TFP GROWTH USING PERPETUAL INVENTORY OF CAPITAL: MIDLAND RAILWAY LOCOMOTIVE POWER IN THE LATE NINETEENTH CENTURY

DRAFT: VERSION 2C

John Dodgson (J.S.Dodgson@lse.ac.uk)

May 19th 2008

1. INTRODUCTION

This paper is concerned with the costs of providing locomotive power on the Midland Railway in the final quarter of the nineteenth century and with the measurement of the productivity of that activity over the period. The main source of data are detailed statistics presented by Samuel Waite Johnson, the railway's Locomotive Superintendent from 1874 to 1903, in his presidential address to the Institution of Mechanical Engineers in 1898 (Johnson,1898). Johnson provides detailed information on annual expenditure of the different components of providing locomotive power, together with statistics on staff numbers, coal and coke consumed, and train- and engine-miles operated.[1] In the present study we have filled the missing gap of capital inputs by using detailed information on the Midland Railway's locomotive fleet (Baxter and Baxter, 1982; Stephenson, 2007). In addition, we have drawn on published data for the Midland Railway from the Board of Trade's annual Railway Returns (Board of Trade, annual), and from unpublished records (especially the minutes of the Locomotive Department) from the Midland Railway in the National Archives.[2]

There is an extensive literature on the measurement of late nineteenth and early twentieth century British railway productivity (see Crafts, Leunig and Mulatu, 2007; Crafts, Mills and Mulatu, 2007; Dodgson, 1993). This is concerned to show that productivity growth was slow, and to compare productivity growth between different companies. A major difficulty in measuring productivity is to measure total factor productivity by taking account of the contribution of capital to total factor productivity. This paper adopts a 'micro' level, perpetual inventory (see Christensen and Jorgenson, 1969), approach to the measurement of capital inputs and their costs by developing a database of the individual members of the main individual component of the capital in the Locomotive Department, namely locomotives, for which detailed records of each individual machine, including building date and scrapping date, survive. These records can be combined in an Excel database so that the changing composition of the capital stock over time can

[1] These statistics appear to be based on the six-monthly returns that Johnson provided from 1877 onwards following detailed analysis of data for the years 1871 to 1875.
[2] The main source of Midland Railway records in the National Archives is RAIL 491. The Locomotive Department minutes for the period from 1873 to 1896 are filed under RAIL/491/174 to 182.

be recorded, manipulated and valued. Oum et al's detailed survey of productivity measurement in the railway industry notes that "(a)lthough the Christensen-Jorgenson perpetual inventory method of measuring capital is preferred methodologically, it is very data- and time-intensive" (Oum, Waters and Yu, 1999, p.17).

2. COSTS OF PROVIDING LOCOMOTIVE POWER, 1873-1896

Johnson's presidential address provides detailed data on the costs of the department for which he was responsible over the years from 1873 to 1896. Annual costs were provided for: wages of drivers and firemen; wages of cleaners and coalmen; water; oil and stores; coal and coke; wages for repairs and renewals; materials used in repairs and renewals; salaries; turntables and buildings; and gas. Table 2.1 shows these figures, and Table 2.2 shows their share of total Locomotive Department expenses, for selected years, namely 1873, 1878, 1883, 1888, 1893, and 1896.

Locomotive costs are themselves an important component of total costs. From 1889 onwards the Railway Returns provided a breakdown of costs into major categories for 14 railways, including the Midland. This breakdown shows that locomotive costs accounted for between 35 and 38 per cent of total operating costs on the Midland between 1889 and 1896.

Figure 2.1 charts Midland Railway locomotive costs, including our estimates of capital costs, per net train-mile at current and constant 1873 prices (deflated by the Board of Trade wholesale price index).[3] At current prices these unit costs initially fall through to the late 'eighties, and then rise in the 'nineties. After the adjustment for changing prices, the fall through to the mid 'eighties is less sharp, and the subsequent rise greater.

Figures 2.2 and 2.3 show trends in the prices of two main inputs, coal prices and wages. Figure 2.2 shows the large fluctuations in coal prices in both nominal and inflation-adjusted terms. Figure 2.3 shows estimated average weekly wages of footplate staff, namely drivers, firemen, and passed cleaners. These are relatively stable in nominal terms, though there seems to be some downward drift but, after adjustment for inflation, they almost double.

There is evidence that productivity of footplate staff was actually falling. Although passenger train speeds increased, it appears that goods train speeds were reduced as track capacity problems were encountered. In addition the Midland's small engine policy meant that increased recourse was made to double-heading, the use of more than one engine on a train. This required two sets of footplate crews and hence increased wage costs. Figure 2.4 shows the ratio of engine-miles to train-miles on the Midland between 1873 and 1896. There were sharp increases between 1873 and 1876, and between 1889 and 1893, so that by 1896 the ratio had increased by 12.5

[3] Costs per net train-mile are equal to gross expenditures less the costs of engine power for ballasting and for working on other railways.

per cent since 1893. A further factor reducing productivity was the introduction of legislation which limited daily shifts of footplate staff to a maximum of 12 hours, thus requiring provision of relief crews, especially for mineral trains (Johnson, 1898, p.10 and p.11).

