316	1.272	1.414	1.712	1.584	1.801	1.397	1.292	1.604	1.568	1.650	1.214	1.230	1.013	1.150	1.414
1899	1.326	1.280	1.428	1.738	1.605	1.831	1.410	1.302	1.625	1.588	1.673	1.220	1.237	1.013	1.155	1.429
1900	1.337	1.289	1.442	1.765	1.626	1.863	1.424	1.311	1.648	1.609	1.698	1.227	1.245	1.014	1.159	1.444
1901	1.348	1.299	1.457	1.794	1.649	1.896	1.438	1.321	1.671	1.630	1.723	1.234	1.252	1.014	1.164	1.459
1902	1.359	1.308	1.473	1.824	1.672	1.930	1.453	1.332	1.695	1.653	1.750	1.242	1.260	1.015	1.169	1.476
1903	1.371	1.318	1.489	1.855	1.696	1.966	1.468	1.343	1.721	1.676	1.778	1.249	1.269	1.015	1.174	1.493
1904	1.384	1.329	1.506	1.887	1.722	2.004	1.484	1.354	1.747	1.701	1.807	1.257	1.277	1.015	1.180	1.510
1905	1.396	1.339	1.523	1.921	1.748	2.044	1.501	1.365	1.775	1.727	1.837	1.265	1.286	1.016	1.185	1.529
1906	1.409	1.350	1.542	1.957	1.776	2.085	1.518	1.377	1.804	1.753	1.869	1.274	1.295	1.016	1.191	1.548
1907	1.423	1.362	1.560	1.994	1.805	2.129	1.536	1.390	1.834	1.781	1.902	1.282	1.305	1.017	1.197	1.568
1908	1.437	1.374	1.580	2.033	1.835	2.175	1.555	1.403	1.866	1.811	1.937	1.291	1.314	1.017	1.203	1.589
1909	1.452	1.386	1.601	2.074	1.867	2.223	1.574	1.416	1.899	1.841	1.973	1.301	1.325	1.018	1.209	1.611
1910	1.467	1.399	1.622	2.118	1.900	2.273	1.594	1.430	1.933	1.873	2.011	1.310	1.335	1.018	1.215	1.633
1911	1.483	1.412	1.644	2.163	1.935	2.327	1.615	1.445	1.970	1.906	2.051	1.320	1.346	1.019	1.222	1.657
1912	1.500	1.426	1.667	2.210	1.971	2.383	1.637	1.460	2.008	1.941	2.093	1.331	1.357	1.019	1.229	1.682
1893-1912	1.182	1.308	1.192	1.863	1.498	1.771	1.196	1.476	1.816	1.432	1.524	1.711	1.043	1.017	1.035	1.404

Table A.3. Regression estimates of the translog cost frontier model, 1893-1902

	Time variant cost inefficiency		Time-invariant cost inefficiency	
Coefficient	*Estimate*	*t-ratio*	*Estimate*	*t-ratio*
α_0	14.268	14.296	14.266	14.283
α_P	-1.046	-1.504	-0.972	-2.209
α_F	0.520	0.648	0.503	0.653
α_D	0.233	0.303	0.247	0.309
β_K	1.689	1.012	1.763	1.065
β_L	-0.740	-0.765	-0.856	-0.900
β_C	0.726	0.747	0.826	0.854
β_M	-0.675	-0.709	-0.734	-0.773
γ_{PP}	0.028	2.289	0.026	2.254
γ_{PF}	-0.018	-1.684	-0.019	-1.631
γ_{PD}	-0.010	-0.798	-0.007	-0.549
γ_{FF}	0.011	0.902	0.009	0.820
γ_{FD}	0.001	0.103	0.004	0.290
γ_{DD}	-0.018	-1.490	-0.015	-1.288
ρ_{KK}	0.140	0.513	0.086	0.326
ρ_{KL}	0.177	1.123	0.153	1.003
ρ_{KC}	0.065	0.396	0.041	0.261
ρ_{KM}	-0.102	-0.669	-0.108	-0.736
ρ_{LL}	-0.193	-1.655	-0.172	-1.508
ρ_{LC}	-0.065	-1.136	-0.064	-1.128
ρ_{LM}	0.081	0.897	0.083	1.000
ρ_{CC}	-0.109	-0.922	-0.093	-0.851
ρ_{CM}	0.109	1.096	0.116	1.202
ρ_{MM}	-0.088	-1.223	-0.092	-1.283
δ_{PK}	0.008	0.126	0.005	0.081
δ_{PL}	0.050	0.472	0.054	0.681
δ_{PC}	0.119	2.747	0.105	2.640
δ_{PM}	-0.001	-0.053	-0.001	-0.033
δ_{FK}	-0.024	-0.180	-0.030	-0.232
δ_{FL}	0.092	0.736	0.088	0.739
δ_{FC}	-0.059	-1.502	-0.047	-1.206
δ_{FM}	-0.009	-0.310	-0.012	-0.402
δ_{DK}	-0.020	-0.155	0.008	0.063
δ_{DL}	0.023	0.220	0.004	0.040

