

Determinants of Rail Productivity in the 20th Century

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Abstract

Productivity growth in Australia's railways through the 20th Century was neither smooth nor uniformly positive. It was static or falling for much of the century, before increasing rapidly with dieselisation and the rise of minerals traffic. This paper uses regression analysis to develop an understanding of the factors which drove productivity growth throughout the 20th Century, using a unique dataset developed at the Centre for Research in Applied Economics at Curtin University. It aims not only to understand the growth of rail in the 20th Century, but also to provide lessons for policymakers about what can assist it in continuing to grow in the 21st.

Introduction

In 1995 a team from the Institute of Transport Studies at the University of Sydney published "A Comparative Assessment of the Productivity of Australia's Rail Systems 1971/72 – 1991/92". It concluded:

"Given the growing importance of productivity measurement for both improved decision-making within the rail enterprises and for on-going monitoring of performance by regulators, the importance of the topic is only now beginning to be appreciated fully." (Hensher, Daniels & DeMellow, 1995, p221)

Almost 15 years later, there have been no further studies of rail productivity in Australia reported in published sources, apart from that of the Productivity Commissions' Inquiry Report of November 1999. This outcome is curious, given the significance of the transport industry to Australia of transport in general and of rail in particular. It is even more curious given the major structural changes imposed upon the industry by policymakers during these 15 years. This paper endeavours to begin to respond to Hensher et al's (1995) exhortation by examining factors contributing to the productivity of Australia's railways through the 20th Century.

Section Two of the paper explores the analytical framework of the analysis. Section Three discusses the data used. Section Four discusses the modelling and results, and Section Five concludes.

Analytical Framework

This paper explores total factor productivity in the context of the Australian railways, using a Tornqvist measure (TTFP). These indices are reproduced in Figure One, which shows productivity growth in the railways over the course of the Twentieth Century. The paper follows on from an earlier paper where TTFP measures were developed for the seven publicly-owned railways in Australia (Wills-Johnson, 2008), and the reader is referred to that paper for further details on how the index was calculated. Here, we seek

to explore what has driven productivity by regressing TTFP against a number of explanatory variables.

The paper is not the first to explore productivity in the context of the railways. Tae, Waters & Chunyan (1999) carried out a review of 48 railway productivity studies conducted in the interval between the end of World War II and 1996. Apart from the Hensher study referred to above, and two other studies undertaken by Australian railways all of these studies were carried out in Europe and North America, principally in the USA. Tae et al (1999) grouped the studies into two groups according to the technology of their methodologies. The first consists of studies which used Index Number or Data Envelopment Analysis procedures to produce productivity and efficiency measurements. The second group consisted of those using econometric models. Over a quarter of the subject studies used Divisia-Tornqvist index approach to measuring total factor productivity in the same manner that we have done here.

The Australian literature is much more limited, being restricted to essentially three papers, by Hensher, Daniels & DeMellow (1995), by Bruncker (1992) and by the Productivity Commission (1999).¹ The study reported by Hensher and his colleagues (Hensher et al 1995) use the productivity measure developed by Caves, Christiansen & Diewert (1982) which allows a comparison across firms, rather than the Tornqvist measure used here which focuses on each railway alone.² It plotted variations in productivity of railways in each of the five mainland state's systems over the period 1971/72 to 1991/92. It proceeded to look for causes in these variations in terms of technical change on the one hand, and management change on the other. The technological change variables they found to be significant were the introduction of extra long freight wagons and containers, the introduction of automated points and turnouts, the major extension of electrification (especially suburban systems), the introduction of centralised train controls, and the introduction of fibre optics in communications. It should be noted that what makes it difficult to compare these conclusions with this study is that its timeframe excluded the changeover from steam to diesel traction. As we have done, the study used the isolation of breakpoints in their series to identify changes in management as well as relevant structural changes. Their key conclusion is that

“... there is strong evidence that South Australia's Australian National and Queensland's Queensland Rail have benefited substantially by good management direction, giving these railways a productive edge over the rail systems.”
(Hensher et al, 1995, p221)

¹ Table 2 in Tae et al (1999) refers to studies of productivity trends carried out by the State Rail Authority NSW for the period 1981 – 91, and by the Australian National Railway Corporation in respect of the period 1979 – 91. Neither of these studies is included in the list of references of the Tae study, nor are they referenced in the Productivity Commission's Report of November 1999. Because of the relatively short time-frames covered by these two studies, we have not sought to examine them.

² The index of Caves et al (1982) takes an average value across all firms studied as its base, whilst the Tornqvist index has its base in an observation of productivity at a given firm (usually the first year). Unless two firms have identical productivity in their base years, one can obviously not compare the indices directly across firms. Wills-Johnson (2008) also constructs a productivity index using the methodology of Caves et al (1982) and the same data used to construct the TTFP here.

Our conclusion is generally supportive but it begs the question of whether or not there were changes in political direction which allowed managements greater discretion, competently deployed.³

Brunker (1992) uses a shorter timeframe than Hensher et al, (1979 to 1988) and focuses only upon Australian National (CR/AN).⁴ He also focuses upon the methodological question of how to estimate productivity when some factors of production are not being optimised due to forces beyond the control of the firm in question. For CR/AN, this was its community service obligations and its staffing levels. Whilst the paper provides some useful insights into the effects of these factors on a single railway, it does not cover the breadth which we wish to explore here.

The Productivity Commission's enquiry (Productivity Commission 1999) was even more specific in its objective than was that of Hensher et al (1995), and was very limited in scope and objectives compared to this study. Its purpose was "to provide an assessment of the economic performance of rail transport in Australia within a broad international context" (Productivity Commission, 1999, p1) over the period 1990 to 1998.

Its conclusions were not particularly incisive. It concluded that there was a significant gap between the performance of Australian railways and best practice standards, an unknown proportion of which were due to differences in technical efficiency, as distinct from the structure of markets. It further concluded that (ibid. p65).

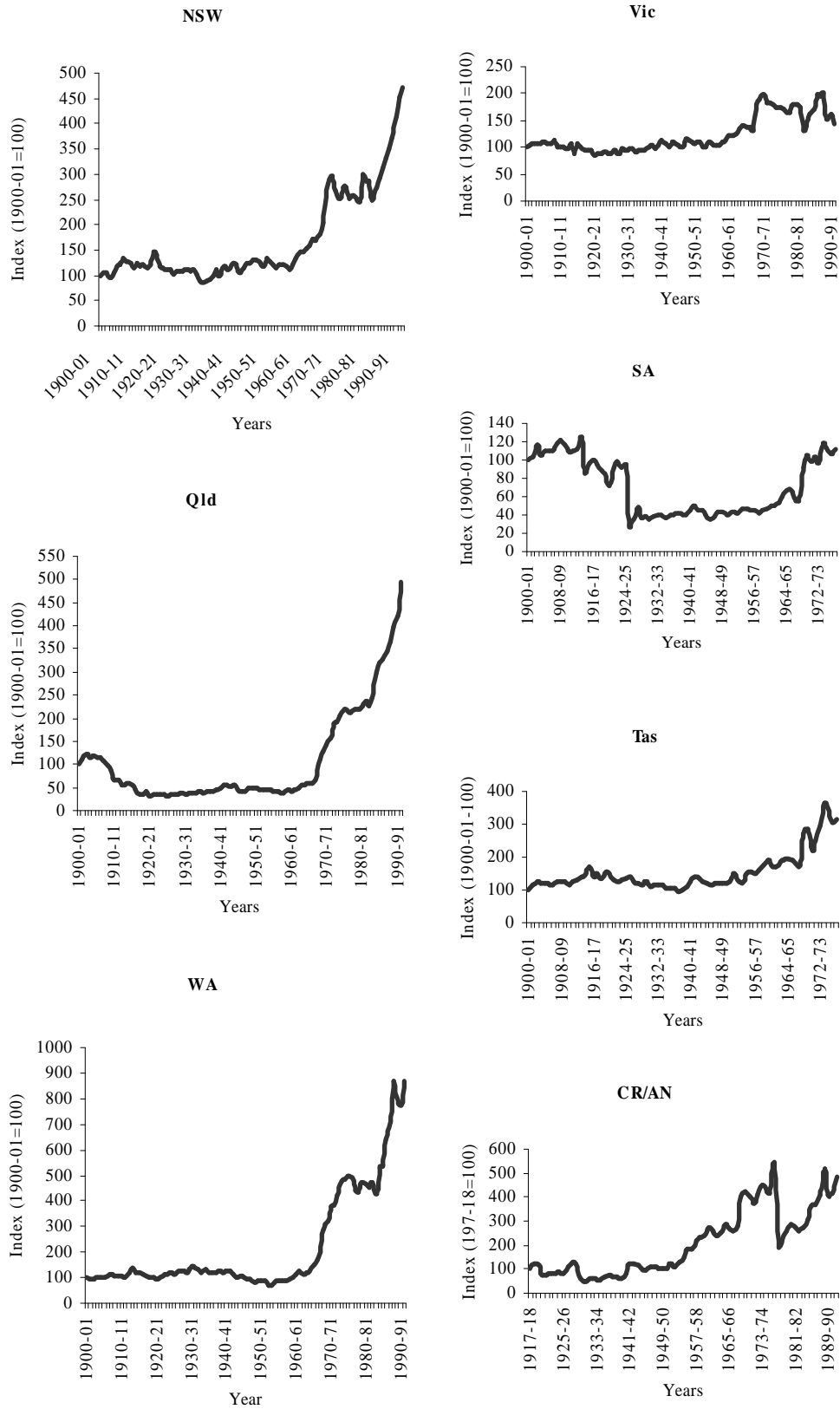
"Improvements in performance thus far have coincided with substantial reform of the Australian rail industry ... the recent nature of many reforms means that their full impact would not yet have been realised. However, it is more than likely that reform has had a positive impact on performance."