Table 2.1 Midland Railway Locomotive Expenditure, 1873-1896 (£)

Year	**1873**	**1878**	**1883**	**1888**	**1893**	**1896**
Wages: drivers and firemen	*190077*	*268647*	*341153*	*366138*	*457061*	*549026*
Wages: cleaners, coalmen, etc	*64211*	*73218*	*89192*	*94348*	*122389*	*136554*
Water	*18750*	*21303*	*28802*	*28807*	*38037*	*43526*
Oil and stores	*37634*	*42747*	*57474*	*39129*	*48819*	*51520*
Coal and coke	*364835*	*183135*	*233462*	*232642*	*449816*	*355601*
Total running expenses	675507	589050	750083	761064	1116122	1136227
Wages: repairs and renewals	*107557*	*159905*	*172037*	*186689*	*210948*	*253794*
Materials: repairs and renewals	*129020*	*163354*	*188704*	*164164*	*180452*	*209170*
Total repairs and renewals	236577	323259	360741	350853	391400	462964
Salaries	16496	21779	23737	23737	28854	29851
Turntables and buildings	2086	3704	2898	2898	3111	3148
Gas	4936	7311	8111	8111	13808	18946
Gross expenditure	935602	945103	1145570	1146663	1553295	1651136

Table 2.2 Shares of MR Locomotive Department Expenditure, 1873-1896 (%)

Year	**1873**	**1878**	**1883**	**1888**	**1893**	**1896**
Wages: drivers and firemen	*20%*	*28%*	*30%*	*32%*	*29%*	*33%*
Wages: cleaners, coalmen, etc	*7%*	*8%*	*8%*	*8%*	*8%*	*8%*
Water	*2%*	*2%*	*3%*	*3%*	*2%*	*3%*
Oil and stores	*4%*	*5%*	*5%*	*3%*	*3%*	*3%*
Coal and coke	*39%*	*19%*	*20%*	*20%*	*29%*	*22%*
Total running expenses	72%	62%	65%	66%	72%	69%
Wages: repairs and renewals	*11%*	*17%*	*15%*	*16%*	*14%*	*15%*
Materials: repairs and renewals	*14%*	*17%*	*16%*	*14%*	*12%*	*13%*
Total repairs and renewals	25%	34%	31%	31%	25%	28%
Salaries	2%	2%	2%	2%	2%	2%
Turntables and buildings	0%	0%	0%	0%	0%	0%
Gas	1%	1%	1%	1%	1%	1%
Gross expenditure	100%	100%	100%	100%	100%	100%

Figure 2.1 Midland Railway Locomotive Costs per Net Train Mile at Current and 1873 Prices

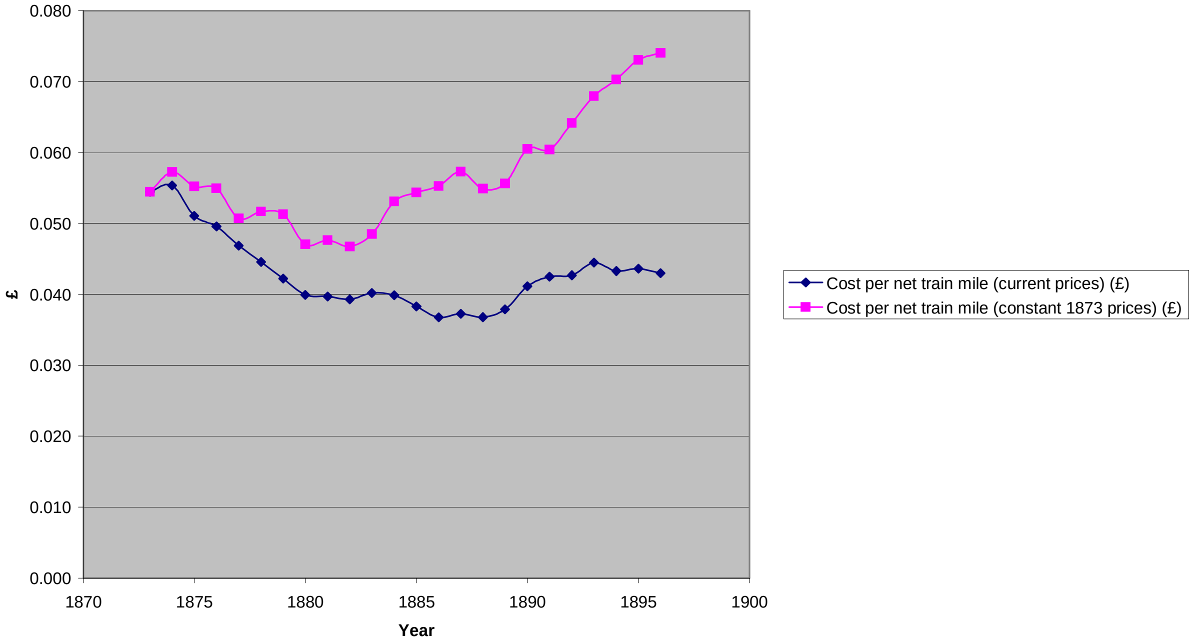


Figure 2.2 Cost of Coal and Coke on the Midland Railway at Current and 1873 Prices, 1873 to 1896

