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710-151 Slater Street
Ottawa, Ontario
K1P 5H3

613-233-8891
csls@csls.ca

CENTRE FOR THE STUDY OF LIVING STANDARDS

FIRM-LEVEL TOTAL FACTOR PRODUCTIVITY GROWTH: CANADIAN FREIGHT RAILWAYS, 1986-2009

James Uguccioni

CSLS Research Report 2016-08

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Abstract

Canadian railways are a vital part of the country's transportation sector, moving goods and people across the country. We perform firm-level productivity analysis of Canadian freight railways for 1986 to 2009, focusing on the two railways which dominate the market: Canadian National (CN) and Canadian Pacific (CP). We obtain total factor productivity (TFP) estimates both by constructing productivity indices and by econometrically estimating cost functions. Driven in part by operational improvements, the strong TFP growth at both firms considerably outpaced aggregate TFP growth in Canada over the period of interest. This robust TFP growth, together with significant capital deepening, led to impressive labour productivity gains. We pay special attention to the productivity effects of the 1995 privatization of CN. While CN enjoyed much stronger productivity growth over the 1986-2009 period than CP, its performance was equally superior before and after the 1995 privatization.

Firm-level Total Factor Productivity Growth: Canadian Freight Railways, 1986 to 2009[1]

I Introduction

Drummond et al. (2013) argue that research at the firm-level is one of the most promising new frontiers in the productivity literature. They note that increasingly available microdata allows researchers to focus on how and why firms enter and exit a market, investigate the growth decisions faced by new, small businesses, and study managerial and operational decisions with an economic lens. The OECD (2015) points out that firm-level data also allows researchers to test the validity of industry-level findings at a finer level of detail. In a recent report by the Centre for the Study of Living Standards, Sharpe (2015) asserts that researchers ought to focus on the firm level to help policymakers develop more targeted interventions. Sharpe suggests that the increasingly available microdata at the firm level provided by Statistics Canada allows research to improve understanding of drivers of productivity growth.

Canada's two major freight railways, Canadian National (CN) and Canadian Pacific (CP), operate transcontinental networks which carry more than 80 per cent of Canadian rail freight by most metrics (Cairns, 2015).[2] Even more impressive than their dominance of the Canadian freight rail market is their total factor productivity (TFP) growth, which by our estimates averaged well above the -0.11 per cent per year annual average for the Canadian business sector for the same period.[3] Given their sustained success, the two railways are natural candidates for firm-level productivity analysis.

CN and CP are not by any means the only freight rail firms in Canada. Over the years both firms sold off their less profitable branch lines, and dozens of shortline railways have entered the market to fill regional demand by taking over the lines. While the Canadian freight rail sector is made up of a number of firms, each of them is dwarfed by CN and CP in terms of market share. As Statistics Canada has not made any firm-level data available on the shortlines, they will not be discussed at any level of depth. Most of the literature regarding Canadian freight rail applies a similar scope to their study (see Freeman et al. 1987, Tretheway, Waters, and Fok, 1997; Waters and Tretheway, 1999; Iacobacci and Schulman, 2009). McKellips and Calver

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[1] The author is an economist at the Centre for the Study of Living Standards. The author would like to thank Erwin Diewert, Andrew Sharpe, Matthew Calver, Alexander Murray, and the two anonymous referees for their insightful comment on this paper. This paper is the unabridged version of Uguccioni (2016). An earlier version of this paper was presented at the 50th General Conference of the Canadian Economics Association in Ottawa. Email: james.uguccioni@csls.ca

[2] These metrics include kilometres of rail operated, capital expenditures, and number of employees. The one exception is tonnes originated, where CN and CP only make up 60 per cent of the market. This is largely due to two railways in Northern Quebec and Labrador which are owned by the shipper and handle iron ore from nearby mines: the Cartier Railway (owned by Arcelor Mittal Mines Canada) and the Quebec North Shore and Labrador Railway (owned by the Iron Ore Company of Canada). Neither railway connects to the main line nor is under competitive pressures from other railways, being owned by the shipper. CN and CP account for more than 80 per cent of tonnes originated once these two firms are removed.

[3] Compound average annual growth rate calculated using the Statistics Canada Multifactor Productivity index available in CANSIM table 383-0021.

(2015) do provide a sector level analysis, estimating that TFP in the railway transportation sector grew 1.26 per cent per year from 2000 to 2013.

Our paper provides estimates for TFP growth at the firm level, as well as for the two railways combined. As Statistics Canada does not provide TFP estimates beyond the three-digit NAICS level for transportation, our estimates provide valuable information about productivity developments in freight rail.[4] Furthermore, to the best of our knowledge we are the first to apply the method of Caves, Christensen, and Swanson (1981a) to estimate TFP growth at CN and CP since Freeman et al. (1987).

Ultimately, we reaffirm the general finding in the literature that CN and CP are productivity success stories when compared with Canadian industry as a whole. This paper estimates TFP for both railways individually and the two combined, as well as other productivity measures to unpack their various successes. Ultimately, TFP for the two Canadian freight railways grew at an estimated rate of 3.94 per cent per year from 1986 to 2009.[5] Experts attribute much of the growth to operational efficiency improvements arising from Hunter Harrison's precision railroad model. Using indices, we estimate TFP growth to be 4.42 per cent per year at CN and 3.12 per cent per year at CP. Econometric estimates put annual TFP growth throughout the period at 4.23 per cent per year at CN and 3.52 per cent per year at CP.

Section II reviews the literature regarding the major empirical methods of analysis, presents relevant past findings on railway productivity, and considers operational developments described by industry specialists. Section III discusses the data employed in this study. Section IV presents the index method for obtaining measures of partial and total factor productivity, as well as the estimated measures themselves. Section V presents the econometric method for obtaining TFP measures via cost function estimation, as well as the estimates themselves. Section VI discusses the results obtained in Sections IV and V, looking at what contributed to the robust partial productivity and TFP growth from 1986 to 2009. Section VII concludes and provides some avenues for future research.

II Literature review

To situate the data analysis, section II(A) reviews the three major approaches in transportation productivity research: analysis using index numbers, econometric estimation of a cost function, and data envelopment analysis estimation of the theoretical efficient frontier. Section II(B) proceeds to discuss some empirical findings relevant to the Canadian experience with freight railways for reference when considering our estimates. Section II(C) concludes with an overview of recent developments in the industry from the point of view of key experts involved in freight rail operations.

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[4] Statistics Canada does not provide TFP estimates down to NAICS 482 (Rail transportation), but rather an aggregate of NAICS 481-483. McKellips and Calver (2016) did obtain TFP growth estimates for NAICS 482 from Transport Canada, and estimate TFP to have grown 1.26 per cent per year in rail transportation from 2000 to 2013. Notably, this estimate still includes the shortlines and passenger railways in addition to CN and CP, and thereby does not provide specific information about productivity growth in the freight rail sector as we treat it.

[5] As measured using the index approach.

A. Methodological approaches

i. Index number approach

The most widely used methodology to measure productivity growth is an index number approach, used by official bodies such as Statistics Canada and researchers alike. The most widely used measure in transportation research is TFP. Single factor productivity measures are also popular, and some employ more esoteric measures such as variable factor productivity. TFP measures productivity by comparing an index of outputs produced to an index of inputs used, and over time it shows whether (or how much more) firms are able to make more with less. TFP takes into account outputs and inputs, thereby giving the "big picture" of a firm's productivity level and how it's productivity evolves over time.

In the same vein as TFP, single factor productivity measures such as labour productivity compare a single input with output to measure the efficiency of using the input. Oum, Waters, and Yu (1999) note the usefulness of measures such as man-hours per carload or tonne-miles (or tonne-kilometres) per full-time employee to help identify productivity differences across firms. The Railway Association of Canada (2014) also employs tonne-kilometres of revenue producing freight (RTKs) per employee as its primary productivity metric.[6] Tretheway, Waters, and Fok (1997) employ measures of single factor productivity to compare the growth of an individual input of CN and CP to the overall growth in an output index (dominated by freight tonne-kilometre outputs). A similar analysis is undertaken below.

In terms of TFP analysis, Caves, Christensen, and Diewert (1982a) propose a revenue-weighted, multilateral Tornqvist index to compare input growth to output growth, thereby estimating TFP growth. Caves, Christensen, and Diewert (1982b) show that this method performs equally well under conditions of decreasing, constant, or increasing returns to scale. Tretheway, Waters, and Fok (1997) and Waters and Tretheway (1999) both employ the Tornqvist index approach to estimate TFP for CN and CP.

Diewert (1992) argues that an index approach to TFP measurement is far superior to econometric estimation because it requires fewer underlying assumptions about the behaviour of firms (e.g. profit maximization versus maximizing shareholder value). A revenue-weighted Tornqvist index approach is employed below. The form of the index is presented in section IV(A).

An analysis of productivity at CN and CP is undertaken using the index number approach in Section IV. We calculate partial productivity measures and employ a Tornqvist index to generate TFP growth estimates.

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[6] The Railway Association of Canada provides these labour productivity estimates in their annual reports. Their estimates are revenue tonne kilometres per employee for the sector as a whole. As CN and CP account for around 80 per cent of the sector, their estimates are broadly similar to those we provide in Chart 5 and Appendix Table 1.

ii. Econometric estimation

Another approach to analyzing TFP growth is through econometric estimation of a cost function, and imputing productivity growth. Caves, Christensen, and Swanson (1981a) model a variable cost function for a panel of American railways using a translog approximation. By Shephard's lemma, they break up their variable cost function into factor demands, which are in turn estimated using Zellner's (1962) method of seemingly unrelated regressions. By assuming cost minimizing behaviour by the firm, Caves, Christensen, and Swanson use the factor demands to infer the structure of the firm's production function, which they then estimate over time to evaluate TFP growth. As their model assumes short run cost minimizing behaviour, they incorporate three separate time periods via dummy variables to allow fixed inputs to adjust. Caves, Christensen, and Swanson (1981b) expand the breadth of application of this method.[7]

Many variations on the Caves, Christensen, and Swanson (1981a) approach to estimating railway TFP via the variable cost function have been developed since 1981. De Broger (1991a) estimates a hedonic model for outputs rather than weighting outputs by revenue. De Borger (1991b) treats rolling capital stocks as fixed in his estimation because of its highly subsidized nature in Belgium, arguing stocks are determined exogenously from the point of view of the firm. Similarly, McGeehan (1993) treats output of an Irish railway as exogenous to the model, given the railway's status as a public transport operator and output obligations. Much like McGeehan, Wang and Liao (2006) assume output is exogenously determined by the state in their study of Taiwan's Railways.

An alternative to the Caves, Christensen, and Swanson (1981a) approach of estimating the variable cost function was first proposed by Christensen, Jorgensen, and Lau (1973), estimating the total cost function (and following the same factor-demand procedure). Smith (2006) employs the Christensen, Jorgensen, and Lau (1973) method for British railways from 1963 to 2002. Smith argues that treating some inputs as quasi-fixed for several years when estimating the variable cost function is highly unrealistic, as managers are able to choose annual capital expenditures in any given year to minimize costs.

The motivation for an econometric analysis of productivity is to disentangle "black box" productivity gains. Specifically, Caves, Christensen, and Swanson's (1981a) goal is to disentangle movements along the production function and movements of the production function. By modelling a cost function, they show that separate estimates for productivity growth as a result of returns to scale and as a result of technological change can be obtained. Smith (2006) adds to their model, proposing a method to generate estimates for returns to density in addition to returns to scale and technological change.[8]

While Diewert (1992) prefers the use of index numbers to generate TFP, he is quite explicit in arguing that the estimation of a quadratic form of a cost function is a superior

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[7] The cost function method had been applied in other contexts prior to Caves, Christensen, and Swanson (1981a). For example, Denny and May (1978) applied the approach to firms in the Canadian manufacturing sector.

[8] Whereas returns to scale is the effect of firm growth on output (e.g. increasing all inputs results in some change in output), returns to density is the effect of increased throughput for a given transportation network (e.g. increasing all inputs excluding track employed results in some change in output). See Keeler (1976) for full discussion.

econometric approach than simply estimating a production function. The primary advantage of the cost function is the degrees of freedom which can be added to the estimation with Shephard's lemma. Diewert objects to several assumptions made by the cost function model: that firms are in reality minimizing costs; that the cost function nicely decomposes into a part which is time invariant and a part which is dynamic; and how the errors enter into the model (e.g. logarithmically or additively).

In Section V(A), we discuss the particulars of how we conducted our econometric estimation of productivity. Our method is by and large the same as Smith's (2006), with only minor modifications to the cost function to suit data realities.

Table 1: Methods of Analysis for TFP Estimation

	DEA	Indices	Econometric Estimation
Advantages	• Does not require assumptions regarding firm behaviour • Does not require assumptions regarding weights inputs/outputs	• Does not require assumptions regarding firm behaviour or returns to scale • Not constrained by small datasets	• Flexible models allow for constraints faced by firm to be specified (e.g. exogenously determined output) • Allows returns to scale and density to be separated from technological change
Diadvantages	• Constrained by sample size • Assumptions about the efficient frontier	• Requires assumptions regarding index weights	• Constrained by sample size • Requires assumptions about firm behaviour

iii. Data envelopment analysis

Data envelopment analysis (DEA) is a relatively new method in productivity research which applies mathematical programming to compare the relative productivity of a group of firms (Cooper, Seiford, and Tone, 2007). The objective of DEA is to estimate an outer boundary of production possibilities which encompasses all firms studied, called an efficient frontier. As the efficient frontier envelops all firms, each individual firm can then be compared to the frontier to measure its relative productivity.