A more recent study of Australian railway productivity has been conducted by the Apelbaum Consulting Group (Australian Railway Association, 2004). However, this study is not longitudinal; where it makes comparisons over time, it is generally in two successive years. As a snapshot in time, it is not relevant to this study.

³ Gunn (1989) has an account of what he sees as political constraints to effective railway management.

⁴ Australian National was, until the early 1970s, known as Commonwealth Railways. Thus, here we make reference to CR/AN.

Figure One: TTFP Growth in Australia's Railways – 1901 to 1992



Description of Data Used

The international literature points to a number of factors which might drive productivity. In particular, Chapman & Martland (1997) provide a useful categorisation into four groups of factors:

- Economics of traffic density.
- Technical improvements.
- Network rationalisation.
- Equipment productivity.

To these, we would add demand-side factors which shift railway operations to more productive fields. This is especially important in Australia, where the railways went from being universal service providers to focussing on narrower niche markets which played to their productive strengths, like minerals freight. Also, Chapman & Martland (1997) were writing for the US context, where the railways and the data available on their operations, are rather different than is the case in Australia. This thus limits to some extent the degree to which their framework is translatable to an Australian context. The first two factors are translated with relative ease; traffic density can be measured by train kilometres per route km, and indeed this measure has long been used by Australian railways. The most important technical improvement made by the railways is arguably the switch from steam to diesel locomotives, and we capture this in the model.

Network rationalisation and equipment productivity are more problematic, because in Australia they are both influenced by very different structural and regulatory regimes to those in the US. In both Australia and the US, there have been significant branch line closures. In Australia, particularly in recent times, branch line closures have been part of government owners' response to increasing cost pressures on lines no longer regarded as commercial and which were not subject to political pressures to remain open. In the USA the *Staggers Act* of the early 1980s encouraged branch line rationalisation by private sector railway owners influenced only by commercial concerns. Unlike Australia, this led to development of so-called "short line" operations – the formation of narrowly and locally focussed railway corporations operating at lower standards than the USA's Class I railways, rather than abandonment of the line or its continuing to be operated inefficiently by a larger railway. Neither Australian railway operators, nor policymakers, seem to have absorbed the lessons of short line railways operating branch lines. In the case of equipment productivity, Australian railways routinely made use of old, less productive assets for decades longer than was commonly the case in the US. This is because capital budgets for new equipment had to be approved by parliaments, which rarely did so, and the railways thus maintained old assets well past their use-by date. In the process, some capital expenditures were funded as operating costs. The base for assessing capital productivity in government –owned railways is thus problematic.

The remaining factors considered, apart from shocks to productivity captured in a series of dummies, are demand-side factors. In particular, we explore whether the shift towards more intensive minerals traffic has increased productivity, and whether an increase in passenger traffic decreases it.

All of the data are presented as Laspeyres indices, to match the form of the dependent TTFP variable and, like that variable, are give a value of one in 1901 (1922 for CR/AN). The data themselves, with the exception of population and GNP variables, have been sourced from the Australian Railways database, available from <http://tiny.cc/ozrail> and are described therein. Before using the data, we test it for stationarity, and test the models for structural breaks. The process followed is quite involved and is discussed in an appendix. We found that all of the variables are non-stationary, which we address by including an error correction term from the cointegrating relationship between the non-stationary variables. We also find structural breaks in the series for Queensland, South Australia and Tasmania and, since it was not clear whether the breaks were in the intercept, the slope or the long run relationship, we estimate each subsample separately. Details on each of the variables are provided below.

Staff Numbers (STF)

Number of full-time staff employed per annum. A reduction in staff numbers during the 1980s, when many railways halved their number of workers, was an important factor in improving productivity into the 1990s, and hence we examine how staffing levels were associated with productivity throughout the century. Full-time equivalent staff would be a more appropriate measure, but such data are unavailable. The prior on this variable is negative.

Density (DEN)

Measured as the number of train kilometres per route km, density is essentially a measure of how intensively the railway is using its below-rail infrastructure, and reflects the first of Chapman & Martland's (1997) factor groupings. It is also often used as a measure of economies of scope for railways. The prior expectation on this variable is positive, as it seems unlikely that Australia's relatively lightly travelled track would have reached economies of density.

Passenger Journeys (PJ)

The number of passenger journeys made in a year. This may have a positive or negative influence on productivity. If more passenger journeys are made using existing rolling stock, then this could increase productivity. However, passenger trains are usually given absolute priority over freight trains on rail networks in Australia, meaning that a freight train might be required to wait for hours in a passing loop so that a passenger train can maintain its schedule. To the extent that freight trains are a more productive use of a railways overall assets, and to the extent that increasing passenger journeys crowd-out freight trains, this may result in a decrease in productivity.

Proportionate Increase in Passenger Train km (PASS)

This variable endeavours to capture the effect mentioned above whereby passenger trains displace freight trains. It is constructed by dividing an index of passenger train km by an index of all other train km. The expectation is that this variable will have a negative coefficient; that a railway substituting freight train km for passenger train km will experience a reduction in productivity.

Proportion of Train Kilometres Accounted for by Steam Locomotives (SP)

Perhaps the most pervasive technical change in the railways during the Twentieth Century was the shift from steam to diesel. Diesel locomotives are much more efficient than steam. They require fewer staff to operate them and have lower fuel expenses. They are also more easily maintained, and require much less work to prepare for use. Lee (2007) has much more detail on the sources of productivity gain from the use of diesel locomotives, and these efficiency gains were magnified in Australia due to the rather dilapidated state of much of the steam fleet (Gunn, 1989). It would thus be expected that, in the roughly 20 years from 1950 to 1970 when Australian railways undertook the switch from steam to diesel, that productivity at these railways would increase rapidly. Indeed, this is what we see, by and large, in Figure One. Since this variable measures the proportion of train miles accounted for by steam locomotives, the prior expectation on the sign of its coefficient is negative.

Minerals Tonnage (MINT)

This variable measures the tonnes of minerals hauled by the railways. Net tonne kilometres would have been a better measure, but these were not available for most of the railways prior to World War Two. Since minerals are usually hauled in unit trains, the most efficient form of freight transport, an increase in minerals traffic, *ceteris paribus*, should increase productivity. Thus, the prior for this variable is positive.