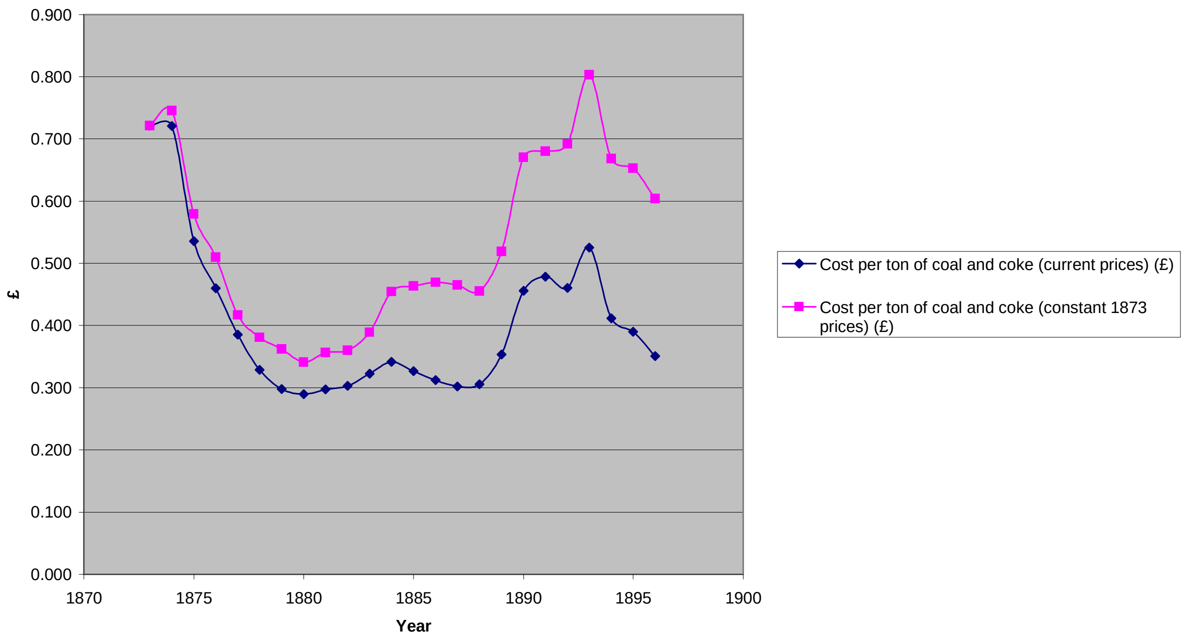


Figure 2.3 Weekly Wage Costs for Footplate Staff on the Midland Railway 1873-1896

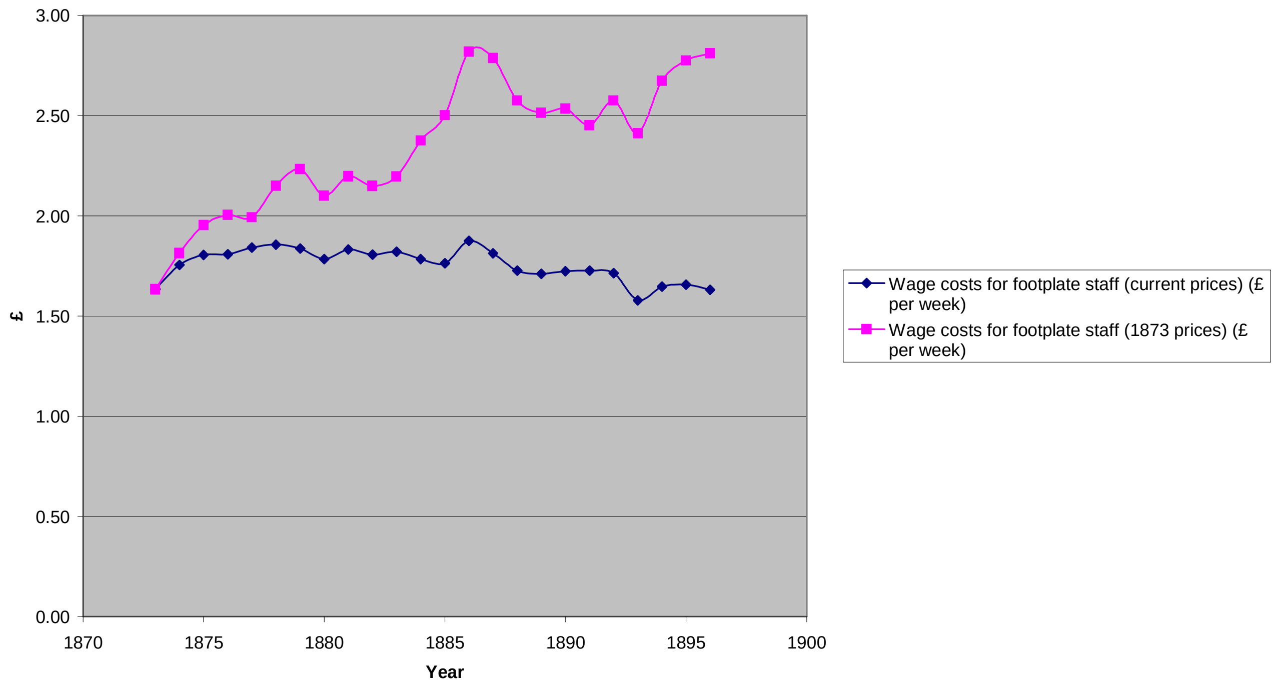
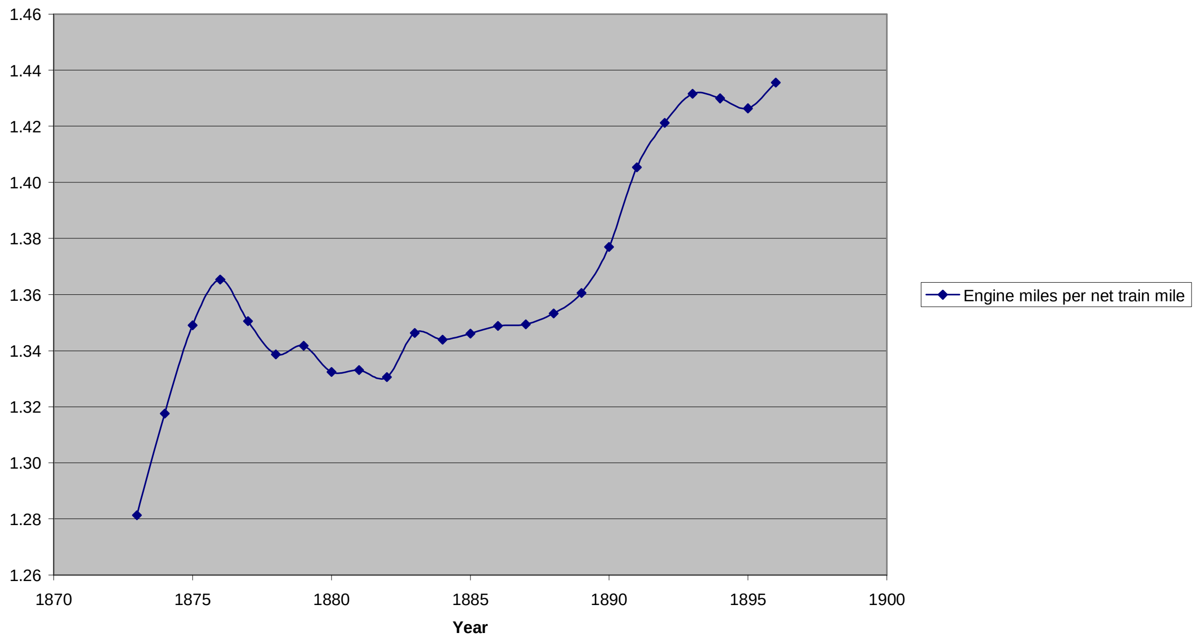