Cooper, Seiford, and Tone (2007) argue that DEA is superior to econometric approaches because it requires no assumptions about the firm's behaviour (e.g. profit maximizing versus maximizing shareholder value) or the firm's cost function structure. They also argue that because the use of weights for inputs can wildly affect results for index approaches, DEA also requires fewer assumptions than index approaches to TFP estimation.

Some studies of rail productivity have employed DEA to analyze underlying industry trends. However, as noted by Shi, Lim, and Chi (2011), rail industries tend to have fewer firms, which may create a dimensionality problem when solving the linear programme. Shi, Lim, and Chi avoid this problem by using sequential frontier envelopes, arguing that the efficient frontier cannot move inwards because technologies made available to firms in a given period will be available in all sequential periods. Tulkens and Vanden Eeckhaut (1995) observe that in sequential frontiers, the theoretical efficient frontier can only ever progress over time, and any backslide is interpreted to be inefficiency.

Table 2: Relevant Empirical Results regarding Canadian Freight Rail

Paper	Subject of Study	Results
Tretheway, Waters, and Fok (1997)	CN and CP, 1956 to 1991	CP had slightly higher levels of TFP relative to CN for the majority of the period, but was overtaken by CN around 1990. Average TFP growth for both railways from 1956-81 was 3.4 per cent per year, but it slipped to 3.0 per cent per year for CN and 2.7 per cent per year for CP in the period of 1981-91. They argue that 1.8-1.9 percentage points of annual TFP growth was due to technical progress while the remainder was due to operational efficiency, and that significant productivity gains could be reaped if the railways were allowed to abandon unprofitable lines.
Waters and Tretheway (1999)	CN and CP, 1956 to 1995	Extends the analysis of Tretheway, Waters, and Fok (1997) to 1995, and they report annual TFP growth around 3.1 per cent per year for CN and 2.8 per cent per year for CP during the period of 1981-1995. For both firms, accounting for the newly added period of 1991-1995 indicates CN and CP averaged TFP growth around 3.4 per cent per year and 3.1 per cent per year respectively during those 4 years.
Iacobacci and Schulman (2009)	Canadian railways, 1981 to 2006	Reports average TFP growth of 3.6 per cent per year at CN and CP during the period of 1981 to 2006. Attributes this strong growth to deregulation, changes in governance structures (e.g. 1995 privatization of CN) and increased competition through the proliferation of regional, short line carriers.
Cairns (2015)	Canadian railways, with emphasis on CN and CP, 1981 to 2012	The operating ratios of CN and CP decreased towards their values in 2013 of 63.4 per cent and 76.8 per cent respectively. CN and CP have averaged 3 per cent per year TFP growth between 1981-2012, compared to < 1 per cent per year in the Canadian economy. Cairns argues the sources of the productivity gains include the CN and CP ridding themselves of unprofitable lines, a shrinking workforce, improved locomotives, and improved operational practices.

While this assumption is not necessarily a strong one, it is not needed for the analysis it delivers. The two previous methods do not estimate an efficient frontier, but rather exploit an individual firm's increased or decreased efficiency over time to measure its productivity growth. This produces equally valid results, without any assumptions regarding the efficient frontier or the concerns associated with too few firms for analysis.

B. Past empirical findings

Table 2 provides some empirical results relevant to the study of productivity growth at Canadian railways. Tretheway, Waters, and Fok (1997) undertake a major study of CN and CP using data from 1956-1991. Waters and Tretheway (1999) extend the Tretheway, Waters, and Fok analysis to 1995. While the period of interest for these two papers only provides 9 years of overlap with our 1986-2009 data, it can be used to compare some results against. Studies by Iacobacci and Schulman (2009) and Cairns (2015) provide an overview of recent sources of productivity growth in the Canadian freight rail context.

Many studies of rail productivity in other geographic contexts exist, and can be in part relevant to the study of Canadian freight railways. It is important to note that geography makes these results only partially relevant because of the ever increasing importance of intermodal transportation. The locations of ports and availability of transport trucks versus the location of rail networks mean that the effects of competition among different modes of transportation in each country are unique.

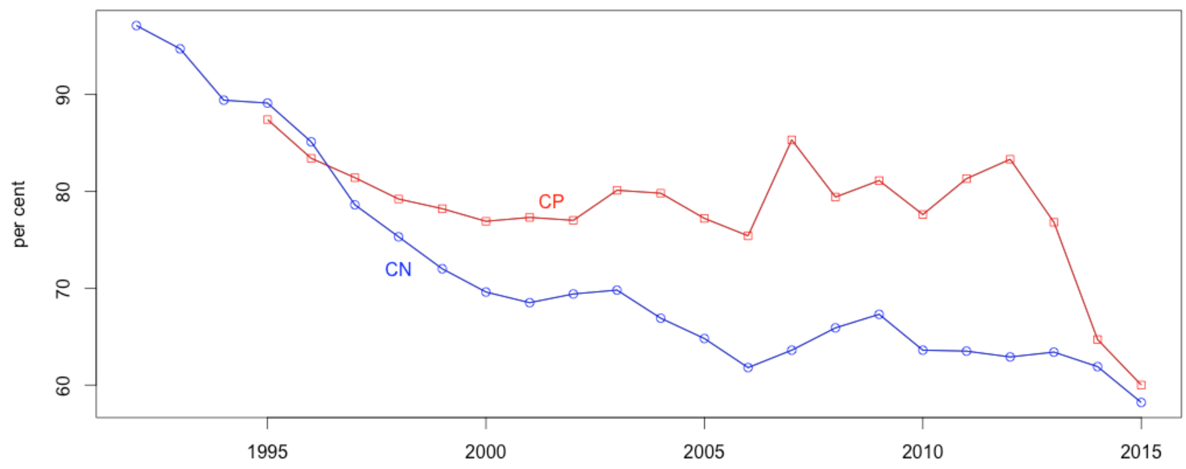
Tretheway, Waters, and Fok (1997) argue American Class I railways exhibited higher TFP growth than CN and CP in the 1980s because of economies of density, as the American railways tended to reduce track inputs for a fairly steady output level while the Canadian railways tended to increase outputs relative to inputs. Network density is an important factor, and is considered in the discussion of results in Section VI. Some other studies investigate small, regional railways in Belgium (De Borger, 1991a, 1991b), Ireland (McGeehan, 1993), and Taiwan (Shi, Lim, and Chi, 2011).

C. Operational developments in the freight rail sector

While economists can provide estimates on productivity developments in the freight rail sector, industry executives are better suited to discuss the specifics of where efficiency is lost or improved. In late 2010, CN CEO Claude Mongeau was asked by the Railway Association of Canada to reflect on the first 15 years of CN as a private firm (Railway Association of Canada, 2011). Mongeau lauded CN's first CEO, Paul Tellier, for leading the charge towards privatization and expanding CN across North America through acquisitions. He then proceeded to discuss how Hunter Harrison, Tellier's successor, improved CN operations by turning it into a precision railroad.

Harrison served as President and CEO of Illinois Central before the firm was acquired by CN in 1998. From 1998 to 2003, he served as COO under Tellier. In 2003, Harrison took over from Tellier as CEO of CN, stepping down in 2009. Harrison (2000) dates the beginning of CN's metamorphosis into a precision railroad in September 1998. Under his operational framework, CN not only scheduled trains and their cars, but also the support processes underlying their service provision (e.g. maintenance and car inspections). This meant that each individual railcar had its own personalized timetable to ensure that most delays to deliveries were expected. Two years after CN's transformation into a scheduled railroad, Harrison had drastically reduced the number of late arrivals and managed to shrink CN's active locomotive fleet by 600 vehicles. In 2002, Harrison won the prestigious Railroader of the Year award from Railway Age, an industry

Chart 1: Operating ratios 1992-2015, per cent



Data from CN and CP annual shareholder reports.

journal, for changing the face of the industry with his concept of a precision railroad (Railway Age, 2002).

Harrison (2000) distills operating a precision railroad to a handful of operational goals, including: minimizing car dwell time in rail yards; using general purpose trains; balancing train movement by direction across corridors; minimizing power requirements; and optimizing yard schedules. Reductions in down time spent in yards and time spent by trains "dead heading" (waiting for oncoming traffic to clear the line) have obvious productivity effects, as decreasing the amount of time spent per output frees up resources to produce more. By keeping yard schedules with the steady arrival and departure of trains, rather than an ebb and flow, railways eliminate the need to keep excess capacity on hand at yards for high volume periods. Minimizing power requirements per train is an important, but admittedly counter-intuitive, prescription of a scheduled railroad. Under Harrison, CN balanced train velocity against horsepower requirements, sometimes sacrificing velocity. As adding a locomotive to a train results in a large step of horse power (think 3000 hp increments), Harrison found instances where the removal of a locomotive did not affect the network's schedule and reaped net savings from slowing trains.

Many freight rail experts use operating ratios (ratio of operating expenditures to revenues) of railways as their primary productivity metric. In 2011, CN posted the lowest operating ratio of any North American Class I at 63.5 per cent, while CP posted the highest at 81.3 per cent (Barrow, 2012). Interestingly, in 2012 Pershing Square Capital Management lead a coup at CP and replaced CEO Fred Green with the recently retired Hunter Harrison (Barrow, 2012). After a single year in charge, Harrison was able to reduce the operating ratio at CP by 4.5

percentage points to 76.8 per cent, while CN only reduced their operating ratio by 0.1 percentage points over the same period (Cairns, 2015).[9] Chart 1 provides time series of the operating ratios from 1992 to 2015 for CN and from 1995 to 2015 for CP.

From an economist's point of view, an operating ratio is a less than ideal metric for productivity because it is sensitive to input price shocks. For example, if a railway benefits from a windfall one season simply because of a light winter, it is captured as a decrease in the operating ratio, though no productivity gains actually took place. So long as these shocks are more or less rare, however, operating ratios ought to more or less inversely track TFP growth (as firms are able to create more output per input). With this rough interpretation, Chart 1 shows that CN had a much higher level of productivity (be it labour productivity or TFP) than CP for most of 2002 to 2015 and that CP experienced massive productivity improvements under Harrison.

Unfortunately, as our data end in 2009, we are not able to analyze Harrison's time at CP beyond looking at operating ratios. We are, however, able to assess his effect at CN. In Section V(B), four major events are considered concurrently with Iacobacci and Schulman's (2009) argument that the privatization of CN lead to its stellar productivity growth: the installation of Tellier at the head of CN in 1992; the appointment of Harrison as COO and the advent of precision railroading in 1998 and 1999 (as Harrison only established the precision railroad in September 1998, 1999 was the first full year of the precision railroad); and Harrison's move to CEO in 2003.

III Data

Section III(A) summarizes how the data used in our analysis was obtained by Statistic Canada and specifics of what is made available to the public. Section III(B) presents trends of individual factors of production to gain an overall understanding of the trends in inputs employed at both firms during the period of 1986-2009. Section III(C) undertakes a similar study of the outputs of CN and CP. Finally, Section III(D) presents the importance of individual inputs to production overtime, as measured by their share of overall cost.

A. Data employed

All data employed are publicly available from Statistics Canada's CANSIM data repository.[10] Specifically, the data come from the annual *Railway Transport Survey*.[11] The survey collects operational, financial, and employment statistics on all common carrier railways (both freight and passenger) in Canada. Response is mandatory and data are reported directly by the firms themselves. The publicly available dataset covers the period of 1986 to 2009. While both CN and CP have networks which extend into the United States, the *Railway Transport Survey* dataset

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[9] Admittedly, CN did have a lower operating ratio to start the period, and likely had less slack to remove than CP.

[10] Specifically, we use CANSIM tables 404-0004 (financials), 404-0010 (track), 404-0012 (fuel), 404-0012 (operating statistics), 404-0017 (equipment), and 404-0019 (labour).

[11] For specific details, please refer to: http://www23.statcan.gc.ca/imdb/p2SV.pl?Function=getSurvey&SDDS=2734 and
http://www23.statcan.gc.ca/imdb/p3Instr.pl?Function=assembleInstr&Item_Id=138433&TET=1

only covers operations in Canada. All inputs and outputs are strictly evaluated within Canadian borders (e.g. labour costs assigned to a Canadian line).

Conducting our analysis in 2016 but ending the scope of study in 2009 is unfortunate. However, in order to publish detailed rail data Statistics Canada requires permission from the large carriers. Beginning in 2010, Statistics Canada was unable to secure the cooperation of all parties involved, and as such the data are not publicly available beyond this point.[12] A longer and more recent time series would improve the precision of the estimates we obtain and the overall relevance of our work.

One unique aspect of the *Railway Transport Survey* dataset is that it contains physical values of inputs and outputs. This means our productivity estimates do not rely on deflating nominal values to real values as most other studies do, and thereby avoid any measurement error arising from the use of deflators which are not perfect fits to the individual input or output.