Time variant cost inefficiency			Time-invariant cost inefficiency	
Coefficient	*Estimate*	*t-ratio*	*Estimate*	*t-ratio*
δ_{DC}	-0.005	-0.074	-0.019	-0.324
δ_{DM}	0.002	0.042	0.007	0.147
Observations	150		150	
Log-Likelihood function	268.088		263.481	
σ^2	0.008	7.165	0.008	7.937
γ	0.887	51.231	0.891	49.203
μ	0.164	3.795	0.166	3.995
η	0.004	0.480	0	
LR	195.864		190.651	

Note: *P* = passenger train miles; *F* = freight train miles; *D* = density; *K* = capital; *L* = labour; *C* = coal; *M* = materials.

Table A.4. Regression estimates of the translog cost frontier model, 1903-1912

Time variant cost inefficiency			**Time-invariant cost inefficiency**	
Coefficient	*Estimate*	*t-ratio*	*Estimate*	*t-ratio*
α_0	17.128	16.700	20.807	3.309
α_P	-0.225	-0.605	-0.016	-0.038
α_F	-0.157	-0.459	-0.468	-1.129
α_D	-0.251	-0.486	-1.066	-1.983
β_K	1.215	0.914	1.005	0.893
β_L	-0.496	-0.588	-0.669	-0.886
β_C	-0.058	-0.070	0.893	1.456
β_M	0.339	0.548	-0.229	-0.404
γ_{PP}	0.010	1.193	0.012	1.759
γ_{PF}	-0.006	-0.851	-0.008	-1.095
γ_{PD}	0.000	0.001	0.000	-0.034
γ_{FF}	0.013	1.548	0.002	0.296
γ_{FD}	0.002	0.282	0.011	1.532
γ_{DD}	-0.003	-0.396	-0.002	-0.302
ρ_{KK}	0.203	0.952	0.412	2.019
ρ_{KL}	0.046	0.340	0.055	0.424
ρ_{KC}	0.122	0.979	0.206	1.779
ρ_{KM}	0.036	0.325	0.152	1.402
ρ_{LL}	-0.010	-0.101	0.082	0.914
ρ_{LC}	-0.087	-1.313	-0.091	-1.388
ρ_{LM}	0.052	0.849	-0.045	-0.705
ρ_{CC}	0.054	0.717	-0.036	-0.554
ρ_{CM}	-0.088	-1.192	-0.079	-1.124
ρ_{MM}	0.001	0.019	-0.028	-0.535
δ_{PK}	0.011	0.163	-0.109	-1.738
δ_{PL}	0.051	1.021	0.042	0.792
δ_{PC}	0.088	1.690	0.070	1.494
δ_{PM}	-0.069	-1.919	-0.045	-1.391
δ_{FK}	-0.041	-0.549	-0.112	-1.528
δ_{FL}	0.031	0.576	0.041	0.783
δ_{FC}	-0.052	-1.288	-0.001	-0.029
δ_{FM}	0.063	1.891	0.072	2.382
δ_{DK}	0.032	0.312	-0.028	-0.306
δ_{DL}	0.011	0.156	0.049	0.797

Time variant cost inefficiency			Time-invariant cost inefficiency	
Coefficient	*Estimate*	*t-ratio*	*Estimate*	*t-ratio*
δ_{DC}	-0.038	-0.676	-0.102	-1.928
δ_{DM}	-0.005	-0.103	0.081	1.829
Observations	150		150	
Log-Likelihood function	341.858		307.876	
σ^2	0.046	15.856	0.064	1.816
γ	0.994	1216.81 1	0.992	228.011
μ	0.429	12.217	0.377	3.426
η	-0.015	-9.822	0	
LR	375.609		307.645	

Note: *P* = passenger train miles; *F* = freight train miles; *D* = density; *K* = capital; *L* = labour; *C* = coal; *M* = materials.