Proportionate Increase in Minerals Tonnage (MIN)

Since gross increases in minerals tonnages might be associated with all freight increasing, rather than minerals traffic coming to greater prominence, we also explore a proportional measure, similar to that used for passenger traffic above. This variable is constructed as the index of minerals freight tonnages divided by the index of all other forms of freight haulage. It is expected to have a positive coefficient.

Real GNP (RGNP)

This variable captures economic growth over the period analysed. GNP was used instead of GDP, because GDP figures were not available for the whole time period. The figures from 1900 to 1960 are from Butlin (1962) and the figures from 1960 are from the ABS (various years). All figures are expressed in real 1992 dollars. It is not clear what the prior on real GNP should be. On the one hand, as the economy grows, one would expect rail traffic to increase as well. However, the history of Australia's railways has been one of losing modal share to road in the post-war period. Also, the GNP figure is a national figure and, to the extent that growth in a state served by a railway differs from national growth, this variable might not be strongly correlated with productivity. This is especially the case for states like WA and Queensland, where minerals booms can result in periods where state growth and national growth are quite different.

Population (POPN)

This is the population in each state, and for Australia as whole for CR/AN (all indexed). Like growth in the economy, one might expect population growth to result in greater opportunities for the railways (it may in fact form a weak proxy for state-based economic

growth) or, alternatively, if people eschew rail for other modes of transport, then the coefficient may be negative.

Real Revenue (RREV)

This shows real gross revenues for each of the railways in each year. Real revenues are used in lieu of profits because the profit statements of Australian railways are often not a very good guide to performance. As organisations owned by their State governments, the railways remitted profits to State treasuries, and received funds for capital investment from them. However, since the latter were often not forthcoming, the railways would often retain earnings to fund maintenance of assets rather than replacing them for want of sufficient capital grants. Real revenues could be positive or negative in their impact on productivity. The railways often pursued growth in services with high public benefits, but little revenue. Even if they did so productively, one would thus not necessarily expect revenue growth to be positively correlated with productivity growth. However, as Butlin, Barnard & Pincus (1982) note, a lack of focus on revenues can also lead to a lack of focus on costs and thence to an inefficient use of inputs, which would reduce productivity. Thus, a growing railway not paying attention to revenues may in fact become less productive over time as it uses its assets less efficiently.

Dummy Variables

Dummy variables are used to capture some key events in the history of each of Australia's railways. These were:

- **WAR:** given a value of one for each year of the First and Second World War (when rail assets were used particularly intensively) and zero otherwise.
- **OIL:** given a value of one from 1972 to 1981 and zero otherwise, the variable is intended to capture a period of very high input cost inflation coupled with fares and charges kept constant as part of government initiatives to combat inflation. The period resulted in massive debt increases for almost all of Australia's railways.
- **WEBB:** In 1923, William Webb, an American, was employed at great expense as the Commissioner of the South Australian railways. Webb immediately embarked upon a major programme of reform and modernisation. This reform, which Webb made little effort to sell to local stakeholders, was both very costly and deeply unpopular (see Jennings, 1990). The high costs associated with new capital purchases and upgrades lead, unsurprisingly, to an immediate drop in productivity in the middle of the decade as the railway became over-capitalised. Webb managed to claw back some of this productivity loss through application of improved operating procedures during the latter part of the decade, but when he left office in 1930 these unpopular management reforms were immediately reversed. With expensive infrastructure additions but without the operational procedures to make best use of them, South Australia's railways stagnated for almost 50 years.
- **ELEC:** In 1915, Melbourne began electrifying its urban rail network. Sydney followed in 1927, and Brisbane in 1979. This dummy variable endeavours to capture productivity increases related to this electrification.
- **AN:** In 1978, AN absorbed the railway operations of South Australia and Tasmania, resulting in a massive decrease in its productivity, which it began to claw back in the early 1980s. This variable is zero prior to the takeover in 1977 and one thereafter. It

picks up, in a rather crude fashion, the changes that occurred in the railway consequent to the takeover, and is used in lieu of a structural break, because there are insufficient observations after the break point for robust estimation.

Modelling and Results

The relationship between TTFP and the nine of the explanatory variables above was modelled using an error correction framework which separates out the short-run from the long-run reversion to trend by use of a cointegrating vector to account for non-stationarity in the data.⁵ Most of the railways exhibit homoscedasticity and no serial correlation, but for those exhibiting heteroscedasticity, White's (1980) heteroscedastic-consistent covariance matrix was used, and for those exhibiting serial correlation (only Victoria and WA), Newey & West's (1987) covariance estimator for models containing autocorrelation was used to obtain consistent results for the estimated parameters. Where there is evidence of structural breaks (Queensland, South Australia and Tasmania) the sub-periods are estimated separately. Modelling was undertaken using SHAZAM (Northwest Econometrics, 2004) and, where structural breaks occurred, each sub-sample was modelled separately. Model diagnostics, including heteroscedasticity and serial correlation results, are presented with each model.

Table One presents the results for NSW.

Table One: NSW Regression Results – 1901-1992

<i>Variable</i>	<i>Coefficient</i>	<i>t-ratio</i>	
STF	- 0.2054	-3.7330	
DEN	-0.0413	-0.2555	
PJ	0.1098	3.3230	
PASS	0.0752	0.8446	
SP	-0.4933	-2.2320	
MINT	0.1578	4.5410	
MIN	0.1543	5.0540	
RGNP	0.1032	2.9040	
POP	- 0.7543	-2.7600	
RREV	- 0.0746	-1.2830	
LECV	0.7909	9.8080	
WAR	0.0119	0.2481	
ELEC	0.0186	0.1647	
OIL	0.0626	0.8301	
CONSTANT	2.1923	4.8410	
Diagnostic Test Results		Heteroscedasticity Tests	
Durbin-Watson	2.0173	e ² on Y-hat	7.4220
R-Squared	0.9832	e ² on (Y-hat) ²	6.0280
Adjusted R-Squared	0.9801	Arch (Engle (1982))	0.0040
Log of Likelihood function	68.5406	Harvey (1976)	22.8700
F-Test	321	Glejser (1969)	40.9740

⁵ The dummy variables and the SP variable were not included in the cointegrating framework. The former are zero one and the latter ranges between zero and one, and hence cannot by construction be non-stationary.

The results accord, for the most part, with expectations. Staffing levels are inversely related to productivity, which suggests that staff reductions are associated with improving productivity, particularly in the 1980s when staff reductions were largest and associated with major improvements in productivity. Note also the relatively large and negative coefficient associated with the SP variable; clearly, the switch from steam to diesel had a substantial impact upon the productivity of NSW railways.

Both of the minerals traffic variables are positive and significant, highlighting the way in which minerals traffic underpinned post-war rail productivity in the NSW railways. Passenger journeys are positive and significant, but the proportional passenger variable, although positive, is not significant. This suggests that passenger growth increased, but only at roughly the same rate as overall traffic growth. GDP also has a positive coefficient, suggesting that the railways grew as the national economy did so.

Population and real revenue both have negative coefficients. In the latter case, the coefficient is not significant, but we might conclude that revenue was not tied particularly strongly to productivity. This does not seem unreasonable given the way in which the railways were operated on a public service basis and not for profit. The former, is less clear. It might be reflective of the fact that population grew in NSW in areas not served by rail, and hence provided no impetus for more productive rail services.

Table Two presents the results for Victoria.