B. Trends in inputs

Below, Charts 2 and 3 illustrate the trends in locomotives, freight cars, kilometres of track operated, labour, and fuel over the period of 1986-2009.[13] Chart 2 breaks down the inputs used by CN and CP individually relative to their values in 1986 (1986=100), while Chart 3 explores trends in the uses of labour to perform various jobs at both firms.

The most striking trend in Chart 2 is the severity of the magnitude in labour over the period—by 2009 CP employed 43.6 per cent and CN employed 31.4 per cent of the labour it employed in 1986.[14] Chart 3 plots the labour employed at both firms in terms of average full time employees to help disaggregate the stark decline in employment. The largest declines for both CN and CP were equipment maintenance positions, which may reflect higher quality equipment (e.g. more reliable locomotives) or improvements in the track infrastructure causing equipment to require servicing less frequently. This will be discussed in greater depth in Section VI. Another striking trend in Chart 2 is the decline in kilometres of track operated, as both railways sold off or closed lines which were not economically sustainable (see Cairns, 2015).

Overall, both firms reduced their labour, track, and freight car inputs over the 24 year period. CN also reduced its locomotive input, whereas CP's number of operational locomotives has stayed fairly steady since 1986. There is some evidence of CN's reduction gaining steam in 1998 with the advent of Harrison's precision railroading, however there is also an obvious long term trend towards fewer locomotives in service. Both CN and CP used slightly less diesel in 2009 than they did in 1986, but there is little evidence of a steady, downward trend.

Section VI deals with some possible causes for the trends observed in Charts 2 and 3. Increasing output (as seen in section III(C)) despite these large declines in inputs shows the

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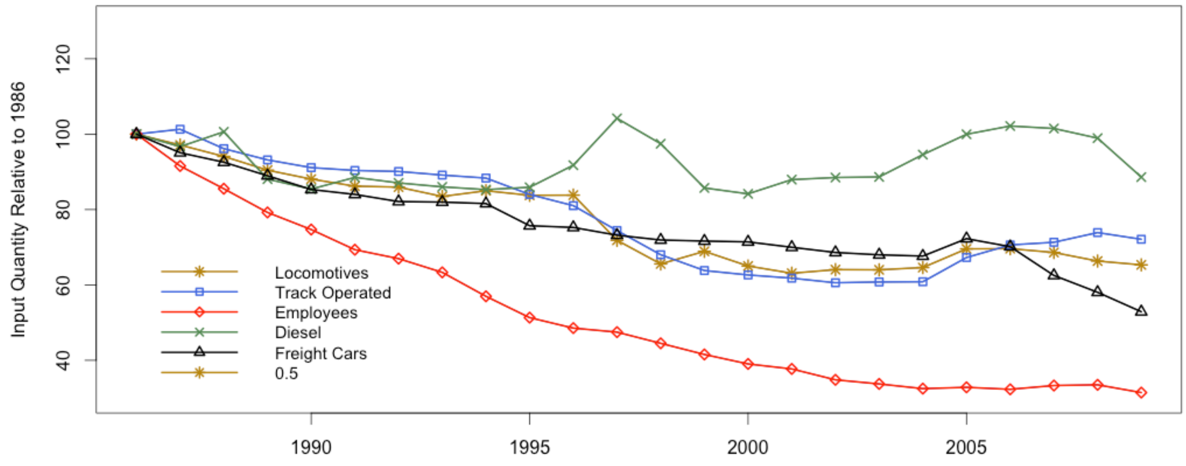
[12] Information obtained in special correspondence with Statistics Canada.

[13] Ideally we would also include a land input in our production function, as the track does not exist in a vacuum. Unfortunately, Statistics Canada does not publish any figures on land used by the railways and as such we are unable to construct a land input.

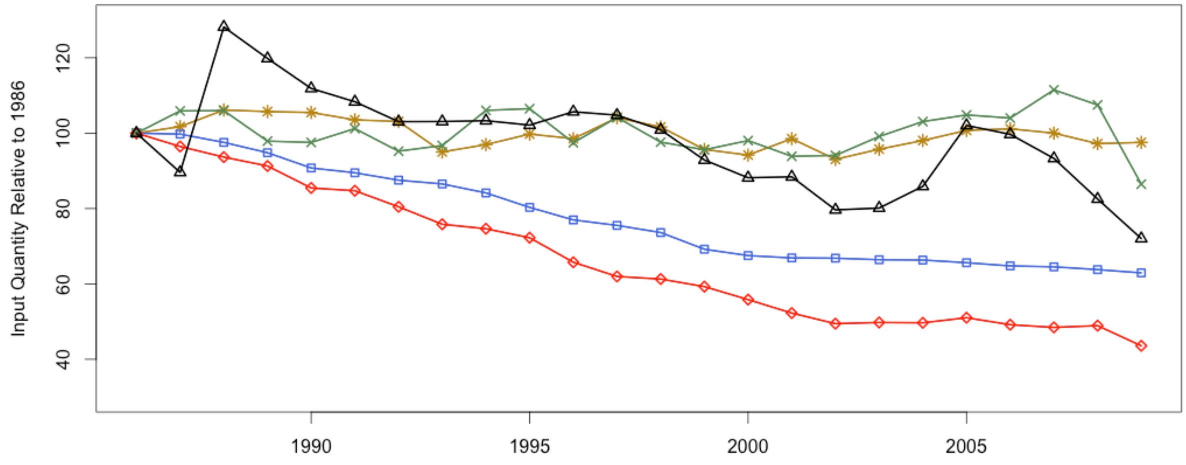
[14] CP had 11,310 employees in 2009 compared to 25,953 in 1986, and CN had 14,484 employees in 2009 compared to 46,074 employees in 1986 — falls of 68.6 per cent and 56.4 per cent respectively.

Chart 2: Firm-level inputs 1986-2009, (1986=100)

Panel A: CN Inputs 1986-2009



Panel B: CP Inputs 1986-2009

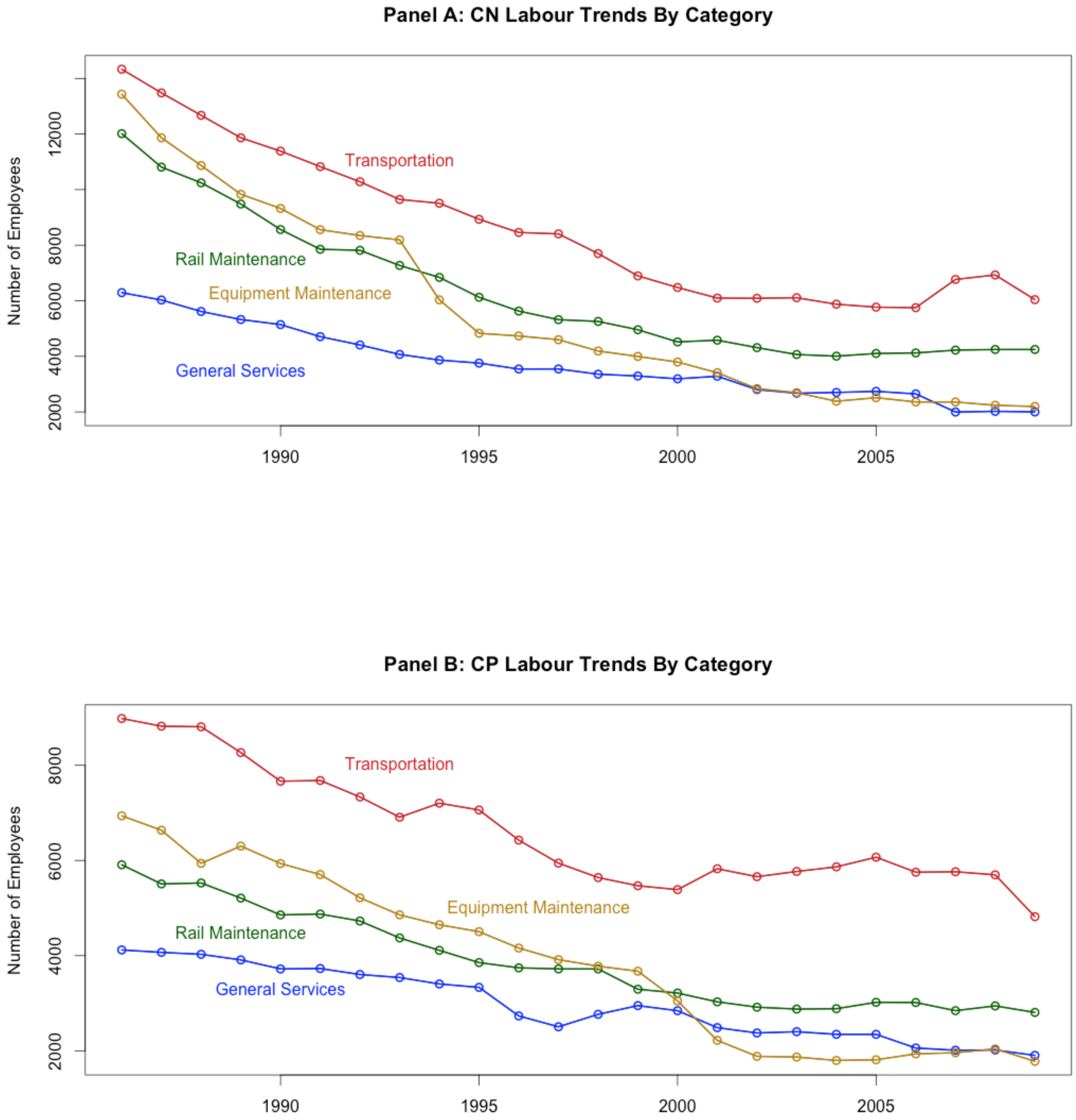


Data from Statistics Canada Tables 404-0010, 404-0012, 404-0014, 404-0017, and 404-0019; obtained from CANSIM October 5, 2015.

Average annual growth rate (per cent per year)

	Locomotives	Track Operated	Employees	Diesel	Freight Cars
CN	-1.83	-1.41	-4.91	-0.52	-2.73
CP	-0.11	-1.99	-3.55	-0.63	-1.42

Chart 3: Firm-level employment trends, 1986-2009



Data from Statistics Canada Table 404-0019; obtained from CANSIM October 5, 2015.

Average annual growth rate (per cent per year)

	Transportation	Equipment Maintenance	Rail Maintenance	General Services
CN	-3.69	-7.57	-4.42	-4.86
CP	-2.67	-5.74	-3.19	-3.30

Canadian freight railways' stellar reputation for productivity growth.

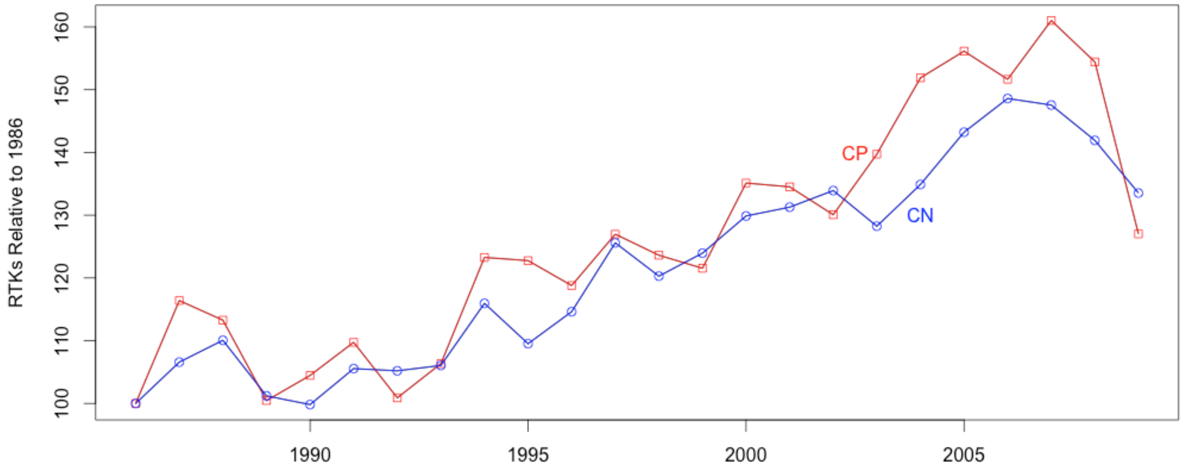
C. Trends in output

Revenue-tonne kilometres (RTKs) are the principal unit of output measurement in freight rail, and are often used in other freight transportation sectors. One unit of RTK measures a tonne of freight which will generate revenue transported one kilometre. The outputs of CN and CP are almost exclusively RTKs — they tend to account for between 89 per cent and 97 per cent of revenue depending on the firm and year.

Chart 4 illustrates a strong growth trend for both firms from 1989 to 2007, at which point the output of both CN and CP declines until 2009. As a rough measure of productivity, it is important to observe that output is increasing despite significant falls in inputs. Even by simply looking at Charts 2 and 4, it is remarkably obvious that both CN and CP became much more able to produce more with less over the time period.

It is also worth noting that the severe drop in output begins in 2008 with the financial crisis. The drop in gross tonne kilometres freight output from 2007 to 2009 is the most stark change in either direction over the entire period.