Figure 2.4 Engine Miles per Net Train Mile on the Midland Railway



With 24 annual observations we do not have enough data to estimate a production or cost function for provision of locomotive power unless we were to restrict ourselves to a Cobb-Douglas or other very simple form. However, the Cobb-Douglas format presumes that input shares would remain constant as relative input prices changed.[4] Figures 2.2 and 2.3 illustrate how relative input prices did change, while Table 2.2 shows that input cost shares (particularly those for drivers' and firemen's wages, and coal and coke) did not remain constant. Consequently in this paper we do not attempt any econometric estimation of the production or cost function.

3. PRODUCTIVITY MEASUREMENT

3.1 Overall productivity measurement

The rate of growth of productivity is equal to the rate of growth of output minus the rate of growth of input. As noted above, Oum et al (1999) provide a detailed survey of the measurement of productivity in the rail industry.

Where firms produce more than one output it is normal to weight the different outputs by their contributions to total revenue. Caves, Christensen and Swanson (1980) show that productivity growth is equal to the proportionate change in outputs weighted by their elasticities of cost with respect to output, minus the proportionate change in inputs weighted by their respective input cost shares. If there are constant returns to scale and outputs are priced at marginal costs, Caves et al note that the cost elasticity weights on output can be replaced by revenue shares. Dodgson (1993) finds constant returns to scale for British railway companies in the early years of the twentieth century, though the present study is concerned with the output of the Locomotive Department, which is an intermediate output in final production. In the present study we have been able to make an estimate of the cost elasticities of Locomotive Department output with respect to passenger train-miles (0.2949) and goods train-miles (0.6660) in 1892, which sum with rounding to 0.96.[5] We cannot provide any statistical significance to these figures though they look broadly consistent with the hypothesis of constant returns to scale in the provision of locomotive power. These figures are also not far from revenue shares in that year, which were 0.32 for passenger and 0.68 for goods.[6]

Where productivity is measured for more than one input, cost minimising behaviour by firms implies that input growth rates should be weighted by input cost shares.

[4] If, in addition, technological progress was neutral. Constancy of input shares would also imply that elasticities of substitution between pairs of inputs would equal one.

[5] Since we have not been able to estimate an econometric function to do this, we have drawn on the fact that the elasticity of cost with respect to output is equal to marginal cost divided by average cost. Johnson published estimates of marginal cost per train-mile in 1896, which we have divided by (total locomotive costs, divided by passenger or goods train-miles).

[6] When scaled up to sum to one the cost elasticities for passenger and goods are, respectively, 0.31 and 0.69.

Both output and input weights will change over time and in this study we use a 'chained' index in which the weights are equal to the average revenue or cost shares in the two years between which individual annual growth rates are calculated.