Table A.5. Relative inefficiency scores in Britain's railway companies (with the translog model) 1893-1902 & 1903-1912

Year	Great Eastern	Great Northern	Great Western	Lanca-shire & York-shire	London, Brighton, & South Coast	London & North Western	London & South Western	M+S+L (after 1897, Great Central)	Midland	North Eastern	South Eastern (+ Chatham after 1899)	Taff Vale	Caled onian	Glasgow + S. W	North British	Mean
1893	1.233	1.088	1.246	1.408	1.568	1.529	1.315	1.198	1.318	1.392	1.543	1.500	1.132	1.010	1.124	
1894	1.232	1.088	1.245	1.406	1.566	1.526	1.314	1.197	1.316	1.390	1.540	1.498	1.132	1.010	1.123	
1895	1.231	1.087	1.244	1.404	1.563	1.524	1.312	1.196	1.315	1.389	1.538	1.496	1.131	1.010	1.123	
1896	1.230	1.087	1.243	1.403	1.560	1.522	1.311	1.195	1.314	1.387	1.536	1.493	1.131	1.010	1.123	
1897	1.229	1.087	1.242	1.401	1.558	1.519	1.310	1.194	1.313	1.385	1.533	1.491	1.130	1.010	1.122	
1898	1.228	1.086	1.241	1.399	1.556	1.517	1.309	1.194	1.311	1.384	1.531	1.489	1.130	1.010	1.122	
1899	1.228	1.086	1.240	1.398	1.553	1.515	1.307	1.193	1.310	1.382	1.528	1.487	1.129	1.010	1.121	
1900	1.227	1.086	1.239	1.396	1.551	1.512	1.306	1.192	1.309	1.381	1.526	1.485	1.129	1.010	1.121	
1901	1.226	1.085	1.238	1.394	1.548	1.510	1.305	1.191	1.307	1.379	1.524	1.483	1.128	1.010	1.120	
1902	1.225	1.085	1.237	1.393	1.546	1.508	1.304	1.191	1.306	1.377	1.521	1.481	1.128	1.010	1.120	
1893-1902	1.239	1.097	1.254	1.422	1.586	1.538	1.328	1.203	1.327	1.394	1.556	1.495	1.141	1.013	1.125	
1903	1.579	1.632	1.761	2.312	1.807	2.444	1.593	1.620	2.329	1.976	2.016	1.236	1.386	1.060	1.316	
1904	1.589	1.644	1.776	2.341	1.823	2.477	1.605	1.632	2.358	1.997	2.038	1.239	1.393	1.060	1.322	
1905	1.600	1.657	1.792	2.371	1.840	2.511	1.616	1.644	2.389	2.017	2.060	1.243	1.400	1.061	1.327	
1906	1.612	1.669	1.808	2.402	1.857	2.546	1.628	1.656	2.420	2.039	2.082	1.248	1.407	1.062	1.333	
1907	1.623	1.682	1.824	2.434	1.874	2.582	1.640	1.669	2.453	2.061	2.105	1.252	1.414	1.063	1.339	
1908	1.635	1.695	1.840	2.467	1.892	2.619	1.652	1.682	2.486	2.083	2.129	1.256	1.422	1.064	1.345	
1909	1.647	1.709	1.857	2.501	1.910	2.657	1.664	1.695	2.520	2.106	2.153	1.260	1.429	1.065	1.351	
1910	1.660	1.723	1.874	2.535	1.929	2.696	1.677	1.708	2.555	2.130	2.178	1.265	1.437	1.066	1.357	
1911	1.672	1.737	1.892	2.571	1.948	2.736	1.690	1.722	2.592	2.154	2.204	1.269	1.445	1.067	1.363	
1912	1.685	1.751	1.910	2.608	1.967	2.778	1.704	1.736	2.629	2.179	2.230	1.274	1.453	1.068	1.369	
1903-1912	1.328	1.491	1.413	2.077	1.455	2.108	1.219	1.605	2.286	1.697	1.613	1.514	1.188	1.014	1.223	