Chart 4: Firm-level revenue-tonne kilometres 1986-2009, (1986=100)



Data from Statistics Canada Table 404-10016; obtained from CANSIM October 5, 2015

Average Annual Growth Rate (per cent per year)	1986-2009	1986-2007	2007-2009
CN	1.27	1.87	-4.87
CP	1.04	2.29	-11.19

D. Trends in factor cost shares

Factor cost shares are key parts of both the index and econometric methods employed to obtain productivity estimates for the two firms, and consequently deserve some discussion. First and foremost, it is worth noting that the cost shares employed in the analysis are not equal to the costs of the individual inputs over the total operating expenses because the data includes some costs which do not have an underlying physical value to include in our index. Rather, we sum the costs of each of our inputs to obtain our "total cost" denominator used in input cost shares. This is purely for technical purposes, as cost shares must sum to 1 for both the Tornqvist index used in Section IV(A) and equations (ii) through (v) from the system of equations discussed in Section V(B). Comparing the total cost we used to construct our cost shares with the total operating costs published in the Statistics Canada dataset, our numbers typically account for 70 to 80 per cent of total operating expenditures reported by the firms depending on the year. Most of this gap is accounted for by expenses categorized as miscellaneous (e.g. miscellaneous way and structure expenses) and net equipment rents. However, as we have no *a priori* reason to allocate these costs to one specific input over another, we leave them aside.[15]

The cost shares of variable inputs such as labour and diesel are calculated simply using expenses on the inputs in a given year. Capital expenses are slightly less straightforward given that an expenditure in one year can factor in as an input for years in the future. Statistics Canada, publishes numbers on amortization of capital assets. The expense on a capital input in a given year is maintenance and servicing costs assigned to the input plus amortization of capital stock. We acknowledge that weighting our capital assets this way likely underestimates their contributions to production, particularly for locomotives and freight cars, by valuing the user cost of capital across new and old inputs the same. While this is certainly an issue, better data on the user cost of capital is not available from Statistics Canada at this time.

Cost shares strive to capture the "importance" of an input to overall production. Trends in the costs indicate changes in the importance of inputs overall. Appendix Tables 3 and 4 outline the cost shares attributed to each input in every period. At CN, the cost shares of labour, locomotives, and freight cars fell over time while the shares of diesel and track both increased. The changes in diesel and labour cost shares were especially important, rising and falling 10 percentage points respectively from 1986 to 2009. At CP, the cost share of labour fell around 7 percentage points and the cost share of diesel increased 10 percentage points. The cost shares of locomotives and freight cars slightly decreased and the cost share of track slightly increased.

IV Productivity analysis - Index Approach

This section employs the index approach to transportation productivity research described in Section II(A)(i). Section IV(A) provides an overview of the Tornqvist index and the specific form we employ in our analysis. Section IV(B) explores partial productivity measures in

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[15] This could results in the underweighting of certain inputs and the overweighting of others if miscellaneous costs are not equally distributed across inputs. For example, if most of the miscellaneous costs relate to the locomotive input, then the cost share of locomotives is understated. This could distort any productivity estimates which employ underestimated cost share. While this is a concern, we have no evidence of any such underweighting.

Canadian freight rail. Section IV(C) reports our total factor productivity estimates for CN and CP over the course of the 1986 to 2009 period.

A. Index methodology

The revenue-weighted multilateral Tornqvist index employed by Caves, Christensen, and Diewert (1982a) and by Tretheway, Waters, and Fok (1997) for their analysis takes the following form:

$$\ln \frac{\mathrm{TFP}_s}{\mathrm{TFP}_t} = \left[\Sigma_i \tfrac{1}{2}\left(R_{i,s} + \overline{R}_i\right) \ln\left(\frac{Y_{i,s}}{\overline{Y}_i}\right) - \Sigma_j \tfrac{1}{2}\left(C_{j,s} + \overline{C}_j\right) \ln\left(\frac{X_{j,s}}{\overline{X}_j}\right)\right] - \left[\Sigma_i \tfrac{1}{2}\left(R_{i,t} + \overline{R}_i\right) \ln\left(\frac{Y_{i,t}}{\overline{Y}_i}\right) - \Sigma_j \tfrac{1}{2}\left(C_{j,t} + \overline{C}_j\right) \ln\left(\frac{X_{j,t}}{\overline{X}_j}\right)\right] \quad (1)$$

This index computes TFP growth between years *s* and *t*, by evaluating the ratios of outputs to inputs for each year. Y_i and X_j are output *i* and input *j*. R_i and C_j are the revenue and cost shares of output *i* and input *j*. Terms with bars and no time subscripts denote the variable's average value throughout the 24 year period.

Using a similar modification to the Tornqvist index employed by Denny et al. (1992) to measure relative TFP levels between countries, we can easily generate estimates for the relative TFP levels between firms. This can be done by fixing the first and second terms in the same year, making the first term all CN variables and the second all CP variables. The results is an index of TFP levels at CN relative to CP. See Panel A of Chart 6 and Chart 9 for this comparison.

The index weights inputs by the arithmetic mean of the input's cost share in a given year and the input's average cost share throughout the 24 year period. This weighting procedure allows the index to capture the importance of an input to the firm, while smoothing out annual variability with the input's average "importance" throughout the period.[16] The inputs used for analysis are locomotives, freight cars, kilometres of track operated, diesel, and labour.

Table 3: Summary of key productivity growth estimates, per cent per year

		CN	CP
Labour Productivity	1986-2009	6.49	4.76
	1986-1995	8.78	6.07
	1995-2009	5.04	3.93
TFP	1986-2009 (index)	4.42	3.12
	1986-1995 (index)	5.91	3.98
	1995-2009 (index)	3.47	2.58
	1986-2009 (econometrics)	4.23	3.52

Anticipating the criticism

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[16] While this weighting procedure is quite standard in the literature, there is one notable flaw with it. By smoothing out annual variability, we could inadvertently diminish the importance of trends within the cost shares themselves described in Section III(D). For example, the physical amount of labour fell quickly from 1986 to 2009, but so did its cost share. By smoothing cost shares with the period's average, we may be overemphasizing the importance of labour to production in the later periods. We test the robustness of our TFP growth estimates to an index constructed without cost share smoothing in section IV(C).

from Cooper, Seiford, and Tone (2007), Tretheway, Waters, and Fok (1997) do note that estimates obtained in this fashion are sensitive to the weights used, but ultimately argue that results are not too sensitive to weights. Tretheway, Waters, and Fok (1997) use the same weighting procedure for outputs (in this case, passenger and freight outputs) with revenue shares. However, as passenger outputs are not considered in the analysis below, no weights are needed for output.

Notably, the revenue-weighted multilateral Tornqvist index can be easily modified to provide estimates of productivity for subsets of inputs, such as the three capital inputs. Capital productivity growth can be obtained by weighting capital inputs by a "capital cost share" and comparing it to our index of output as usual.[17]

Finally, as suggested by Diewert (1992), the procedure above was employed to generate the growth in productivity between pairs of years. These growth rates were then applied sequentially (i.e. chain-linked) to an arbitrary base value of 100 in 1986 to generate the series shown in Panel B of Chart 9.

B. Partial productivity measures

Chart 5 measures labour productivity in thousands of RTKs per employee and shows the spectacular growth experienced by both CP and CN over the 24 years studied.[18] CP labour productivity grew at an average rate of 4.76 per cent per year and CN labour productivity at an average rate of 6.49 per cent per year (see Chart 5 Panel C). In absolute terms, labour productivity at CP grew from 3,574,451 RTKs per employee to 10,417,737 RTKs per employee and labour productivity at CN grew from 2,779,688 RTKs per employee to 11,807,364 RTKs per employee (see Chart 5 Panel A). Chart 5 Panel B compares the levels of labour productivity between CP and CN. Notably, CP achieved higher RTKs per employee than CN from 1986 until around 1996. From around 1998 to 2009, CN has attained higher RTKs per employee than CP. As such, CN's labour productivity growth over the period falls into two slightly different categories. Prior to around 1996, CN was converging to a level of labour productivity which had already been attained by CP, and its higher growth rate may have been driven in part by excess slack in its system. Following 1998, CN's growth is more of a matter of productivity gains by blazing ahead of CP.

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[17] This "capital cost share" is simply the proportion one capital input's cost makes up of the sum of the costs of all capital inputs.

[18] We recognize that by measuring labour productivity in terms of output per employee rather than output per hour worked, we may be somewhat underestimating the extent of labour productivity growth. We use employees instead of hours because no direct data on hours of work is provided in our dataset. We are able to generate indirect estimates of hours worked per employee from average annual compensation and average hourly compensation, but we do not employ these numbers because it is unclear how (if at all) salaried workers are accounted for in the average hourly compensation data. Using our indirect method, we do find that in 2009 employees worked 95 per cent of the hours per year that they did in 1986. This result is broadly similar with the Canadian experience on the whole, as a back of the envelope calculation from CANSIM table 383-0012 shows that the average Canadian worker worked just under 95 per cent of the hours in 2009 that she did in 1986. Assuming hours worked per worker fell 5 per cent on average at both CN and CP over the 1986-2009 period, our labour productivity estimates are understated by about 0.2 percentage points per year.

McKellips and Calver (2016) provide a decomposition of labour productivity growth in other transportation sectors (trucking and urban transit). They decompose growth in labour productivity into TFP growth, the importance of labour to production (proxied by its cost share in our case), and capital intensity. We are unable to perform their decomposition in this context because its assumption of perfect competition is simply unrealistic in the freight rail industry and the assumption of constant returns to scale may not be appropriate either.

Nevertheless, McKellips and Calver (2016) provide a framework for considering our labour productivity numbers. Our figures in part reflect increasing capital intensity over the period, as labour declined much more quickly than the capital inputs. As shown in Chart 8, capital intensity grew 3.17 per cent per year from 1986 to 2009 at CN and 2.31 per cent per year at CP. The number of workers employed at CN in 2009 fell to 31.4 per cent of its 1986 value (shrinking 4.90 per cent per year), while the number of workers employed at CP fell to 43.6 per cent of its 1986 value (3.55 per cent per year). At CN, the labour input fell more than 2 percentage points per year faster than any other input; at CP, labour fell over 1.5 percentage points per year more than any other input. The increased productivity may also reflect disembodied technical change which led to increased productivity of each unit of labour, such as Harrison's precision railroading. Finally, improved labour productivity could also reflect a change in the quality of labour, changes in the stocks of human capital for example.

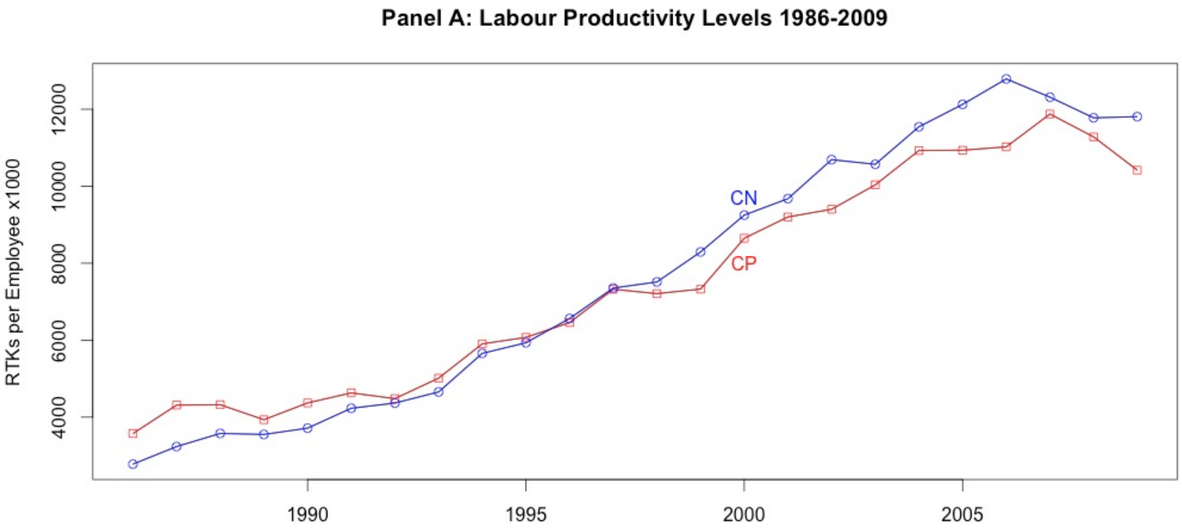
Chart 6 presents capital productivity estimates. Unlike our labour productivity measure, our capital productivity measures lack levels because the three capital inputs are measured in different units (i.e. kilometres of rail, locomotives, railcars). As such, we computed a Tornqvist index of the same form presented in equation (1) to generate estimates for the growth of capital productivity at either firm and the relative levels of capital productivity between the firms. As shown in Chart 6 Panel B, capital productivity growth at CN (2.92 per cent per year) outstripped growth at CP (1.93 per cent per year) from 1986 to 2009 by about 1 percentage point per year.

In terms of the relative levels of capital productivity between the two firms, the story is largely the same as it was in the labour productivity case (see Chart 6 Panel A). Prior to the mid-1990s, CN's level of capital productivity was well below CP's. CN converged with CP in the late 1990s, and had attained a capital productivity level around 10 per cent higher than CP's by the end of the period. As a result, CN's high growth throughout the period can once again be described as convergence to CP in the first half of the period and blazing ahead in the second half.