3.2 Growth of outputs

The main measure of output available is train-miles, which were published for both passenger trains, and for merchandise and mineral trains (i.e. goods trains) combined. Johnson's address provided estimates of costs per train-mile in 1896 for three categories of train, passenger train, merchandise train, and mineral train. These figures, derived from a detailed analysis of the costs of working different types of traffic on a specific route for the purpose of providing evidence to a rate case before the Railway Commissioners gave figures per train-mile of 6.94d for passenger trains, 9.29d for merchandise trains, and 11.68d for mineral trains. Since the costs for merchandise trains are different from those for mineral trains, it would be preferable if there were separate series for mineral train-miles and merchandise train-miles, but this is not the case, although we have found a split for one year, 1892. While costs per train-mile were higher for mineral trains than merchandise trains, we would expect average train-load to be higher for mineral traffic such as coal than for general merchandise traffic, since mineral traffic generally has a higher weight-to-volume ratio.

We have investigated the appropriate output index to use given the available statistics. Important components of freight output are average train load (which is equal to ton-miles divided by train-miles) and average length of haul (which is equal to ton-miles divided by tons carried). Unfortunately, the absence of ton-mile statistics has bedevilled measurement of productivity growth on nineteenth century British railways.

However, in their recent study of productivity growth in the industry Crafts, Mills and Mulatu (2007, pp.5-6,14) estimate ton-miles using an estimate by Sir George Paish (1902) for receipts per ton-mile of 0.7d for mineral traffic and 2.0d for merchandise traffic in 1900. These figures, which Crafts et al report were found to be typical for the whole of the period from 1880 to 1900 for the largest single company, the London and North Western Railway, can be divided into the published figures for Midland Railway receipts from mineral and from merchandise traffic to give ton-miles estimates for each category of traffic for the years 1873 to 1896 for the Midland. The ton-miles estimates can then be combined with goods train-miles (from Johnson's presidential address, and from the Railway Returns) and with goods tons (from the Railway Returns) to give series of average load and average length of haul respectively. This shows both average load and average haul to be reasonably stable over the period from 1873 to 1896: average train load was 62.6 tons in 1873 and 60.5 tons in 1874, but thereafter to 1896 fluctuated between 50 and 59 tons; average length of haul in miles for goods traffic fluctuated around the low forties. Overall between 1873 and 1896 ton-miles calculated by this method rose

at a slower rate than train-miles, so use of train-miles figures would not lead to underestimation in goods output.

While this evidence suggests that there was not any increase in output as a result of rising load factors (or change in the composition of output as a result of major changes in length of haul), we still need to consider whether there was any change in the mix between mineral and merchandise traffic. The Paish method to calculate ton-miles enables us to estimate average load and average length of haul on the Midland in 1892, the year for which we can split train-miles between minerals and merchandise.[7] We estimate average train load for minerals at 72.0 tons, and for merchandise at 30.8 tons (overall average 50.8 tons), thus confirming our expectation that mineral trains would be more heavily loaded than ones carrying general merchandise. We estimate average length of haul for mineral traffic at 47.6 miles and for general merchandise at 33.4 miles (overall average, 42.0 miles). However, we cannot see any evidence of any significant change in the balance between mineral and merchandise traffic on the Midland that could have shifted the broad balance between these two main categories of goods traffic over the 1873 to 1896 period: the mineral proportion of tonnage fluctuated around 57 per cent, while the mineral proportion of receipts increased from 38 to 43 per cent.

The question also arises as to whether passenger train-miles are an accurate reflection of passenger output. They might under-reflect output growth if:

- **The number of passengers carried per train-mile were to rise over time, because of an increase in the average number of passengers per train; or**
- **The quality of output increased because of an increase in average speed so that travel time fell for passengers; or**
- **Passengers benefited from an increase in the comfort of their journey. There were improvements in carriage heating and lighting over this period, though the main change was that the Midland abolished second class facilities at the beginning of 1875. Ordinarily the removal of an intermediate quality option might present problems in interpreting how customers benefit from the different range of options now available, but in the case of the Midland the effect of the abolition of second class was that first class travel was charged at former second class prices, while third class facilities were upgraded to former second class levels at former third class prices. So former third class travellers would get better quality at the same price, former second class passengers would get the same quality at lower prices, and former first class passengers would get the same quality at lower prices, which sounds like a change that makes everyone better off.[8] However, we should note in regard to improvements**

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[7] But note that any such split cannot be exact, since some goods trains would have conveyed both merchandise and mineral wagons.

[8] Though not necessarily, since social implications were a matter of concern in the public debate. For example, 'Those who chiefly use the second-class are largely single ladies or other persons who cannot afford first-class, and shrink from the possible rough companionship of the third (while) the first-class passengers would probably prefer even to have their fares raised than to be packed up with a crowd of

in comfort that most of the impact of such improvements would be achieved through provision of better coaches than better locomotive power, and so should not be credited to the Locomotive Department.

We have made an adjustment to passenger-train miles to allow for a general increase in speeds over the period of this study. To do this we have used a series of maximum booked speeds on different Midland Railway routes in each year published in Johnson's address (Johnson, 1898, pp.38-41).[9] Over the period from 1873 to 1896 average booked speeds of passenger trains on the Midland increased by 15 per cent. The index of actual passenger train-miles was adjusted upwards by this index.