Table A.6. Regression estimates of the Cobb-Douglas cost frontier model, 1893-1902

Time variant cost inefficiency			**Time-invariant cost inefficiency**	
Coefficient	*Estimate*	*t-ratio*	*Estimate*	*t-ratio*
α_0	0.687	0.850	-2.059	-2.060
α_P	0.325	11.472	0.460	0.578
α_F	0.512	15.552	0.403	0.505
α_D	0.042	0.618	0.142	0.153
β_K	0.422	2.876	0.162	0.101
β_L	0.566	3.925	0.873	0.896
β_C	0.041	2.205	0.095	0.106
β_M	-0.029	-1.517	-0.130	-0.143
Observations	150		150	
Log-Likelihood function	267.754		243.036	
σ^2	0.035	1.961	0.091	0.105
γ	0.974	96.810	0.984	1.302
μ	0.371	3.559	0.016	0.016
η	-0.015	-3.185	0	
LR	336.857		287.422	

Note: *P* = passenger train miles; *F* = freight train miles; *D* = density; *K* = capital; *L* = labour; *C* = coal; *M* = materials.

Table A.7. Regression estimates of the Cobb-Douglas cost frontier model, 1903-1912

Time variant cost inefficiency			Time-invariant cost inefficiency	
Coefficient	*Estimate*	*t-ratio*	*Estimate*	*t-ratio*
α_0	7.161	7.266	3.302	2.525
α_P	0.393	12.598	0.637	16.017
α_F	0.335	9.396	0.230	4.614
α_D	-0.416	-8.905	-0.545	-10.310
β_K	0.468	4.532	-0.031	-0.335
β_L	0.448	4.604	0.890	10.737
β_C	0.069	2.437	0.114	3.536
β_M	0.015	0.708	0.027	1.157
Observations	150		150	
Log-Likelihood function	322.513		289.521	
σ^2	0.043	11.182	0.069	1.527
γ	0.992	584.304	0.991	154.917
μ	0.414	7.245	0.268	1.565
η	-0.017	-7.916	0	
LR	431.774		365.789	

Note: *P* = passenger train miles; *F* = freight train miles; *D* = density; *K* = capital; *L* = labour; *C* = coal; *M* = materials.

Table A.8. Relative inefficiency scores in Britain's railway companies (with the Cobb_Douglas model) 1893-1902 & 1903-1912