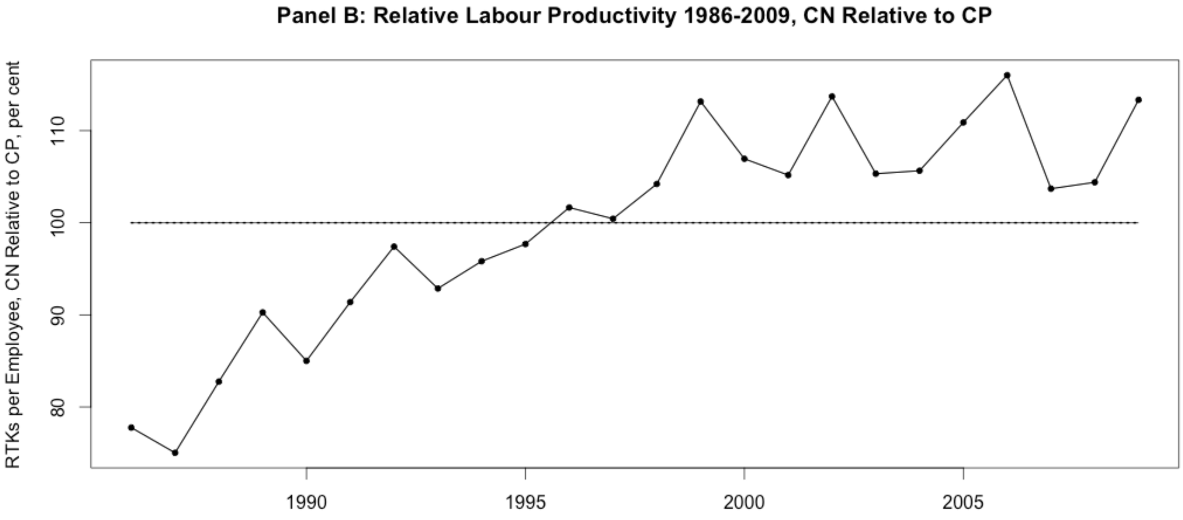
Chart 7 compares the fuel productivity at both firms in RTKs per litres of diesel consumed. As shown in Panel C, CN attained an average annual growth rate in fuel productivity of 1.80 per cent per year over the period, while CP attained an average growth rate of 1.69 per cent per year. The similarity in growth likely reflects both firms having access to the same types of locomotives over the period, thereby experiencing improvements in fuel efficiency at approximately the same rate (Cairns, 2015).

In terms of fuel productivity levels, CP produced fewer RTKs per litre of diesel than CN throughout the period. This finding has not been discussed by the literature, and likely is driven by the geographical realities faced by the two firms as mountains make up a larger proportion of

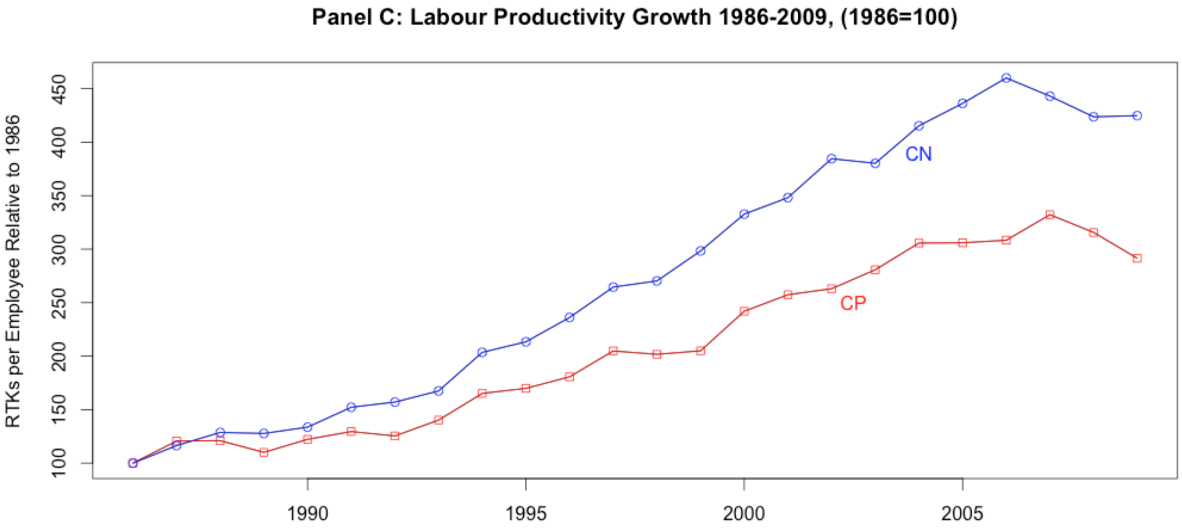
Chart 5: Firm-level labour productivity 1986-2009



Panel A: Labour Productivity Levels 1986-2009



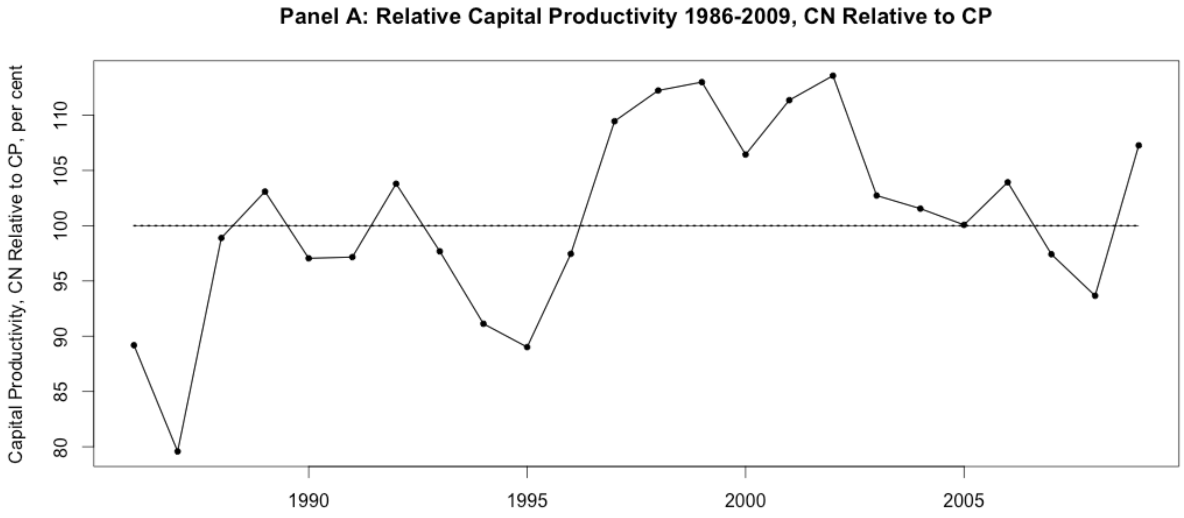
Panel B: Relative Labour Productivity 1986-2009, CN Relative to CP

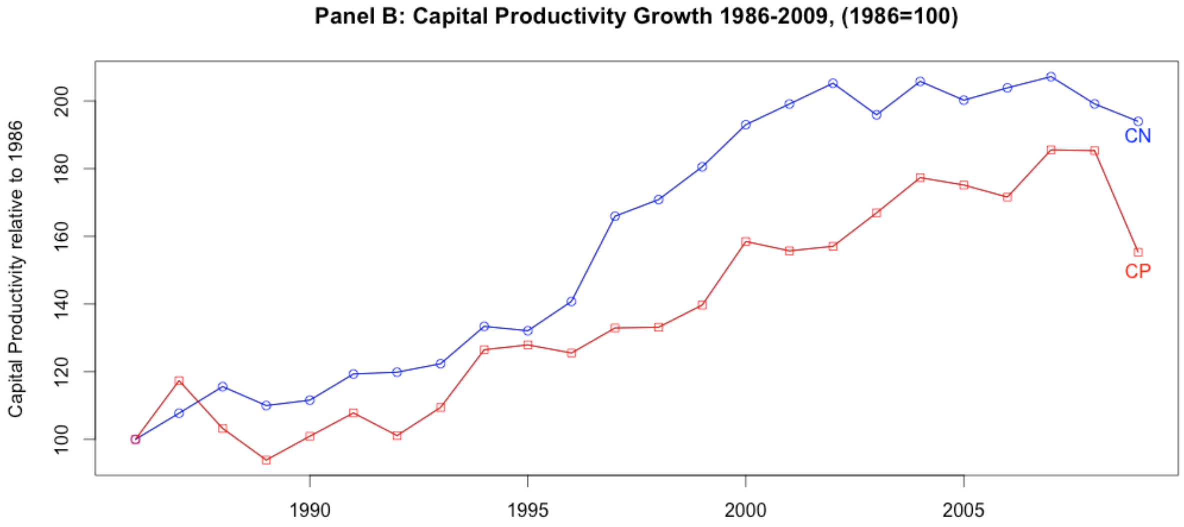


Panel C: Labour Productivity Growth 1986-2009, (1986=100)

Data from Statistics Canada Tables 404-10016 and 404-0019; obtained from CANSIM October 5, 2015.

Chart 6: Firm-level capital productivity 1986-2009

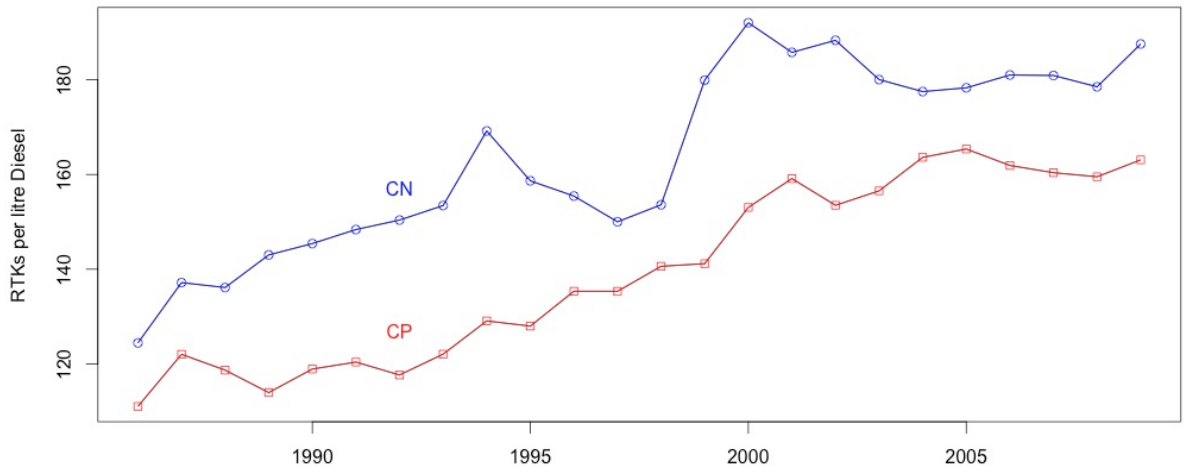

Panel A: Relative Capital Productivity 1986-2009, CN Relative to CP


Panel B: Capital Productivity Growth 1986-2009, (1986=100)

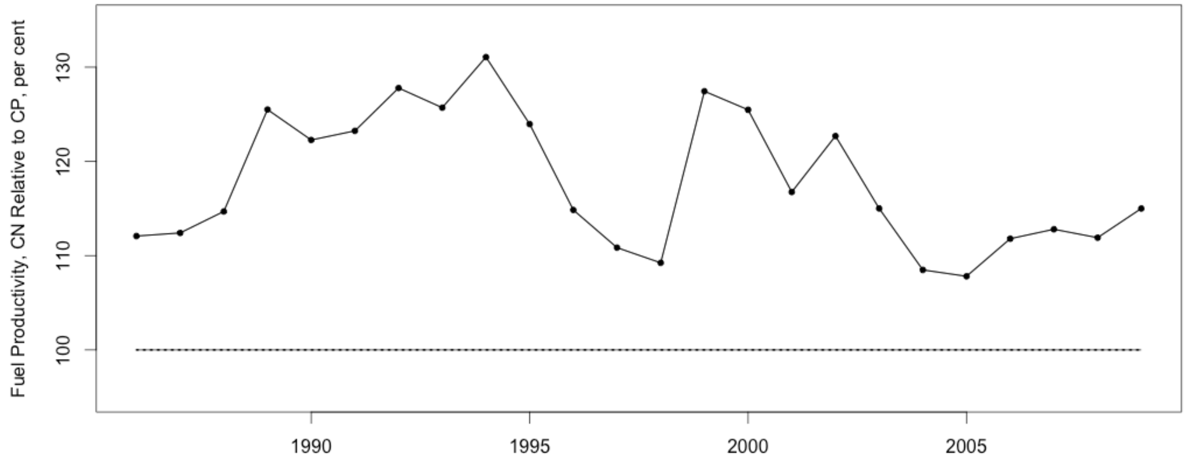
Data from Statistics Canada Tables 404-0010, 404-0014, 404-0016, and 404-0017; obtained from CANSIM October 5, 2015.