Table Two: Victoria Regression Results – 1901-1992

<i>Variable</i>	<i>Coefficient</i>	<i>t-ratio</i>	
STF	-0.2899	-3.633	
DEN	0.1963	1.213	
PJ	0.1531	2.895	
PASS	-0.0009	-0.014	
SP	-0.4338	-2.601	
MINT	-0.0290	-2.478	
MIN	0.2071	3.556	
RGNP	0.0177	2.391	
POP	-0.1033	-0.688	
RREV	-0.1249	-4.661	
LECV	0.5810	6.081	
WAR	-0.0139	-0.4162	
ELEC	-0.0941	-2.001	
OIL	0.0239	0.5467	
CONSTANT	1.4368	4.886	
<i>Diagnostic Tests</i>		<i>Heteroscedasticity Tests</i>	
Durbin-Watson	2.3606	e ² on Y-hat	8.7950
R-Squared	0.9406	e ² on (Y-hat) ²	8.1500
Adjusted R-Squared	0.9298	Arch (Engle (1982))	2.9300
Log of Likelihood function	101.1310	Harvey (1976)	35.2320
F-Test	87	Glejser (1969)	44.9890

In terms of staffing, passenger journeys and steam, the results are similar to those for NSW. The minerals results seem at first glance to be anomalous; mineral tonnages have a negative effect whilst the proportional growth of minerals freight tonnages has a positive effect. This may simply reflect an imperfection in the model. Alternatively, it may reflect the fact that all freight, including minerals, grew at a slower rate than productivity (and declined at points when productivity increased), but that minerals freight growth was closer to productivity growth rates than were other freight types.

Revenues too, have a statistically significant negative coefficient. This is suggestive of inefficient growth on the part of the Victorian railway; rather than providing more services which the system could perform efficiently and divesting itself of services which it provided inefficiently, the Victorian railways did the opposite. In contrast to NSW, density here has a positive coefficient, but it is not significant (the same as NSW). This suggests, perhaps, that neither railway was making sufficient use of its infrastructure for density to be an important part of the productivity equation. Finally, the coefficient for electrification is negative, suggesting that electrifying Melbourne's suburban rail network decreased productivity. This finding is anomalous, but it may be driven by other underlying factors which differentiate the Victorian railways prior to and post the First World War, when electrification began, but for which we do not have data.

Queensland's railways have two structural breaks. Table Three refers to the period prior to 1950, whilst Tables Four and Five refer to the periods from 1950 to 1970, and post 1970 respectively. Roughly speaking, the first period is one of decline for the railway, the second encapsulates the advent of diesel, whilst the third covers the period when coal traffic became increasingly important for Queensland Rail.

Table Three: Queensland Regression Results – 1901-1950

<i>Variable</i>	<i>Coefficient</i>	<i>t-ratio</i>	
STF	-0.1490	-3.8850	
DEN	0.2260	1.3710	
PJ	-0.1183	-3.4640	
PASS	0.0482	0.5583	
MINT	-0.2696	-3.8880	
MIN	0.0654	1.6850	
RGNP	0.3231	6.4920	
POP	-0.7611	-5.6470	
RREV	-0.0052	-0.1426	
LECV	0.4220	3.0470	
WAR	0.0102	0.3403	
CONSTANT	1.7204	8.467	
<i>Diagnostic tests</i>		<i>Heteroscedasticity Tests</i>	
Durbin-Watson	1.8909	e ² on Y-hat	2.099
R-Squared	0.9358	e ² on (Y-hat) ²	1.763
Adjusted R-Squared	0.9172	Arch (Engle (1982))	0.992
Log of Likelihood function	61.4419	Harvey (1976)	4.563
F-Test	50.348	Glejser (1969)	3.715

In the period shown in Table Three, productivity in Queensland's railways declined initially, and then sat in a trough for decades. The negative coefficient on staffing reflects the fact that staff numbers in fact increased during this period, whilst productivity did not. The negative coefficients on population, passenger journeys and minerals tonnages is suggestive of a phenomenon similar to that in Victoria; inefficient growth. However, in Victoria, positive coefficients on one (each) of the passenger and minerals traffic variables suggests that inefficiencies were associated with other haulage tasks (most likely small parcels services, which are particularly inefficient), but in Queensland prior to 1950, the negative coefficients for both passenger and minerals freight suggests the inefficiencies were across the board.

Table Four: Queensland Regression Results – 1950-1970

<i>Variable</i>	<i>Coefficient</i>	<i>t-ratio</i>	
STF	-0.1221	-1.6190	
DEN	0.2467	1.0330	
PJ	-0.0952	-0.7634	
PASS	0.5662	1.7270	
SP	-0.5118	-1.6930	
MINT	0.1710	4.5660	
MIN	-0.0014	-0.0717	
RGNP	-0.0528	-0.9329	
POPN	-0.5515	-2.1390	
RREV	-0.0175	-0.5792	
LECV	-0.7313	-2.8580	
CONSTANT	2.3693	1.9170	
<i>Diagnostic tests</i>		<i>Heteroscedasticity Tests</i>	
Durbin-Watson	2.0444	e ² on Y-hat	0.204
R-Squared	0.991	e ² on (Y-hat) ²	0.204
Adjusted R-Squared	0.9801	Arch (Engle (1982))	0.004
Log of Likelihood function	45.6453	Harvey (1976)	7.976
F-Test	90.495	Glejser (1969)	9.9

During the period from 1950 to 1970, minerals traffic was beginning to grow, and the conversion from steam to diesel took place. This can be seen in the negative coefficient on steam and the positive coefficient on minerals tonnages. The coefficient on the proportional growth of minerals freight is negative, but it is not significant, which suggests that, although minerals are beginning to become an important freight task during this period, they are yet to fully underpin the productive operations of the railway, as they later did. Note the now non-significant coefficient on staff numbers. Queensland was reducing its staffing numbers during this period, and it would seem that this was having an effect on productivity insofar as excess staff were becoming less of an issue. This is confirmed during the following period (see table Five). Note also the switching signs on the coefficients of the mineral freight variables. Formerly, Queensland was like Victoria in terms of its minerals freight, now it is moving more towards NSW.

The other interesting aspect of this period is the negative, but not significant coefficient on steam, which suggests a rather weak response in productivity to dieselisation. This may be because much of the network in Queensland was not suited to diesel. Much of the Queensland system was designed to take light and infrequent traffic at low speeds, and it took some years to replace these lines with lines of sufficient strength to carry the faster and heavier loads facilitated by dieselisation (see Kerr, 1998, for more details). Hence any productivity benefits inherent in diesel locomotives were stalled whilst the infrastructure caught up with the rolling stock. Even now, this replacement process is incomplete. This means that Queensland Railways have not been able to take full advantage of the productivity improvement potential of dieselisation.

Table Five: Queensland Regression Results – 1970-1992

<i>Variable</i>	<i>Coefficient</i>	<i>t-ratio</i>	
STF	-0.1307	-0.7240	
DEN	-3.2569	-11.8200	
PJ	-0.3202	-6.9800	
PASS	0.8517	0.7405	
MINT	0.0565	8.3740	
MIN	0.1422	6.3420	
RGNP	-0.1392	-4.8220	
POP	0.0510	0.3313	
RREV	-0.0820	-2.4090	
LECV	-0.9821	-2.4260	
ELEC	-0.0128	-0.2712	
OIL	-0.0499	-1.1450	
CONSTANT	7.5256	8.7170	
<i>Diagnostic Tests</i>		<i>Heteroscedasticity Tests</i>	
Durbin-Watson	2.6402	e ² on Y-hat	0.14
R-Squared	0.9967	e ² on (Y-hat) ²	0.142
Adjusted R-Squared	0.9918	Arch (Engle (1982))	0.09
Log of Likelihood function	33.036	Harvey (1976)	4.868
F-Test	201.682	Glejser (1969)	8.112

From 1970 minerals became the dominant haulage task of Queensland's railways, with coal being the most important mineral. This is reflected by the positive and significant coefficients on both minerals traffic variables, an important change from previous periods. Staffing is still negative, but it is no longer significant, which is suggestive of productivity gains from reducing staff having largely been played out by 1970. In fact, from 1975, Queensland Rail started increasing its staff numbers again. Also of interest is the negative, significant coefficient on passenger journeys, which is perhaps reflective of the fact that passenger journeys in this period are beginning to constrain more productive coal and minerals traffic. One seemingly anomalous result is the very large negative coefficient for density. In all likelihood, this points to some problem in model specification for the Queensland railways, but it might also reflect diseconomies of scope. That is, as Queensland Rail began to focus more and more on coal haulage, the degree to which it could integrate this task with its other tasks was reduced.

South Australia has a structural break at 1950, and hence two sets of results are presented. Table Six covers the period to 1950, whilst Table Seven covers the period from 1950 to the takeover of South Australia's railways by CR/AN in 1977.