Output weights in the form of passenger, and goods plus mineral, revenue shares are derived from the annual Railway Returns. These shares were quite stable over the period from 1873 to 1896, with the passenger share varying between 30 and 33 per cent of revenue, and the freight share varying between 67 and 70 per cent of revenue.

3.3 Growth of inputs

For this exercise we have divided inputs into four categories:

- **Labour, including both labour in direct operation of locomotives (drivers, firemen, cleaners, coalmen), labour engaged in the repair and maintenance of locomotives, staff at the railway's headquarters in Derby involved with locomotive matters, and staff in the railway's gas department.[10] The measure of input used is the total number of these staff employed;**
- **Coal and coke, and other forms of fuel and related inputs (water, gas, lubricating oils). The measure of input used is tons of coal and coke consumed;**
- **Materials used in the repair of locomotives. The measure used is expenditure on these materials deflated by the Board of Trade wholesale price index (Mitchell, 1988);**
- **Capital in the form of railway locomotives. The volume by Baxter and Baxter (1982) identifies each locomotive employed by the Midland Railway and we have built up a database (locomotive database, or 'locobase') that includes all such locomotives that were in operation during at least part of the period from 1873 to 1896. This database identifies each locomotive's year of build, its date of final withdrawal, its class, running number, weight, and**

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commoner people….The fact is that there are a great many people in a country like England who are only too glad to have a chance of spending money if they can only acquire any sort of special distinction by it' (*New York Times*, October 27, 1874).

[9] See Leunig (2007) for an analysis of the effects of improved train speeds on rail travellers in the nineteenth century.

[10] Johnson's address provides totals, but these are consistent with a detailed breakdown by category in RAIL 491/881.

power class. Data for those locomotives still in operation in 1907, when the Midland Railway instituted a major renumbering programme, have been checked against lists and other information on the renumbered locomotives (Stephenson, 2007).

Using the locomotive database it is possible to identify which locomotives were in the fleet at the end of each year. From this it is possible to construct weighted indices of the locomotive fleet in each year: we used two alternative sets of weights, one based on actual weights of locomotives (including tenders), and one based on power classifications, using the Midland's own classification of locomotives into power categories 0, 1, 2, 3, or 4 (Stephenson, 2007).

The locomotive database was also used to calculate capital costs in the form of depreciation and interest. The Midland had produced its own valuation of the locomotive fleet in 1896 (Midland Railway, 1896). The workbook containing these calculations shows that they took the 'prime value' of each locomotive (which we assume to be the initial cost) and calculated depreciation in two components, depreciation of boilers, the main component that needs to be replaced during an engine's life, and other depreciation. Depreciation of boilers is based on a cost of £400 for replacing the boiler every 400,000 miles (so £0.001 a mile). (Johnson himself reports that the average mileage at which Midland Railway locomotive boilers had been broken up in the ten years to 1896 was 382,890, Johnson, 1898, p.50). Other depreciation in the Midland Railway's calculations was based on 10 per cent a year. While the MR calculations include the prime value of each locomotive in the fleet, many of these values are the same for locomotives in different classes (which suggests to us that the calculations are based on some averaging and shortcuts). However the Midland do distinguish in their calculations between six different categories of engine (4 wheel bogie coupled passenger tender engines, 4 wheel coupled passenger tender engines, single bogie passenger tender engines, 6 wheel coupled goods tender engines, 6 wheel coupled goods tank engines, and 4 wheel coupled bogie passenger tank engines), and we have used average 'prime costs' for these six categories in our calculations. We have made an allowance for changes in construction costs over time by using the index of railway rolling stock prices (which includes carriages and wagons, as well as locomotives) that was constructed by Mitchell. It is possible to reconstruct this index from data supplied by Mitchell to Pollins (1971) (see also Feinstein and Pollard, 1988).

We calculated depreciation costs as follows:

- Total depreciation of locomotive boilers is calculated by multiplying total engine miles operated on the Midland Railway in each year by the railway's own estimate of depreciation costs of £400 per 400,000 miles;
- Remaining locomotive costs were calculated using straight-line depreciation by allocating these capital costs over a fixed period commencing in the year that that locomotive was introduced. The user can specify this depreciation period (which is therefore the same length of time for every class of locomotive) so as to test the sensitivity of final TFP results to the depreciation

period chosen in the calculation (the answer, as we will see in Table 3.2 below, is 'not much').[11]

We calculated interest costs as follows:

- **We used the database to calculate the value of the locomotive fleet in each year of its life by summing the initial values of each locomotive extant in each year, after deducting depreciation up to that point. This gave a total capital value of the stock in each year.**
- **We then applied an interest value to the capital stock in each year to represent the cost of capital. The value of the interest rate is that of 4 per cent used by Acworth in his influential text on railway economics (Acworth, 1905). In this text he gives a simple worked example of railway costs and includes interest, for which he uses a value of 4 per cent, which he notes 'is certainly not high when risk is allowed for' (Acworth, 1905, p.13).**

3.4 TFP growth and sensitivity results

Table 3.1 shows TFP results, split between output changes and input changes. We present results for a base case in which depreciation is calculated over 15 years, and for three definitions of output, namely:

- **Passenger train-miles, and goods train-miles;**
- **Passenger train-miles adjusted for the increase in speeds, and goods train-miles adjusted to allow for changes in average train load on the assumption that average haul length was fixed; and**
- **Passenger train-miles adjusted for the increase in speeds, and estimated goods ton-miles.**

The last column of Table 3.1 shows annual average per cent change over the period from 1873 to 1896. Input use grew by an average of 3.90 per cent per annum. Output grew according to the definition used, by an average of between 3.20 and 3.49 per cent per year, i.e. within a quite narrow range. Consequently TFP fell by between 0.42 and 0.70 per cent per annum.