Chart 7: Firm-level fuel productivity 1986-2009

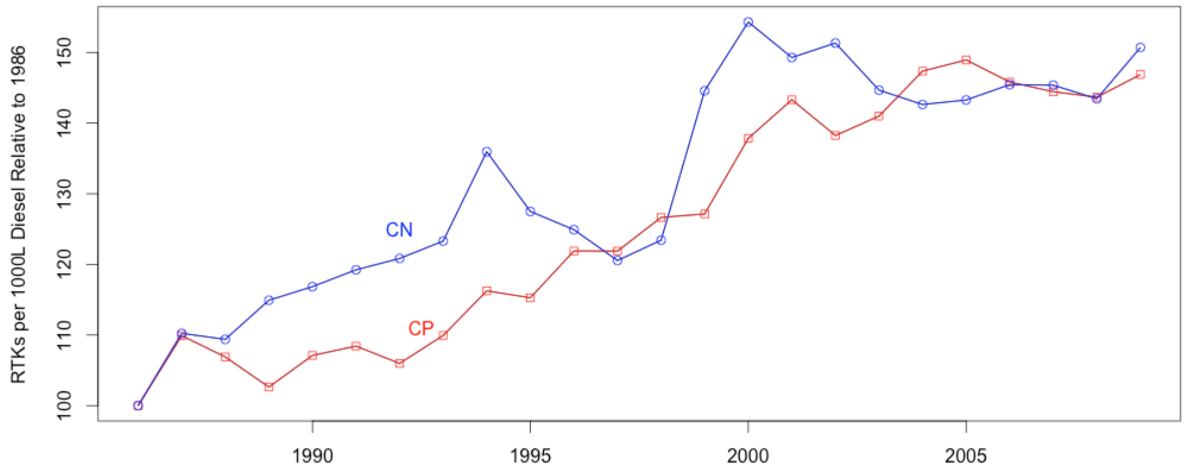
Panel A: Fuel Productivity Levels 1986-2009



Panel B: Relative Fuel Productivity 1986-2009



Panel C: Fuel Productivity Growth 1986-2009, (1986=100)



Data from Statistics Canada Tables 404-10012 and 404-0016; obtained from CANSIM October 5, 2015.

CP's network than their counterpart's. If this is the case, it may also explain CP's slightly slower fuel productivity growth, as more fuel efficient engines may not be as useful in the mountains. The difference may also reflect systematic differences in type of freight hauled (e.g. grain, metallic ore, bitumen), but a more disaggregated dataset would be required to investigate such differences.

C. Total Factor Productivity

Following Tretheway, Waters, and Fok (1997), TFP is estimated by weighting each of the 5 inputs discussed in Section III(B) by their share of factor costs in a Tornqvist index for comparison with RTKs, using the methodology discussed in Section IV(A). TFP growth was evaluated in pairs of consecutive years, and these values were then chained to build the series shown in Chart 9 Panel B. Over the course of the period, CP's estimated TFP grew at an annual average rate of 3.12 per cent per year and CN at an annual average rate of 4.42 per cent per year.

Our estimates are contingent on a weighting procedure which may be problematic, as smoothing cost shares with annual averages dampens the effect of secular changes to an input's cost share over time. To test the robustness of our weighting procedure, we constructed our TFP index and weighted inputs *only* by their cost shares in the period of interest. With this methodology, we estimate TFP growth at CN to have been 4.36 per cent per year and at CP to have been 3.26 per cent per year. While our weighting procedure somewhat underestimated TFP growth at CP and overestimated TFP growth at CN, the magnitude of the bias is quite small. Consequently, we are not concerned that our estimates are not dependent enough on the "importance" of an input in any given period.

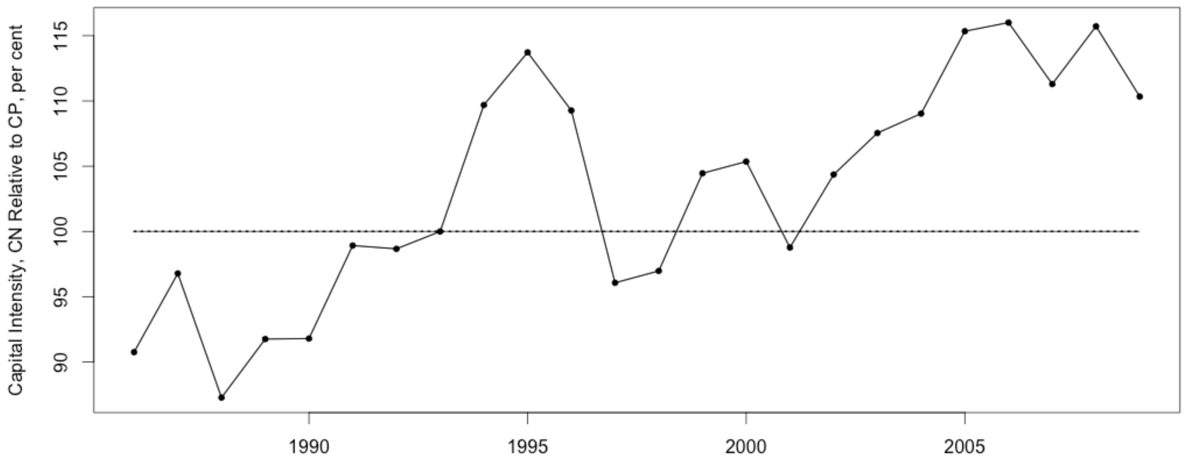
We compare the level of TFP at CN relative to the level of TFP at CP in Chart 9 Panel A. In 1986, CN had a level of TFP which was 83.3 per cent that of CP; in 2009, CN had a level of TFP which was 111.1 per cent that of CP. Much like with labour and capital productivity, CN's TFP growth is largely a matter of convergence prior to the mid-1990s and pulling away from CP afterwards.

To capture how Canadian freight railways performed on the whole, Chart 10 combines the two firms by summing their costs attributed to inputs to build industry-level cost shares. For example, the costs attributed to labour at CN and CP were summed and divided by the sum of the cost of all inputs at both firms. Broadly speaking, CN's inputs and output are double CP's, and therefore TFP growth at CN drives around two thirds of the sector's growth. We estimate an average annual rate of TFP growth of 3.94 per cent per year from 1986 to 2009 at the industry level. Interestingly, there is some evidence of stagnation in productivity growth beyond 2006. However, more recent data is required to confirm whether this slowdown is not simply a brief plateau in growth similar to the one incurred by both firms in the late 1980s/early 1990s.

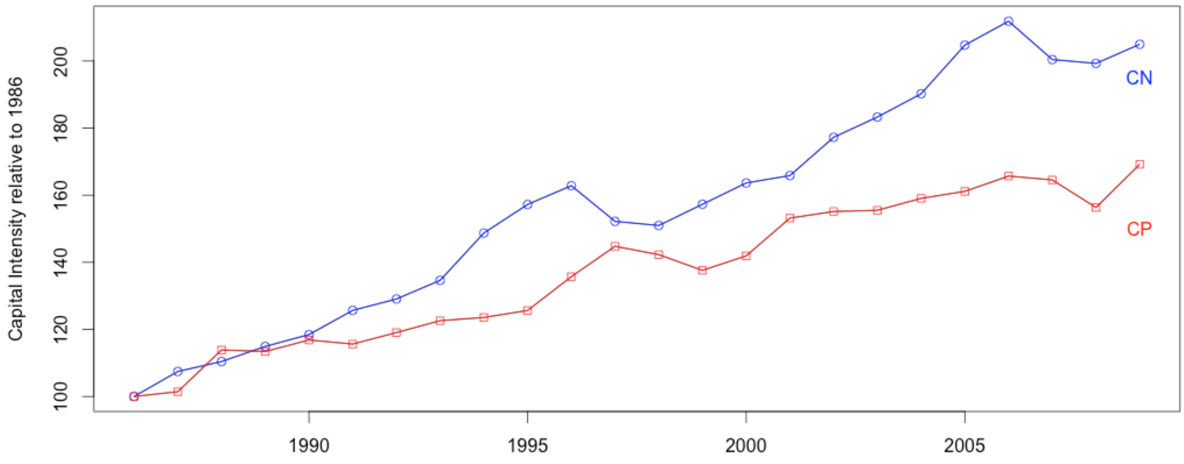
While our estimate for the two firms is slightly above Iacobacci and Schulman's (2009) estimated 3.6 per cent per year annual average TFP growth at CN and CP for 1981 to 2006, the difference is slight. As Iacobacci and Schulman's (2009) scope begins 5 years earlier than and ends 3 years prior to ours, their result is not strictly comparable anyway — the 0.34 percentage point difference may well be due to differences in scope.

Chart 8: Firm-level capital intensity 1986-2009

Panel A: Relative Capital Intensity 1986-2009, CN Relative to CP

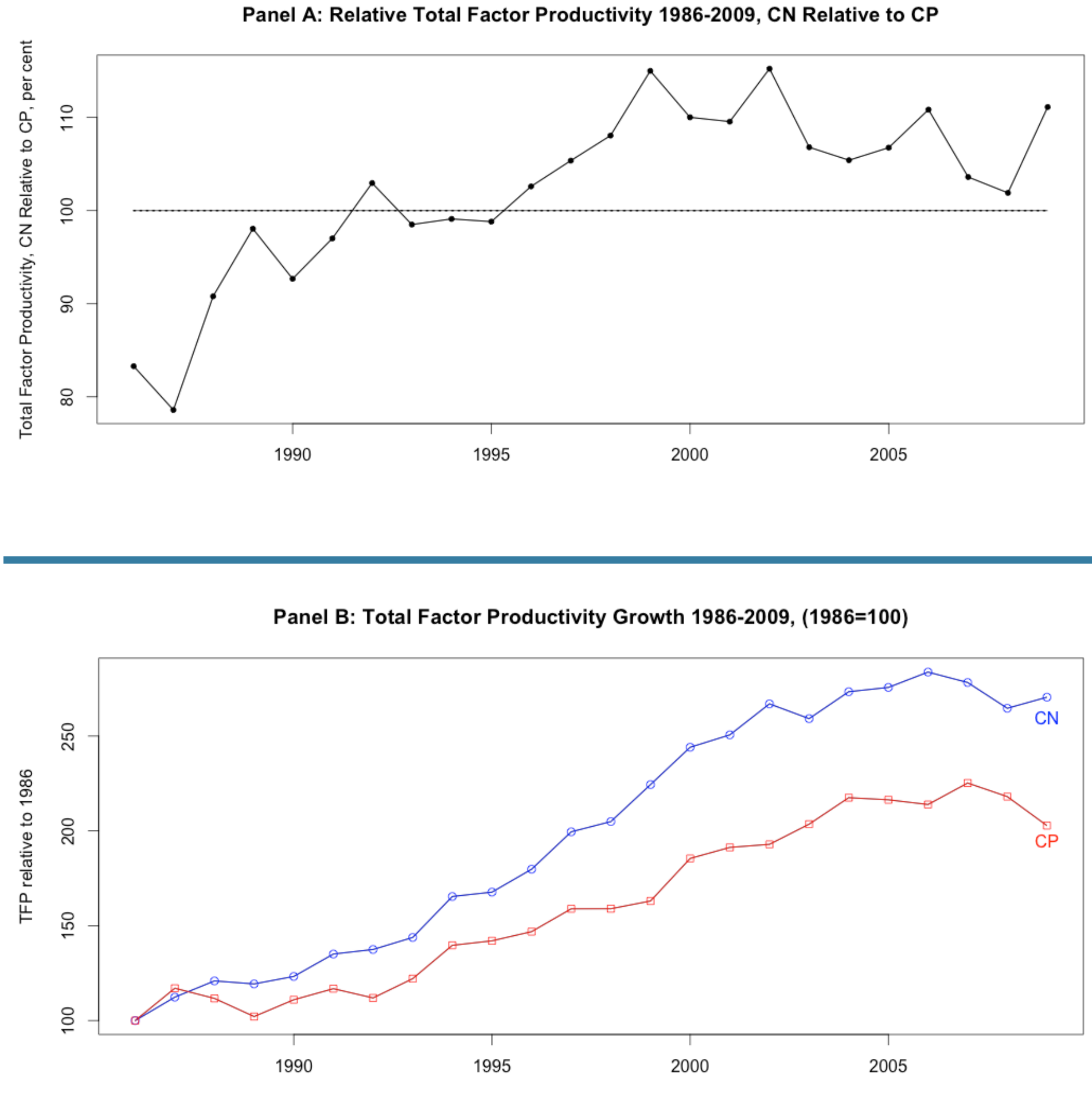


Panel B: Capital Intensity Growth 1986-2009, (1986=100)



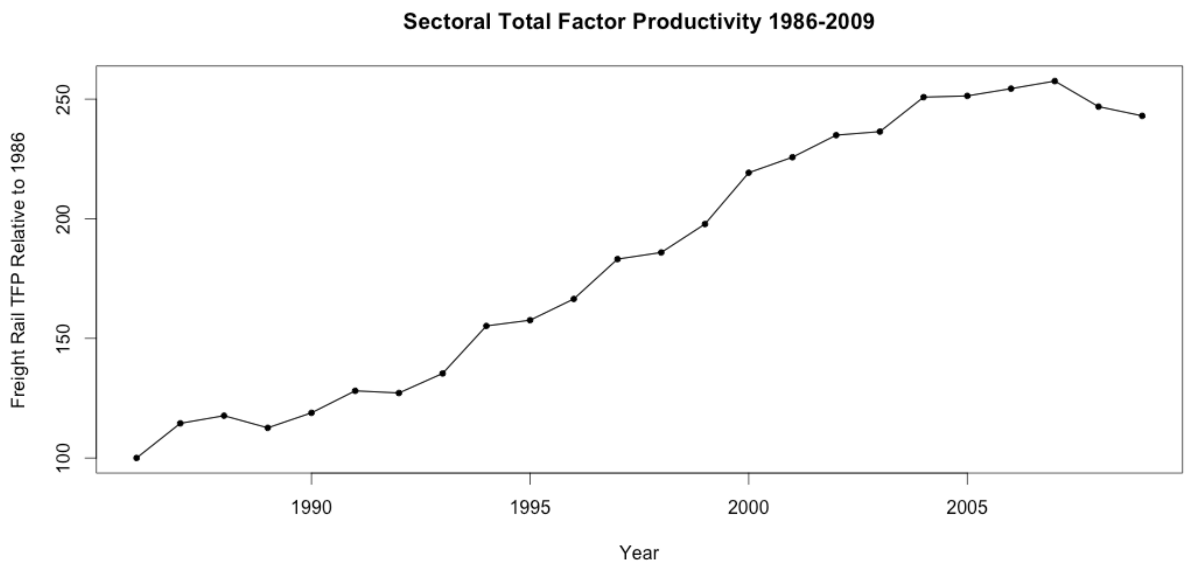
Data from Statistics Canada Tables 404-0010, 404-0014, 404-0016, and 404-0017; obtained from CANSIM October 5, 2015.