Table Six: South Australia Regression Results – 1901-1950

<i>Variable</i>	<i>Coefficient</i>	<i>t-ratio</i>	
STF	-0.0555	-1.6490	
DEN	0.2127	2.6080	
PJ	-0.0428	-0.9083	
PASS	0.0269	0.9397	
MINT	0.0710	1.4950	
MIN	-0.0397	-1.4350	
RGNP	0.0160	0.5858	
POP	-0.0980	-0.5241	
RREV	0.1973	2.6230	
LECV	-0.1030	-1.2170	
WAR	0.0784	3.3660	
WEBB	0.5792	10.8800	
CONSTANT	0.2784	1.2530	
<i>Diagnostic Tests</i>		<i>Heteroscedasticity Tests</i>	
Durbin-Watson	1.9767	e ² on Y-hat	6.702
R-Squared	0.9748	e ² on (Y-hat) ²	6.988
Adjusted R-Squared	0.9667	Arch (Engle (1982))	0.043
Log of Likelihood function	77.1646	Harvey (1976)	12.946
F-Test	119.468	Glejser (1969)	16.146

As with Queensland during the same period, a declining productivity is associated with rising staff levels, leading to a negative relationship between the two variables. However, the fact that the staffing coefficient is only significant at the ten percent level may point to over-staffing being less of an issue during the first half of the century. A very strong negative equipment productivity (following Chapman & Martland, 1997) effect can be seen in the Webb dummy; Webb's overhaul of the South Australian railways and the subsequent discontinuance of his reforms had a profoundly negative effect on the productivity the railways had formerly been enjoying. Unlike many of the other railways, both density and revenue are positive, which perhaps reflects the fact that, early in the century, railways were profitable, and achieving economies of density. War was also good for South Australia's railways. However, neither passenger nor minerals transport seems to have had much of an impact upon the railway's productivity.

Table Seven: South Australia Regression Results – 1950-1977

<i>Variable</i>	<i>Coefficient</i>	<i>t-ratio</i>	
STF	-0.3597	-4.0190	
DEN	-0.0882	-1.0970	
PJ	0.5212	4.2170	
PASS	-0.3637	-5.2700	
SP	0.3932	3.0780	
MINT	0.0870	2.1730	
MIN	0.0197	0.6612	
RGNP	0.0028	0.1336	
POPN	0.6585	3.0680	
RREV	-0.1289	-2.3400	
LECV	0.1820	1.1400	
OIL	-0.2193	-2.6870	
CONSTANT	-0.5614	-1.8460	
<i>Diagnostic Tests</i>		<i>Heteroscedasticity Tests</i>	
Durbin-Watson	1.9921	e ² on Y-hat	0.575
R-Squared	0.9876	e ² on (Y-hat) ²	0.339
Adjusted R-Squared	0.9769	Arch (Engle (1982))	0.327
Log of Likelihood function	56.0758	Harvey (1976)	31.751
F-Test	92.605	Glejser (1969)	23.461

The period after 1950 shows some interesting results. Perhaps the most glaring is the coefficient on the proportion of train km operated by steam locomotives, which is in fact positive and significant. This suggests that South Australia's railways were more productive with their steam locomotives than they were with their new diesel locomotives. It is perhaps reflective of the very poor state the railways system was in prior to its takeover by the Federal Government, and also of why SA was so keen to offload the railway; if diesel locomotives actually made things worse, the railway must have been in a poor state indeed.

Another interesting feature is that passenger journeys are positive and significant, but the relative growth of passenger train km over other kinds of train km is negative, and both are significant. This suggests that passenger journey were increasing during the period, but not in proportion to freight. Also interesting is that staff numbers now have a very important negative effect on productivity. The break point at 1950 is contemporaneous with the advent of steam. Since staff numbers were only weakly significant prior to 1950 and are now strongly significant, this suggests that the problem for South Australia's railways is not over-staffing per se, but rather a very slow reaction to the fact that operating a diesel railway requires far fewer staff than does operating a railway based upon steam locomotives.

Table Eight summarises the results for Western Australia.

Table Eight: Western Australia Regression Results – 1901-1992

<i>Variable</i>	<i>Coefficient</i>	<i>t-ratio</i>	
STF	-1.4771	-5.964	
DEN	0.76196	2.528	
PJ	0.3151	3.234	
PASS	-0.067361	-0.2909	
SP	0.30216	0.147	
MINT	0.040434	3.472	
MIN	0.11585	0.8215	
RGNP	-0.11922	-1.753	
POP	1.1115	4.242	
RREV	-0.51908	-2.789	
LECV	0.72933	6.857	
WAR	-0.15729	-3.501	
OIL	0.106	0.4727	
CONSTANT	0.20831	0.413	
<i>Diagnostic Tests</i>		<i>Heteroscedasticity Tests</i>	
Durbin-Watson	2.116	e ² on Y-hat	17.359
R-Squared	0.9839	e ² on (Y-hat) ²	20.196
Adjusted R-Squared	0.9812	Arch (Engle (1982))	1.465
Log of Likelihood function	-4.70672	Harvey (1976)	23.093
F-Test	366.803	Glejser (1969)	48.027

Perhaps the most striking aspect of the WA results is the very large coefficient on staffing, which suggests that reducing staff was the most important impact on productivity for the railway. This result is important for the other railways as well. WA was amongst the first to begin reforming its railways and endeavouring to operate them on a more commercial footing. It began to do so in the 1970s, in contrast to NSW and Victoria, which began doing so roughly a decade later. Thus, more years of reforms, including reductions in staff numbers, are included for WA than they are for NSW and Victoria, meaning a greater effect of staffing reductions than these other states.

Also different from the other railways is the positive and significant impact of population. Since Perth has a relatively small urban transit system, it seems unlikely this is the driving factor. Instead, population growth may be picking up the growth of the local economy, which can often be out of step with national economic growth due to the prevalence of the minerals industry in WA. This may also account for the relatively weak RGNP results.

Here, minerals tonnages are a significant positive impact on productivity, but not the relative increase of such tonnages over an above other freight. This suggests an increase in minerals tonnages, but not enough that they drove productivity as occurs in Queensland and NSW. It is worth noting that the WA figures include only the public rail system in the South of the State, not the iron ore railways in the Pilbara. Whilst minerals traffic did increase on the public rail system beginning in the late 1960s, other freight also

increased, meaning the proportional share of minerals freight did not increase by as much. Again, as for Victoria, revenues are negatively associated with productivity. This may be reflective of the same phenomena as in that state. Unlike Victoria and NSW, the coefficient on steam is positive, but not significant. This may indicate that, like Queensland, WA's railways were not as able to take advantage of the potential productivity-enhancing benefits of diesel as quickly as other states and hence that such benefits may have taken some time to flow through. There is reason to think this finding has some merit. Much of the WA rail network is very light narrow gauge, laid down before WWII to support grain production and the settlement of the South West. Heavy diesel locomotives could not operate optimally on this track, and hence it would have taken some time for the full benefits of diesel to become apparent.

Finally, WA is the only railway to have had a bad war; with a significant, negative coefficient on the wartime dummies. This may be associated with overuse of the railway's assets during the war. Since the coefficient on railway density is positive and significant, WA's railway may have already been capturing economies of density prior to each war, and increases in track usage thus did not improve productivity, but rather had the opposite effect.

Tasmania is something of an anomaly in Australia's railways; it is a relatively small system, and it is not connected to the mainland system owing to Tasmania's island status. Thus, it is not surprising that some differences emerge between it and the mainland systems. Tasmania is also broken into three distinct eras. The first of these covers the period prior to 1918. The second covers the period from 1918 to 1950, and the last covers the period from 1950 to 1977, when the railway was taken over by CR/AN along with (most of) the assets of South Australia's railways.