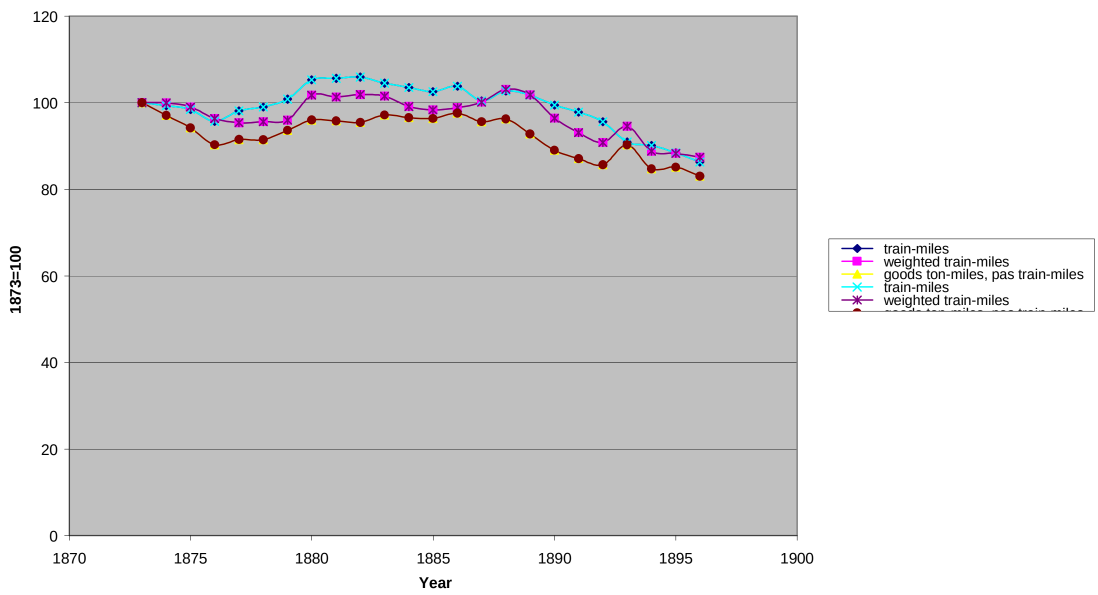
[11] Note that Mitchell used 30 years as the average life for rolling stock assets in his capital stock estimates for railways – reported in Crafts, Mills, Mulatu, 2007, p.7.

Table 3.1 TFP Growth in the Provision of Locomotive Power, 1873-1896
Depreciation period equals 15 years

	Per cent growth on previous year																							Average
	1874	**1875**	**1876**	**1877**	**1878**	**1879**	**1880**	**1881**	**1882**	**1883**	**1884**	**1885**	**1886**	**1887**	**1888**	**1889**	**1890**	**1891**	**1892**	**1893**	**1894**	**1895**	**1896**	**%**
Inputs	5.96	8.9	7.39	1.96	2.71	4.11	4.04	6.25	1.25	4.62	1.07	1.65	-2.30	2.09	4.82	8.23	6.69	6.37	3.54	-4.07	8.6	1.85	4.04	**3.90**
Outputs																								
Weighted train-miles	5.28	8	4.61	4.5	3.64	5.91	8.45	6.6	1.5	3.31	0.12	0.74	-1.13	-1.13	7.11	7.26	4.46	4.72	1.28	-9.00	7.74	0	3.14	**3.35**
Weighted train-miles (with adjustment for passenger train speeds and assuming average freight haul length unchanged)	5.94	7.97	4.66	0.96	2.96	4.49	10.06	5.84	1.78	4.3	-1.32	0.90	-1.79	3.37	7.75	7.02	1.41	2.93	1.05	0.07	2.45	1.33	6.03	**3.49**
Adjusted passenger-train miles and (estimated) freight ton-miles	3.04	5.89	3.28	3.31	2.66	6.49	6.58	6.02	0.88	6.4	0.45	1.46	-1.02	0.07	5.49	4.59	2.66	4.18	1.93	1.28	2.50	2.30	3.12	**3.20**
TFP: different output definitions																								
Weighted train-miles	-0.68	-0.90	-2.78	2.54	0.93	1.80	4.41	0.35	0.25	-1.31	-0.95	-0.91	1.17	-3.22	2.29	-0.97	-2.23	-1.65	-2.26	-4.93	-0.86	-1.85	-0.90	**-0.55**
Weighted train-miles (with adjustment for passenger train speeds and assuming average freight haul length unchanged)	-0.02	-0.93	-2.73	-1.00	0.25	0.38	6.02	-0.41	0.53	-0.32	-2.39	-0.75	0.51	1.28	2.93	-1.21	-5.28	-3.44	-2.49	4.14	-6.15	-0.52	1.99	**-0.42**
Adjusted passenger-train miles and (estimated) freight ton-miles	-2.92	-3.01	-4.11	1.35	-0.05	2.38	2.54	-0.23	-0.37	1.78	-0.62	-0.19	1.28	-2.02	0.67	-3.64	-4.03	-2.19	-1.61	5.35	-6.10	0.45	-0.92	**-0.70**

Figure 3.1 charts the different values of TFP growth as an index with 1873 as 100.