Chart 9: Firm-level total factor productivity 1986-2009



Data from Statistics Canada Tables 404-0004, 404-0010, 404-0012, 404-10016, 404-0017, and 404-0019; obtained from CANSIM October 5, 2015

Chart 10: Cumulative total factor productivity at CN and CP 1986-2009, (1986=100)



Data from Statistics Canada Tables 404-0004, 404-0010, 404-0012, 404-10016, 404-0017, and 404-0019; obtained from CANSIM October 5, 2015

V Productivity analysis - Econometric Approach

This section employs the econometric approach to transportation productivity estimation described in Section II(A)(ii). Section V(A) details the specific model employed in the analysis. Section V(B) provides an overview of some of the estimates obtained, and evaluates the stability of the CN productivity parameter estimate throughout the period, with direct reference to Iacobacci and Schulman (2009). Section V(C) compares the results obtained using econometric estimation with those obtained using the index approach.

A. Econometric Model

Caves, Christensen, and Swanson (1981a) pioneered an econometric method for estimating TFP. They estimated the variable cost functions for railways and obtained the TFP growth rates implied by the functions. Caves, Christensen, and Swanson originally applied their method to an unbalanced panel dataset of American railways covering 19 years with three cross-sections, with each cross-section having between 40 and 58 firms. Their method has since been widely used.[19]

Smith (2006) applies the Caves, Christensen, and Swanson (1981a) approach to a balanced panel dataset of Britain's railways with annual observations. As our data is much more similar to Smith's than Caves, Christensen, and Swanson's, our methodology adapts Smith for the Canadian case to obtain estimates for annual rates of TFP growth for CN and CP.

We assume that each railway is minimizing its total cost, rather than its variable cost. While this assumption is somewhat controversial, we are not the first to make it. Smith (2006) also estimates the total cost function rather than the variable cost function, arguing that managers have sufficient control over capital inputs over the course of the time series to make any assumption of fixed inputs untenable. Looking at Chart 2, there is sufficient variation in the capital inputs to argue that managers have enough control for the inputs to be considered variable, and therefore enter as objective variables in the neoclassical cost minimization problem.

Building up the theoretical model, consider some total cost function (C) which is a function of the level of outputs (Y) and inputs (X). By Shephard's lemma, each input is itself a function of output level and input prices (W), characterized by a cost-minimizing factor demand. More formally,

$$C = \Sigma_i \, W_i \, X_i(Y,\, W) = C(Y,\, W) \tag{2}$$

By differentiating logarithmically with respect to factor prices, we can also obtain the factor cost shares,

$$\frac{\partial \ln(C)}{\partial \ln(W_i)} = \frac{W_i \, X_i(Y,W)}{C} = S_i \tag{3}$$

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[19] See, for example, Caves, Christensen, and Swanson (1981b); De Broger (1991a); De Borger (1991b); McGeehan (1993); Wang and Liao (2006).

As with most of the rail productivity literature, we approximate the cost function using the translog functional form to take advantage of its flexibility. The translog total cost function takes the following general form,

$$\ln(C) = \alpha + \phi \ln(Y) + \Sigma_i \beta_i \ln(W_i) + \tfrac{1}{2} \xi \ln(Y)^2 + \tfrac{1}{2} \Sigma_i \gamma_i \ln(Y) \ln(W_i) \\ + \tfrac{1}{2} \Sigma_i \Sigma_j \delta_{i,j} \ln(W_i) \ln\left(W_j\right) + \zeta t + \eta \ln(Y) t + \Sigma_i \theta_i \ln(W_i) t \tag{4}$$

Making use of the definition of factor cost shares, we can obtain the share equations by differentiating logarithmically with respect to factor i's price,

$$S_i = \frac{\partial \ln(C)}{\partial \ln(W_i)} = \beta_i + \tfrac{1}{2} \gamma_i \ln(Y) + \Sigma_j \delta_{i,j} \ln\left(W_j\right) + \Sigma_i \theta_i t, \;\; \delta_{i,j} = \delta_{j,i} \tag{5}$$

Instead of imposing linear homogeneity restrictions, we follow Smith (2006) in dividing total cost and input price through by one of the input prices.[20] When estimating, we also restrict the coefficients in the share equations to be equal to their counterparts in the cost function, as the share equations are simply partial derivatives of the cost function. This is made explicit in equations (4), (5), and (i) through (v) by using the same notation. For example,

$$\beta_i^{(4)} = \beta_i^{(5)}$$

where (4) denotes the parameter from equation (4) and (5) denotes the parameter from equation (5).

To estimate the cost function, we employ the same output, inputs, prices, and expenditure shares as in the index portion of the report. One output and five inputs creates a system of five equations to estimate: a cost function and four factor share equations. We do not estimate the factor share equation for tracks as it must be dropped to obtain a non-singular system of equations. We estimate the system using Zellner's (1962) method. Results from the econometric model at the firm-level are presented below.

Our TFP estimate obtained from this method of estimation can be understood as the rate at which inputs can be decreased over time to produce a given level of output. Following Caves, Christensen, and Swanson (1981a), we take the total differential of (4) and hold output constant to obtain our annual TFP growth estimate,

$$\text{TFP} = -\frac{\partial \ln(C)}{\partial t} \bigg/ \Sigma_i \frac{\partial \ln(C)}{\partial \ln(W_i)}$$

B. Estimation of the Freight Rail Cost Function

Estimates for the system presented below were obtained after dropping the interaction terms involving time from the cost function (see equation (4) above), as Smith (2006) did. This simplification serves several ends. First and foremost, dropping the interaction terms ultimately

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[20] It is arbitrary which input price is chosen, in this case the price of track per kilometre was chosen. Prior to dividing through by the price of track per kilometre, we normalize prices and expenditure. Like Smith (2006), we use the sample means to do so.

makes the interpretation of the coefficient of the time trend variable become the annual percentage change of TFP over the period. Second, given our small sample of firms, it saves the estimation of six additional parameters which are no where near statistically significant when included. Third, unlike the interaction terms among input shares (S_i) and between input and output shares, the time interaction term lacks any theoretical interpretation.

Specifically, the following system of equations was estimated:

$$\begin{aligned}
\text{(i) } \ln(\text{expense}) = {} & \alpha_{\text{CN}} + \alpha_{\text{CP}} + \phi \ln(\text{gross ton km}) + \xi \ln(\text{gross ton km})^2 + \beta_1 \ln(P_{\text{loco}}) + \\
& \beta_2 \ln\left(P_{\text{freight cars}}\right) + \beta_3 \ln(P_{\text{diesel}}) + \beta_4 \ln(P_{\text{labour}}) + \tfrac{1}{2}\gamma_1 \ln(\text{gross ton km}) \ln(P_{\text{loco}}) + \\
& \tfrac{1}{2}\gamma_2 \ln(\text{gross ton km}) \ln\left(P_{\text{freight cars}}\right) + \tfrac{1}{2}\gamma_3 \ln(\text{gross ton km}) \ln(P_{\text{diesel}}) + \tfrac{1}{2}\gamma_4 \ln(\text{gross ton km}) \ln(P_{\text{labour}}) + \\
& \delta_{1,2} \ln(P_{\text{loco}}) \ln\left(P_{\text{freight cars}}\right) + \delta_{1,3} \ln(P_{\text{loco}}) \ln(P_{\text{diesel}}) + \delta_{1,4} \ln(P_{\text{loco}}) \ln(P_{\text{labour}}) + \\
& \delta_{2,3} \ln\left(P_{\text{freight cars}}\right) \ln(P_{\text{diesel}}) + \delta_{2,4} \ln\left(P_{\text{freight cars}}\right) \ln(P_{\text{labour}}) + \delta_{3,4} \ln(P_{\text{diesel}}) \ln(P_{\text{labour}}) + \\
& \tfrac{1}{2}\delta_{1,1} \ln(P_{\text{loco}})^2 + \tfrac{1}{2}\delta_{2,2} \ln\left(P_{\text{freight cars}}\right)^2 + \tfrac{1}{2}\delta_{3,3} \ln(P_{\text{diesel}})^2 + \tfrac{1}{2}\delta_{4,4} \ln(P_{\text{labour}})^2 + \zeta_1 t_{\text{CN}} + \zeta_2 t_{\text{CP}} + \varepsilon_1
\end{aligned}$$

$$\text{(ii) } S_{\text{loco}} = \beta_1 + \tfrac{1}{2}\gamma_1 \ln(\text{gross ton km}) + \delta_{1,1} \ln(P_{\text{loco}}) + \delta_{1,2} \ln\left(P_{\text{freight cars}}\right) + \delta_{1,3} \ln(P_{\text{diesel}}) + \delta_{1,4} \ln(P_{\text{labour}}) + \varepsilon_2$$

$$\text{(iii) } S_{\text{freight cars}} = \beta_2 + \tfrac{1}{2}\gamma_2 \ln(\text{gross ton km}) + \delta_{2,1} \ln(P_{\text{loco}}) + \delta_{2,2} \ln\left(P_{\text{freight cars}}\right) + \delta_{2,3} \ln(P_{\text{diesel}}) + \delta_{2,4} \ln(P_{\text{labour}}) + \varepsilon_3$$

$$\text{(iv) } S_{\text{diesel}} = \beta_3 + \tfrac{1}{2}\gamma_3 \ln(\text{gross ton km}) + \delta_{3,1} \ln(P_{\text{loco}}) + \delta_{3,2} \ln\left(P_{\text{freight cars}}\right) + \delta_{3,3} \ln(P_{\text{diesel}}) + \delta_{4,4} \ln(P_{\text{labour}}) + \varepsilon_4$$

$$\text{(v) } S_{\text{labour}} = \beta_4 + \tfrac{1}{2}\gamma_4 \ln(\text{gross ton km}) + \delta_{4,1} \ln(P_{\text{loco}}) + \delta_{4,2} \ln\left(P_{\text{freight cars}}\right) + \delta_{4,3} \ln(P_{\text{diesel}}) + \delta_{4,4} \ln(P_{\text{labour}}) + \varepsilon_5$$

where $P_i = \dfrac{W_i}{W_{\text{track}}}$ and expense $= \dfrac{C}{W_{\text{track}}}$.

The data for both firms was pooled to estimate the model, with firm-specific time variables and intercepts included. All results are presented in the appendix.

Estimation of our model pegs annual TFP growth at 4.23 per cent per year and 3.52 per cent per year at CN and CP respectively. One of the major advantages of the Caves, Christensen, and Swanson (1981a) approach is its ability to pull returns to scale out the TFP growth estimate by logarithmically differentiating with respect to gross tonne kilometres and manipulating the results. Smith (2006) takes their method a step further by adding a measure of track usage to capture economies of density. Unfortunately, as estimation of our model does not return significant point estimates for the coefficient of our gross tonne kilometre variable we are unable to unpack TFP growth into returns to scale and technological change. We suspect this is largely a multicollinearity issue with between gross tonne kilometres and the time trend. Moreover, we were unable to attempt to estimate returns to density using Smith's method due to a lack of appropriate data. Consequently, the interpretation of our productivity coefficients is still that they are "black box" measures. They represent the annual per cent reduction in the total cost function at either railway holding output constant.