Table Nine: Tasmanian Regression Results – 1901-1918

<i>Variable</i>	<i>Coefficient</i>	<i>t-ratio</i>	
STF	-0.6390	-2.8590	
DEN	0.0065	0.0445	
PJ	0.2272	3.5850	
PASS	0.6630	5.6000	
MINT	0.1603	1.5240	
MIN	0.0688	0.4102	
RGNP	-0.5830	-4.9890	
POP	0.2138	0.2858	
RREV	0.7872	5.0030	
LECV	-0.6058	-4.4710	
WAR	0.2062	5.1490	
CONSTANT	0.1192	0.1405	
<i>Diagnostic Tests</i>		<i>Heteroscedasticity Tests</i>	
Durbin-Watson	1.8927	e ² on Y-hat	0.007
R-Squared	0.9585	e ² on (Y-hat) ²	0.018
Adjusted R-Squared	0.8825	Arch (Engle (1982))	0.141
Log of Likelihood function	36.4027	Harvey (1976)	8.858
F-Test	12.605	Glejser (1969)	12.172

Although one must be careful about ascribing too much to such a short time period (which leaves few degrees of freedom for the model), some inferences are possible. During this period, the importance of the railway as a form of land transport for passengers is clearly shown, with both of the passenger variables showing significant, positive results. Minerals traffic, however, is not significant; what minerals traffic there was in Tasmania was largely hauled by private railways, particularly the Emu Bay line. There is also a positive relationship between productivity and revenue, which vanishes after WWI, only to return in the 1950s to 1970s. Again, like very railway, there is a negative relationship between staffing levels and productivity. WWI also seems to have increased the productivity of Tasmania's railways, perhaps because a reasonable proportion of its staff went to war to fight, and the railway thus performed a similar output with fewer staff.

Table Ten: Tasmanian Regression Results – 1918-1950

<i>Variable</i>	<i>Coefficient</i>	<i>t-ratio</i>	
STF	-0.2748	-2.7940	
DEN	0.2890	1.6450	
PJ	0.1323	2.3480	
PASS	-0.2251	-2.3940	
MINT	-0.0190	-1.1540	
MIN	0.1917	1.9920	
RGNP	0.0151	0.1789	
POP	-0.8308	-1.0840	
RREV	-0.4134	-3.9420	
LECV	0.2289	1.3550	
WAR	0.0284	0.6094	
CONSTANT	2.5303	2.9030	
<i>Diagnostic Tests</i>		<i>Heteroscedasticity Tests</i>	
Durbin-Watson	1.7775	e ² on Y-hat	4.765
R-Squared	0.8565	e ² on (Y-hat) ²	4.893
Adjusted R-Squared	0.7775	Arch (Engle (1982))	0.453
Log of Likelihood function	50.0959	Harvey (1976)	18.461
F-Test	10.85	Glejser (1969)	14.982

In the period from WWI to 1950, the characteristics of Tasmania's railways changed considerably. Revenue is now negatively associated with productivity, which is perhaps suggestive of the railways gradually worsening productivity. War no longer increases productivity, as it did in WWI, which is perhaps because staffing actually increased in the Second World War, rather than decreasing. A shift in haulage is also apparent; now increasing passenger haulage is associated with lower productivity, whilst minerals haulage has begun to positively affect it.

Table Eleven: Tasmanian Regression Results – 1950-1977

<i>Variable</i>	<i>Coefficient</i>	<i>t-ratio</i>	
STF	-2.5179	-4.0190	
DEN	0.3184	0.9892	
PJ	0.1352	0.7549	
SP	1.0348	2.0220	
PASS	-0.1779	-0.8153	
MINT	0.1097	3.1520	
MIN	0.5057	6.7430	
RGNP	0.1742	2.6350	
POP	-1.5138	-1.1680	
RREV	0.8218	4.7070	
LECV	-0.0583	-0.2580	
OIL	-0.1506	-1.4720	
CONSTANT	2.6617	1.1340	
<i>Diagnostic Tests</i>		<i>Heteroscedasticity Tests</i>	
Durbin-Watson	2.1934	e ² on Y-hat	0.001
R-Squared	0.9833	e ² on (Y-hat) ²	0
Adjusted R-Squared	0.9689	Arch (Engle (1982))	0.212
Log of Likelihood function	27.2757	Harvey (1976)	9.001
F-Test	68.573	Glejser (1969)	10.736

The advent of diesel locomotives in Tasmania, like in South Australia, did not assist productivity. In fact, it would appear that Tasmania's railways did worse with diesel than with steam. This may be partially reflective of the appropriateness of the infrastructure for diesel locomotives, and partially reflective of the very poor state of the Tasmanian railways prior to their takeover.

Table Twelve summarises the results for CR/AN. Of all of the railways, these results are perhaps the least robust because during the latter half of the 1970s, the railway absorbed the operations of South Australia's railways (outside the Adelaide metropolitan passenger service) and Tasmania, resulting in a large increase in costs and a massive drop in productivity from which it took several years to recover. This was almost certainly a structural change in the operations of the railway, but it is difficult to test, because it happened too close to the end of the period of analysis. Since this structural break almost certainly affected both the slope and the intercept of the regression, it is captured only crudely by the AN dummy, which captures only the intercept effect.

Table Twelve: CR/AN Regression Results – 1922-1992

<i>Variable</i>	<i>Coefficient</i>	<i>t-ratio</i>	
STF	-0.36636	-4.404	
DEN	1.2094	8.803	
PJ	-0.15692	-3.162	
PASS	0.23809	1.193	
SP	0.13320	0.5016	
MINT	0.00412	1.582	
MIN	-0.0057	-0.9804	
RGNP	-0.36202	-2.600	
POPN	4.1147	4.841	
RREV	0.01589	0.3947	
LECV	0.30208	2.086	
WAR	0.21325	1.641	
AN	2.9212	7.990	
OIL	0.38382	2.015	
CONSTANT	-3.6949	-3.165	
Diagnostic Tests		Heteroscedasticity Tests	
Durbin-Watson	1.8257	e ² on Y-hat	5.884
R-Squared	0.9725	e ² on (Y-hat) ²	4.999
Adjusted R-Squared	0.9655	Arch (Engle (1982))	1.152
Log of Likelihood function	-10.1345	Harvey (1976)	11.262
F-Test	138.960	Glejser (1969)	21.129

The very large coefficient on the AN variable, occurs most likely because the takeover of the two railways reduced productivity dramatically at CR/AN, before the railway was able to absorb its new assets, and return to the productivity levels it had previously enjoyed . Perhaps the most anomalous finding for CR/AN is the very large positive coefficient associated with the growth of Australia’s population. This may be picking up economic growth effects, but it seems more likely to be an anomaly associated with the takeover, as it is neither large nor significant prior to 1975. Like WA, the coefficient on steam is positive, but not significant, but unlike WA, CR/AN had track better suited to diesel locomotives. It seems likely that this coefficient is being driven by the poor adaptation to diesel of South Australia and Tasmania (see Table 13).

Since the absorption of the railways of South Australia and Tasmania had such a major effect on CR/AN, it is useful to examine the railway before this occurred. Table Thirteen provides the results of the same model applied to CR/AN from 1922 to 1975.

Table Thirteen: CR/AN Regression Results – 1922 to 1975

<i>Variable</i>	<i>Coefficient</i>	<i>t-ratio</i>	
STF	0.06183	0.5347	
DEN	0.20749	1.161	
PJ	0.0355	0.6929	
PASS	-0.6462	-3.414	
SP	-1.4326	-4.576	
MINT	0.00562	2.220	
MIN	0.23253	5.321	
RGNP	-0.0697	-0.3423	
POPN	-1.0816	-1.007	
RREV	-0.0925	-2.567	
LECV	0.32623	2.589	
WAR	-0.18020	-1.723	
OIL	0.17987	1.282	
CONSTANT	3.8259	2.617	
Diagnostic Tests		Heteroscedasticity Tests	
Durbin-Watson	1.8161	e ² on Y-hat	0.05564
R-Squared	0.9875	e ² on (Y-hat) ²	0.16147
Adjusted R-Squared	0.9834	Arch (Engle (1982))	0.04624
Log of Likelihood function	20.4883	Harvey (1976)	0.27874
F-Test	242.862	Glejser (1969)	0.05127

The results prior to 1975 appear more in line with the other railway; density is positive (though not significant), minerals traffic has a positive effect and the large, anomalous result for population has vanished, suggesting it is an artefact of the absorption. Note also the non-significant coefficient on staff numbers. Although not definitive, it suggests perhaps that CR/AN did not have problems of over-staffing, or if it did, that these were of a less significant nature than was the case at other Australian railways. This stands in contrast to Brunker (1992), but Brunker was looking at the railway after it had absorbed the railways of South Australia (outside Adelaide metro-rail) and Tasmania, a process in which CR/AN had to also absorb large numbers of new staff.