Year	Great Eastern	Great Northern	Great Western	Lanca-shire & York-shire	London, Brighton, & South Coast	London & North Western	London & South Western	M+S+L (after 1897, Great Central)	Midland	North Eastern	South Eastern (+ Chatham after 1899)	Taff Vale	Caled -onian	Glasgow + S. W	North British	Mean
1893	1.376	1.155	1.403	1.531	1.850	1.684	1.568	1.169	1.334	1.478	1.772	1.359	1.259	1.094	1.215	1.416
1894	1.383	1.157	1.410	1.541	1.867	1.697	1.578	1.172	1.340	1.487	1.787	1.365	1.263	1.096	1.219	1.424
1895	1.390	1.160	1.418	1.551	1.885	1.711	1.589	1.175	1.346	1.495	1.803	1.371	1.268	1.097	1.223	1.432
1896	1.397	1.162	1.425	1.561	1.903	1.725	1.600	1.178	1.352	1.505	1.819	1.378	1.272	1.099	1.226	1.440
1897	1.404	1.165	1.433	1.572	1.921	1.739	1.612	1.180	1.358	1.514	1.835	1.385	1.277	1.101	1.230	1.448
1898	1.411	1.167	1.441	1.583	1.940	1.753	1.623	1.183	1.364	1.523	1.852	1.391	1.281	1.102	1.234	1.457
1899	1.418	1.170	1.448	1.594	1.959	1.768	1.635	1.186	1.371	1.533	1.869	1.398	1.286	1.104	1.238	1.465
1900	1.426	1.173	1.457	1.605	1.979	1.783	1.647	1.189	1.377	1.543	1.887	1.405	1.291	1.105	1.242	1.474
1901	1.433	1.176	1.465	1.616	2.000	1.799	1.659	1.192	1.384	1.553	1.905	1.412	1.296	1.107	1.246	1.483
1902	1.441	1.179	1.473	1.628	2.021	1.815	1.672	1.196	1.390	1.563	1.923	1.420	1.301	1.109	1.250	1.492
1893-1902	1.283	1.081	1.370	1.355	1.535	1.612	1.351	1.204	1.298	1.479	1.523	1.627	1.223	1.098	1.262	1.353
1903	1.477	1.526	1.663	2.161	1.717	2.283	1.510	1.520	2.155	1.844	1.912	1.211	1.307	1.027	1.233	1.636
1904	1.487	1.536	1.677	2.189	1.732	2.315	1.521	1.531	2.183	1.863	1.933	1.215	1.313	1.027	1.237	1.651
1905	1.497	1.548	1.692	2.218	1.749	2.348	1.531	1.542	2.212	1.882	1.954	1.219	1.319	1.027	1.242	1.665
1906	1.507	1.559	1.707	2.248	1.765	2.382	1.542	1.553	2.241	1.903	1.976	1.223	1.326	1.028	1.246	1.680
1907	1.517	1.571	1.722	2.279	1.782	2.417	1.554	1.565	2.272	1.923	1.999	1.227	1.332	1.028	1.251	1.696
1908	1.528	1.583	1.738	2.311	1.800	2.454	1.565	1.577	2.304	1.945	2.023	1.231	1.338	1.029	1.256	1.712
1909	1.539	1.595	1.755	2.344	1.817	2.491	1.577	1.589	2.336	1.967	2.047	1.236	1.345	1.029	1.261	1.728
1910	1.550	1.608	1.771	2.378	1.836	2.530	1.589	1.601	2.370	1.989	2.072	1.240	1.352	1.030	1.266	1.745
1911	1.562	1.621	1.788	2.413	1.855	2.570	1.602	1.614	2.405	2.012	2.097	1.244	1.359	1.030	1.271	1.763
1912	1.573	1.634	1.806	2.449	1.874	2.611	1.615	1.627	2.441	2.036	2.124	1.249	1.366	1.031	1.276	1.781
1903-1912	1.220	1.370	1.254	1.937	1.377	1.869	1.114	1.509	2.026	1.531	1.511	1.602	1.103	1.014	1.130	1.438

LONDON SCHOOL OF ECONOMICS
DEPARTMENT OF ECONOMIC HISTORY

WORKING PAPERS IN LARGE-SCALE TECHNOLOGICAL CHANGE

For further copies of this, and to see other titles in the department's group of working paper series, visit our website at:
http://www.lse.ac.uk/collections/economichistory/

2004

01/04: Steam as a General Purpose Technology: A Growth Accounting Perspective
Nicholas F.R. Crafts
(First published as 75/03 in the Department of Economic History Working Papers Series).

02/04: Quantifying the Contribution of Technological Change to Economic Growth in Different Eras: A Review of the Evidence
Nicholas F.R. Crafts
(First published as 79/03 in the Department of Economic History Working Papers Series).

03/04: Regional GDP in Britain, 1871-1911: Some Estimates
Nicholas F.R. Crafts

04/04: Market Potential in British Regions, 1871-1931
Nicholas F.R. Crafts

05/04: How did the Location of Industry Respond to Falling Transport Costs in Britain before World War I?
Nicholas F.R. Crafts and Abay Mulatu

06/04: Social Savings as a Measure of the Contribution of a New Technology to Economic Growth
Nicholas F.R. Crafts

2005

07/05 Total Factor Productivity Growth on Britain's Railways, 1852-1912: A Reappraisal of the Evidence
Nicholas F.R. Crafts, Terence C. Mills & Abay Mulatu

08/05 Efficiency among Private Railway Companies in a Weakly Regulated System: The Case of Britain's Railways in 1893-1912
Abay Mulatu & Nicholas F.R. Crafts