Figure 3.1 Index of TFP in Midland Railway Locomotive Department, 1873 to 1896



As well as sensitivity to the definition of output, we have also tested the sensitivity of the TFP results to choice of depreciation period, to the choice of capital stock index, and to the use of cost elasticity weights.

Table 3.2 shows sensitivity to the choice of depreciation period. We have used 5, 10, 15 (the base case), 20, 25 and 30 years, and also include results for use of one year for comparison. The table shows how extending the depreciation period increases the share of capital in total costs, but that the overall impact on the TFP calculation is very small.

Table 3.2 Effect of Depreciation Period on TFP Estimates and on Proportion of Costs Accounted for by Capex

Depreciation period (years)	1	5	10	15	20	25	30
Estimated average annual TFP growth rate (per cent)							
Weighted train-miles	-0.6	-0.56	-0.56	-0.55	-0.55	-0.54	-0.54
Weighted train-miles (with adjustment for passenger train speeds and assuming average freight haul length unchanged)	-0.46	-0.43	-0.42	-0.42	-0.42	-0.41	-0.41
Adjusted passenger-train miles and (estimated) freight ton-miles	-0.75	-0.71	-0.71	-0.7	-0.7	-0.7	-0.7
Capital as a percentage of							

Table 3.3 shows the effect of using cost elasticities to weight output growth. While our base case uses revenue weights that change (though not a lot) from year to year, the cost elasticities (0.2949 for passenger and 0.6660 for goods) relate to data for a single year, 1892. Since the cost elasticities sum to less than one, the effect of their use is to accelerate measured TFP decline, since as output rises the TFP index adjusts for the effect of apparent small economies of scale. However, since we have already remarked that we doubt this evidence is statistically significant, we believe we are safe to stick with the base case, revenue-weighted, TFP estimates.

Table 3.3 Effect on TFP Estimates of Using Cost Elasticity Estimates to Weight Revenue Growth

Depreciation period equals 15 years

Estimated average annual TFP growth rate (per cent)	Base case with revenue weights	Using cost elasticities as weights
Weighted train-miles	-0.55	-0.68
Weighted train-miles (with adjustment for passenger train speeds and assuming average freight haul length unchanged)	-0.42	-0.56
Adjusted passenger-train miles and (estimated) freight ton-miles	-0.7	-0.83

Note: the revenue weights vary from year to year, but by definition always sum to one in each year. The cost elasticity values relate to costs in 1896 and are 0.2949 for passenger traffic and 0.6660 for goods traffic.

Table 3.4 shows the effect on the TFP estimates of using an alternative capital stock index. The base case uses an index derived from the weights of locomotives and their tenders in operation in each year. The alternative index is based on the power classifications for the locomotives in operation in each year. This second index increases more rapidly than the first between 1873 and 1896 so the effect, as Table 3.4 shows, is to increase measured TFP decline.

Table 3.4 Effect on TFP Estimates of Using Alternative Capital Stock Index

Depreciation period equals 15 years

Estimated average annual TFP growth rate (per cent)	Base case with revenue weights	Using alternative capital stock index based on loco power classification
Weighted train-miles	-0.55	-0.68
Weighted train-miles (with adjustment for passenger train speeds and assuming average freight haul length unchanged)	-0.42	-0.54
Adjusted passenger-train miles and (estimated) freight ton-miles	-0.7	-0.83

Note: the base case capital stock index is the total weight of locomotives in operation in each year. The alternative index is the sum of power ratings for the locomotives in operation in each year.

Generally we conclude in regard to the sensitivity analysis that it shows that the TFP results derived are not particularly sensitive to the particular assumptions we have made.

4 CONCLUSIONS

This paper has used a remarkably detailed and internally consistent set of economic data from the fourth quarter of the nineteenth century to construct TFP estimates for an important component of rail industry output. In doing so, the calculations take careful account of the use and costs of capital services. The results show disappointing results in terms of TFP performance over time, and so are consistent with previous conclusions on the performance of the industry at that time.

The Midland Railway's overall TFP performance may have been somewhat better than that in the Locomotive Department. Crafts Mills and Mulatu (2007, p.29) include estimates for output, input and TFP growth on the Midland for the years 1893 to 1912. For the period as a whole they estimate annual output growth at 1.9 per cent, input growth at 1.5 per cent, so annual TFP growth at 0.4 per cent. TFP growth was faster in the first seven years than in the second seven years, at 0.7 per cent per annum between 1893 and 1900 against 0.1 per cent per annum between 1900 and 1912. Both output and inputs grew faster in the first period (4.5 and 3.8 per cent respectively) than in the second (0.4 and 0.3 per cent respectively).

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