Conclusions and Policy Ramifications

There are perhaps four useful conclusions which can be drawn from this analysis of productivity. The first is rather obvious; railways which have expanded into the niche of providing unit train haulage of minerals have, through doing so, increased their productivity dramatically.

The second relates to staffing. On the face of the evidence in Tables One through 13, it would seem clear that reducing staff is a good way for railways to increase productivity; the coefficient on staff is negative and significant for almost all railways at least at some point during the timeframe of analysis. This supports the “over-staffing” hypothesis that has been a consistent theme on the part of policymakers for roughly the past two decades (see for example, Industry Commission, 1991, and the references cited therein). However, the reality is rather more subtle than this. The results on staffing for South

Australia prior to 1950, Queensland after 1950 and CR/AN before it took over the railways of South Australia and Tasmania provide only very weak evidence of an inverse correlation between staff numbers and productivity. NSW, Victoria and WA provide stronger evidence, but to explore the robustness of this evidence, we examined sub-periods for these railways. The results are described in Table 14 below.⁶

Table Fourteen: Staff Numbers and Productivity in NSW, Vic & WA in Periods Prior to 1992

	NSW		Vic		WA	
	<i>Coefficient</i>	<i>t-score</i>	<i>Coefficient</i>	<i>t-score</i>	<i>Coefficient</i>	<i>t-score</i>
1900-1980	-0.14542	-2.941	-0.21242	-3.449	-0.69672	-3.167
1900-1970	-0.07354	-1.382	-0.11792	-1.947	-0.49981	-4.803
1900-1960	-0.05938	-1.228	-0.12265	-2.248	-0.38113	-4.172
1900-1950	-0.03713	-0.663	-0.09867	-1.635	-0.23085	-1.385
1900-1940	-0.07399	-0.858	-0.16405	-1.942	-0.21910	-1.125

The results are fairly clear; not only are the coefficients, in general, becoming smaller the shorter is the time period, but they are also, in general, becoming less significant. Our hypothesis, in regards to staffing, is therefore as follows; Australia's railways (with the exception of Tasmania) had roughly the right number of staff to operate a steam-powered railway efficiently circa 1950. Operating a diesel-powered railway requires far fewer staff and, although the railways began reducing staff numbers when they introduced diesel trains, not all were unable to do so sufficiently rapidly to prevent excess staff from reducing the productivity which they might otherwise have obtained.⁷ Given that the railways were owned by State governments, and were heavily unionised, a slow reaction speed was perhaps not surprising. However, the evidence here of the railways being somehow fundamentally sclerotic in relation to their labour practices (as the Industry Commission, 1991, suggests) is rather weak.

The third lesson is that technological change does not necessarily bring productivity improvement. One would expect, given the potentially large differences in productivity between steam and diesel locomotives, that a railway switching from the former to the latter would receive an immediate productivity boost. However, the full benefits of diesel locomotive technology can only be enjoyed if the track and other infrastructure are optimised for use by diesel locomotives, and if the railway can adjust its staffing profile (see above). In particular, from the perspective of the below-rail infrastructure, light track with many curves (suitable for smaller, lighter steam trains) does not allow diesel locomotives to maximise their productive capacity. Some railways were able to change their track infrastructure more rapidly (or were fortunate to have track already better suited to diesel locomotives), and hence enjoyed more of the productivity benefits which diesel can bring sooner (NSW Victoria and CR/AN). Others took some years to alter

⁶ Further details on each of these regressions are available from the authors upon request. Here we focus just on the staffing effects.

⁷ NSW, Queensland and CR/AN do seem to have adapted relatively quickly, as suggested by the evidence in Tables Four, Five, 13 and 14. In particular, NSW (Table 14) seems to have adapted to dieselisation by 1960, as its coefficient on staffing is not significant. However, at some point in time between 1970 and 1980, something else affected the railways of NSW which meant that overstaffing again became an issue. It is not clear what that something else was, given the data in our models.

their track infrastructure (WA and Queensland). Still others proved unable to adapt to their new diesel locomotives, and actually performed less efficiently with diesel locomotives than they had with steam (SA and Tasmania). This is an important lesson for policymakers going forward; disruptive shocks to one part of the rail system, like rolling stock technology, are not necessarily enough in their own right to improve productivity, which requires a more holistic approach to railway operations and management.

It is conceivable, given their large fixed costs and complexity, that railways have technical limits to scale and scope beyond which they cannot efficiently expand regardless of how well they are managed because, given the technology of the day, the rail system is too complex to be effectively controlled from head-office. Thus, one would not expect size measures like revenue growth or density to be positively correlated with productivity over the whole range of their possible values. However, Australian railways are quite small on a global scale, and it seems unlikely that any have reached such technical limits. Moreover, it is the smaller railways, in general, that show a negative relationship between revenues and productivity, not the larger railways. This suggests that, rather than technical possibilities being the limiting factor, the railways concerned were poorly governed; rather than pursuing business opportunities that could enhance their overall productivity, they expanded into haulage tasks that left them less efficient. Given the pervasive influence of political factors on the railways, it seems unlikely that the blame for this poor governance can be laid solely at the feet of the relevant Commissioners who managed the railways. As Hensher et al (1995) point out, where railway managers were given the ability to manage themselves with a commercial focus, they were able to do so effectively. The lessons for railway policy going forward are therefore two-fold. Firstly, political influence over railway haulage tasks has not disappeared, and politicians and lobby groups which seek to influence the direction railway businesses should take should be aware that the ability of a given railway system to absorb tasks which use its assets inefficiently is rather limited. Secondly, it is not axiomatic that all growth improves railway productivity; the nature as well as the size of the growth, clearly matters.

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Appendix: Data Issues

There are two further important issues to address in a long time series such as this; stationarity and structural breaks. Turning first to stationarity, Table A1 provides a summary of the results of the stationarity tests conducted. Owing to the presence of serial correlation, the Phillips (1987) - Perron (1988) test was favoured over the Dickie Fuller test, although both gave similar results in terms of stationarity. The relevant critical values for each test are as follows:⁸

- A(1)=0 z-test -11.2
- A(1)=0 t-test -2.57
- A(0)=a(1)=0 3.78

The test statistics, presented in the same order as the critical values, are presented in Table A1.

Table A1: Stationarity Test Results

	NSW	Vic	Qld	SA	WA	Tas	Comm.
<i>TTFP</i>	4.572 2.5615 6.2492	-4.7572 -1.5692 1.2922	7.3872 6.1506 24.329	-4.4405 -1.4495 1.0205	4.434 2.9901 7.9822	-1.3999 -0.43718 0.80032	-2.9727 -1.0017 0.9749
<i>STF</i>	-4.1652 -2.0274 2.1408	-5.0672 -1.7743 1.5615	-3.5469 -2.1249 2.888	-8.1878 -2.5252 3.257	-2.7005 -1.0644 0.56725	-3.2415 -1.3929 1.0043	-5.5136 -1.7669 1.6155
<i>DEN</i>	-4.2932 -1.3847 1.4173	-2.776 -1.2092 0.95903	-2.7361 -1.1459 0.8066	-8.7094 -1.9948 1.9616	-8.0574 -2.9369 4.6099	-3.369 -1.3034 0.83544	-7.6157 -1.907 1.8315
<i>PJ</i>	-2.5704 -1.8645 3.7545	-4.678 -1.9894 2.0806	-4.1431 -1.7495 2.6272	-7.8624 -2.2134 2.4435	-9.1661 -2.3293 2.7053	-1.1301 -0.50867 0.1833	-17.94 -3.2793 5.219
<i>PASS</i>	-6.5004 -1.978 2.1235	0.77666 0.24983 0.88538	-12.388 -2.6713 3.5222	-9.253 -2.4397 2.9761	-14.01 -3.0096 4.4013	-2.0788 -0.69129 0.43536	-8.0848 -2.2163 2.7908
<i>MINT</i>	4.1147 2.7826 8.5077	6.8923 -1.9773 1.9316	6.1895 6.5343 30.852	5.77E-02 1.65E-02 0.62191	3.2154 3.1104 10.344	-7.3527 -2.0609 2.1264	0.69057 0.50496 2.4294
<i>MIN</i>	-2.9459 -1.2996 1.2067	-6.9795 -2.2426 2.6571	-1.6412 -0.93314 2.1915	-0.4932 -0.21132 1.5947	0.77049 0.49289 2.1909	0.9147 0.50155 2.0793	0.38364 0.20901 1.132
<i>RGNP</i>	3.3379 7.3255 59.136	3.3379 7.3255 59.136	3.3379 7.3255 59.136	3.4251 7.1952 56.692	3.3379 7.3255 59.136	3.4251 7.1952 56.692	2.464 5.5924 46.753
<i>POP</i>	0.79802 4.017 154.79	1.048 4.0104 80.33	2.3348 14.54 372.35	1.5187 4.8622 69.517	2.0387 8.3061 139.65	1.0057 2.4729 34.309	0.99513 5.21 156.45
<i>RREV</i>	-1.7928 -0.90672 2.0838	-1.902 -0.42462 0.8701	0.5503 0.31296 2.1823	-7.1152 -2.1162 2.3016	-0.58184 -0.34803 1.3477	-3.3512 -1.5105 1.2327	-1.019 -0.5777 1.0753

⁸ These are for the tests with no trend. Results for the test with a trend also give similar results in terms of stationarity, as do the Dickie-Fuller test results, and are available from the author upon request.

As is clear, none of the variables are stationary. We are left with two options; we could either undertake the regressions in first differences, or we could endeavour to find a cointegrating vector for these ten variables, and then examine an error-correction model via the approach first suggested by Engel & Granger (1987) and now widely used. We choose the latter option, because this allows for better interpretability of results, and also because the error correction term coefficient provides a useful summary of how fast each railway responds to productivity shocks. It remains to ascertain whether there is a cointegrating relationship. For this, we use the Johansen & Juselius (1990) procedure, which also indicates how many cointegrating relationships there are. Table A2 below reports the results of the Johansen & Juselius (1990) procedure. Johansen & Juselius (1990) only provide critical values for their test results for cointegrating relationships with up to five variables. Thus, the critical values are from Osterwald-Lenum (1992). For ten variables, the critical value for the trace test statistic (LTRACE) is 232.49 at the 95 percent confidence level, and that for the maximum eigenvalue test statistic (LMAX) is 62.42.⁹

Table A2: Cointegrating Relationships Test Results

	NSW		VIC		QLD		SA	
Number of relationships	<i>LTRACE</i>	<i>LMAX</i>	<i>LTRACE</i>	<i>LMAX</i>	<i>LTRACE</i>	<i>LMAX</i>	<i>LTRACE</i>	<i>LMAX</i>
3	112.815	30.628	137.51	41.548	134.522	50.268	133.84	42.233
2	153.895	41.08	191.196	53.686	190.982	56.46	179.87	46.034
1	218.98	65.085	249.037	57.841	252.348	61.366	246.29	66.419
0	301.773	82.793	312.094	63.056	352.019	99.671	324.02	77.722
	WA		TAS		Comm.			
Number of relationships	<i>LTRACE</i>	<i>LMAX</i>	<i>LTRACE</i>	<i>LMAX</i>	<i>LTRACE</i>	<i>LMAX</i>		
3	152.95	50.787	121.015	32.154	127.724	40.697		
2	211.56	58.603	173.845	52.829	174.656	46.932		
1	276.97	65.409	232.48	58.636	239.549	64.893		
0	363.29	86.32	314.864	82.384	309.288	69.739		

In no cases are there zero cointegrating relationships. Instead, the evidence points towards a single cointegrating relationship in the case of each railway.

We now turn to the structural break tests, which must take the non-stationarity of the variables into account in order that the robust results can be obtained. We do this by incorporating an error correction variable for each sample and sub-sample, and conducting a Chow (1960) test on the results. This required us to estimate three error correction vectors and run three regressions for each structural break test, which proved

⁹ SHAZAM reports the test statistics for up to nine cointegrating relationships. In each case here there were less than three, so the results for more than three have been excluded for brevity. They are available from the authors upon request.

to be a time-consuming process.¹⁰ This procedure effectively allows for structural breaks in the intercept, the slope of the short-run part of the equation and in the long-run cointegrating relationship between the variables, and is thus a very generalised approach.

In order to conduct the structural break tests, we needed some priors about where such structural breaks might lie. Potential structural breaks were found in two ways. Firstly, a Chow (1960) test was run for each year in the sample (following Andrews, 1993) using a simple model with no error correction variable, using a function in SHAZAM (Northwest Econometrics, 2004) which facilitates this test. The results of this test are not robust, given the non-stationarity of the variables involved. However, it does provide a useful starting point of analysis. Secondly, the graphs of productivity of each railway were examined visually to ascertain any particularly obvious break points. This gave rise to the following potential break points for each railway:

NSW	1950	1972
Vic	1929	1951
Qld	1950	1970
SA	1923	1950
WA	1956	1969
Tas	1918	1950
Comm	1952	1967

Each railway contains the advent of diesel as one potential break point. Other break points include years when minerals traffic began to increase rapidly (NSW in 1972, Qld in 1970, CR/AN in 1967 and WA in 1969), the Great Depression, the end of the First World War and the Commissionership of Webb in South Australia in 1923. One might also incorporate other break points, particularly in the 1980s, when the railways changed rapidly. However, structural breaks towards the end of a time period are difficult to establish robustly, due to insufficient data in the second sub-sample.

Each of these potential break points was tested using a Chow (1960) test incorporating the error correction variable into the model as outlined above. In order that the alternate potential break point does not influence the results of the break point which is being tested for at a particular point in time, when testing the earliest potential break point for each railway, we use a sample from the first year in the whole sample (1901 for the State railways, 1922 for CR/AN) to the year before the second break point. When testing the second potential break point, we use a sample from the year after the first potential break point to the last year of the whole sample, 1992. The test statistics for each railway and each year are presented in Table A3 below. Note that a decision labelled “no” indicates that the null hypothesis of no structural break was not rejected.

¹⁰ The sub-samples were also tested for stationarity, and found to be non-stationary. Test results are available from the authors upon request.

Table A3: Structural Break Test Results

	Year	Test Statistic	Decision	Year	Test Statistic	Decision
NSW	1950	0.9556338	no	1972	0.5521758	no
VIC	1929	0.41266012	no	1951	0.6441837	no
QLD	1950	2.87401701	yes	1970	9.7436496	yes
SA	1923	1.72173832	no	1950	5.31835	yes
WA	1956	3.28227008	yes	1969	-0.307811	no
TAS	1918	4.02903656	yes	1950	5.6795389	yes
COMM	1952	3.46203605	yes	1967	0.8892682	no

The critical values differ for each railway in each year, but lie between 2.46 and 2.72. New South Wales and Victoria present no structural breaks; meaning that the relationship between the independent variables and productivity remained the same throughout the century, a rather interesting finding in its own right given the changes experienced by the railways over the century. South Australia, Western Australia and the Commonwealth Railways have one structural break apiece, and Queensland and Tasmania have two. For the Three railways with only one structural break, the Chow test was re-run, using the whole sample rather than truncating the sample at the opposing structural break. This is intended to test the robustness of the results above. For South Australia, the test statistic is 8.44, confirming the result in Table A3 above. However, for WA and the Commonwealth, the results are 1.37 and 2.28 respectively. This suggests that neither railway has a robust structural break in the 1950s, as indicated in Table A3 above. Thus, in the model results, NSW, Vic, WA and the Commonwealth have no structural breaks, SA has one, and Queensland and Tasmania have two apiece.