Our model is, however, able to add some value that the index number approach was unable to. Specifically, we are able to statistically test parameter stability to evaluate whether or not TFP growth at some point fundamentally changed.[21]

Following Iacobacci and Schulman's (2009) claim that the privatization of CN was a major contributor to the stellar productivity growth exhibited by the Canadian freight rail sector, we test the stability of CN's TFP growth estimate in 1995. While it is entirely plausible that the effects of privatization on productivity could have led or lagged the 1995 breakpoint, a parameter stability test using 1995 as the break point *a priori* should split up productivity growth under public ownership and under private ownership. We fail to reject the null hypothesis that productivity growth was unchanged after privatization.[22]

We also consider the possibility that CN's productivity improved drastically around the time it privatized, but not precisely in 1995. We consider the installation of Tellier at the head of CN in 1992, the appointment of Harrison as COO and the advent of precision railroading in 1998 and 1999 (as Harrison (2000) only established the precision railroad in September 1998, 1999 was the first full year of the precision railroad), and Harrison's move to CEO in 2003 as four alternatives. At the 1998 and 2003 alternative thresholds, we fail to reject the null hypothesis that CN's annual productivity growth did not differ on either side of the break.[23]

For the 1992 and 1999 thresholds, we reject the null that CN's annual productivity growth did not differ on either side of the break at the 1 per cent level and 5 per cent level respectively. As we failed to reject the null at CP for both the 1992 and 1999 thresholds, there is evidence that the shock to TFP was firm specific.[24] The results are discussed in Section VI(A).

C. Differences with Index Estimates

First and foremost, the productivity estimates obtained via either form of estimation go hand in hand with the assumptions they rely on. Diewert (1992) argues that the use of indices to measure TFP is preferable to econometric estimation of productivity because indices do not require assumptions regarding firm behaviour. As noted above, we believe the most tenuous assumption in our econometric model is the treatment of capital inputs as variable and therefore estimating a total cost function in lieu of a variable cost function.

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[21] These parameter stability tests simply perform an F-test of an unrestricted model with two productivity coefficients (time trends for only one side of the break and are zero otherwise) against a restricted model with only the one. Ideally we would perform a Chow test, but our sample size is insufficient to support a doubling of the number of parameters to estimate. To ensure we are not simply capturing a technology shock hitting both firms, we run our parameter stability tests on CP as well.

[22] Specifically, the test returns an F-statistic of 0.221 and an associated p-value of 0.6388. We fail to reject the null at CP as well, returning an F-statistic of 1.8044 and a p-value of 0.1807.

[23] The test results were: **1998** - F-statistic of 2.3999 and a p-value of 0.1229; **2003** - F-statistic of 0.0146 and a p-value of 0.9030. We fail to reject the null at CP as well, returning: **1998** - F-statistic of 1.1177 and a p-value of 0.2917; **2003** - F-statistic of 1.0005 and a p-value of 0.3184.

[24] The test results were: **1992** - F-statistic of 8.0169 and a p-value of 0.00511; **1999** - F-statistic of 5.7117 and a p-value of 0.01778. However, we fail to reject the null at CP, indicating that the shock to TFP growth was firm specific. The tests returned: **1992** - F-statistic of 0.1615 and a p-value of 0.6882; **1999** - F-statistic of 2.2611 and a p-value of 0.1342.

Indices, however, do rely on cost shares to approximate the "importance" of an input to production and are therefore sensitive to price shocks. For example, a price shock in labour costs from a union renegotiating its collective bargaining agreement resulting in a one time increase in wages could over exaggerate the importance of labour to production between years. If the price shock for labour costs raised its cost share by several percentage points, output increased and the physical quantities of all inputs *but* labour fell in the same period, the TFP growth estimate between these two years maybe underestimated due to the increased weight suddenly put on labour. Contrarily, if the underlying model assumed cost minimizing by the firm, the productivity estimate between these same two years in question would not *a priori* be biased because the firm is purposely choosing its input levels taking costs into account. As the share equations in our system (equations (ii) through (v)) model this behaviour, an exogenous price shock can be handled by the model.

Another important difference between the index and econometric TFP estimates is what the "black boxes" we obtain actually contain. The traditional method of estimating TFP in economics is the residual change in output that is not captured by the change inputs, and this is effectively what our index method is measuring. The econometric method estimates another productivity catch-all measure but it is not technically TFP. Our catch-all captures all changes in total cost not explained by changes in output levels, input levels, or prices. *A priori* we expect both of the "black boxes" to contain the standard components, such as disembodied technological change and operational efficiency, but we have no way of confirming our suspicions. Consequently, our measures of productivity may be identical.

More technically speaking, there is also the issue of how our productivity estimates are calculated. The index method allows us to compute a compound average annual growth rate, while the econometric estimates compute annual productivity growth using least squares estimation. As such, estimates obtained from either method are broadly comparable, but not perfectly so.

Using indices, we estimate productivity growth to be 4.42 per cent per year at CN and 3.12 per cent per year at CP. Econometric estimates put annual productivity growth throughout the period at 4.23 per cent per year at CN and 3.52 per cent per year at CP. The gap in annual productivity growth between CN and CP over the period is significantly larger when estimated using indices (1.30 percentage points) than econometric estimation (0.81 percentage points). This difference in the size of the gap in growth rates is likely driven by the implicit assumption that both firms face the exact same production function, which keeps the number of parameters to estimate down. Some intuitive evidence of this is the econometric estimates lying between the two index estimates. Minor variations in the production function (driven, for example, by geographical differences) could result in our estimates for CN and CP somewhat diverging.

The crux of the matter is that the structure imposed by econometric estimation gives the model more explanatory power but it also sacrifices some realism (i.e. accuracy) at the firm-level because capital inputs may be quasi-fixed throughout the period of interest and the underlying production function may differ between firms or over time.

Ultimately, our concerns likely account for most of the differences between estimates obtained using the two estimation procedures. We are partial to Diewert's criticism of the use of firm behaviour assumptions in the econometric estimation, and are more confident in the accuracy of our index number results.

VI Discussion

Section VI(A) discusses our partial productivity results, and considers where they stand in the literature as a whole. Section VI(B) discusses our TFP growth results, and proposes several sources which drove them.

A. Partial productivity growth

The narrative of labour productivity growth, capital productivity growth, and TFP growth at CN and CP over the period of 1986 to 2009 is broadly similar. In the earlier years, CP enjoyed higher productivity levels than CN, and CN exhibited higher growth rates in part due to the removal of the added slack in their system that comes with being the less productive firm. However, in the mid-1990s the growth narrative changed. CN did not slow to a rate of productivity growth similar to CP's once its level of productivity converged. Rather, CN's productivity growth steamed ahead of CP, and by 2009 it had almost entirely reversed the gap which existed between the levels of productivity at the two firms in 1986.

The improvement in labour productivity is captured in Chart 5, with CP and CN growing 4.76 per cent per year and 6.49 per cent per year respectively. McKellips and Calver (2016) show that labour productivity growth can be broadly decomposed into changes in capital intensity and total factor productivity growth. The number of workers employed at CN in 2009 fell to 31.4 per cent of its 1986 value (shrinking 4.90 per cent per year), while the number of workers employed at CP fell to 43.6 per cent of its 1986 value (3.55 per cent per year). At CN, the labour input fell more than 2 percentage points per year faster than any other input; at CP, labour fell over 1.5 percentage points per year more than any other input. With such steep falls in labour, both CN and CP were in the odd position of experiencing fairly rapid capital deepening while their capital stocks were also falling fairly quickly (see Chart 8 Panel A). Sources of TFP growth are discussed below, but their robust growth also sustained strong labour productivity progress throughout the period of 1986-2009.

Our narrative of the sources of labour productivity growth is very much in line with Cairns (2015). He argues that Canadian freight rail productivity benefitted significantly from selling off the marginally profitable lines to regional shortlines and the discontinuance of lines which did not make economic sense (i.e. marginal costs of operation exceed marginal revenue). Cairns also argues that reduction in the freight rail labour force in tandem with the new profit sharing labour agreements with unions contributed significantly to productivity growth from 1981 to 2012.

Chart 6 details the growth of capital productivity at CN and CP from 1986 to 2009, showing that it grew 2.92 per cent per year and 1.93 per cent per year at CN and CP respectively. Cairns (2015) argues that the productivity growth experienced by CN and CP came through improved quality of capital assets (i.e. embodied technological change). Specifically, he cites: locomotives with more horsepower which allow longer trains to travel faster, locomotives able to sense weakened axels or tracks before they fail, lighter freight cars able to bear greater loads, and continuously welded tracks.

Evidence of Cairns' proposed improvements of the capital stock are evident in the data. For example, the free fall in the equipment maintenance workers employed by both CN and CP from 1986 to 2009 is likely due to the improved quality of the rolling stock and not neglect, as railway safety has steadily improved in recent decades (see Cairns, 2015). Some of these gains were also captured in fuel productivity growth over the period, as better engines could produce more RTKs with less diesel. While less obvious, the improvements in the capital stock also contribute to labour productivity growth implicitly through capital intensity.

B. Total factor productivity growth

While TFP growth follows the same narrative as labour and capital productivity growth, some of the drivers of the black box's growth are more open to interpretation. As discussed in Section V(B), one of the main advantages of econometric estimation is separating out returns to scale and returns to density from TFP growth. While we were not able to do so in this paper, it is still entirely possible that increasing and/or decreasing returns to scale and/or returns to density make up part of our TFP growth estimate.

Studying 1956 to 1991, Tretheway, Waters, and Fok (1997) argued that Canadian railways stood to make significant productivity gains if they were allowed to abandon lines as freely as their American counterparts were able to following the 1980 *Staggers Rail Act*. Specifically, Tretheway, Waters, and Fok (1997) argued that productivity at American railways benefited from economies of density in the wake of the *Staggers Rail Act*. CP's kilometres of track operated steadily declined at an average annual rate of 1.99 per cent per year from 1986 to 2009, and in 2009 it sat at 62.9 per cent of its 1986 value. CN's kilometres of track operated has also declined steadily since 1986. Although CN's reduction of kilometres of track operated effectively ended in 2006, in 2009 CN operated 72.1 per cent of the track it did in 1986 (a decline of 1.41 per cent per year). Given the TFP growth during this period of abandoning lines, CN and CP may well have benefited from the economies of density Tretheway, Waters, and Fok (1997) predicted.

Cairns (2015) argues that Canadian freight rail productivity benefitted significantly from selling off the marginally profitable lines to regional shortlines and the discontinuance of lines which did not make economic sense (i.e. marginal costs of operation exceed marginal revenue). While selling off unproductive capital assets contributes to capital productivity growth, it could lead to TFP growth either because the firms were experiencing diseconomies of scale where they operated on their production function or they benefitted from economies of density as a result of more throughput on the central lines.

Most of the literature on Canadian freight railways agrees that one of the major sources of their stellar TFP growth was operational efficiency. Iacobacci and Schulman (2009) argue that the operational efficiency gains came by way of the privatization of CN in 1995. Harrison (2000) and Cairns (2015) offer more specific operational changes which fundamentally altered the way firms transported goods.

Iacobacci and Schulman (2009) argue that one key driver of TFP growth in the rail sector was the privatization of CN in 1995. McKellips and Calver (2016) also argue that CN's decreased operating ratio after 1998 is evidence that the privatization of CN significantly improved productivity. Anecdotally, CN does exhibit its more significant declines in locomotives, freight cars, and track operated after 1995. Its labour productivity, capital productivity, and TFP levels also converged with CP around 1995, so it could be the case that incoming market pressures helped CN remove excess slack from its system.

Iacobacci and Schulman (2009) are not, however, supported by CN's TFP growth trajectory. In the 10 years prior to privatization, CN's average annual TFP growth was 5.91 per cent per year while the 10 years following privatization its average annual TFP growth rate was only 5.58 per cent per year. For comparison, CP grew 3.75 per cent per year in the decade prior to 1995 and 4.85 per cent per year in subsequent decade, so CN's growth slowdown doesn't appear to reflect new realities facing the market. Econometric estimation also showed no evidence of the effect of privatization in 1995.

Admittedly, using 1995 itself as the threshold for productivity gains from privatization is not ideal for this sort of analysis. Smooth privatization of a firm the size of CN would not be possible on short notice, and no doubt upper management at CN knew of the coming privatization well in advance of its arrival. It is entirely possible that the pressures of the privatization came in advance of 1995, and therefore its effects were manifest prior to 1995. As such, we performed stability test on the productivity coefficient estimate for CN employing other key years in the railway's history: the installation of Tellier at the head of CN in 1992, the appointment of Harrison as COO and the advent of precision railroading in 1998 and 1999 (as Harrison (2000) only established the precision railroad in September 1998, 1999 was the first full year of the precision railroad), and Harrison's move to CEO in 2003. We fail to reject the null hypothesis of no change in productivity growth at the 1998 and 2003 thresholds.

While we are not able find direct statistical evidence of Iacobacci and Schulman's (2009) argument, we are able to provide two credible alternatives. We found statistically significant evidence that TFP growth differed before and after 1992, and before and after 1999. Admittedly, 1992 may provide some evidence of Iacobacci and Schulman's hypothesis, as Tellier was installed as CEO to prepare CN for privatization. With Tellier at the helm and the 1995 IPO only a handful of years away, looming market pressures may have bolstered TFP growth.

Cairns (2015) argues that further productivity gains arose due to improved operational practices, such as the addition of a locomotive in the middle of long trains, and improved management due to better informational technologies at the firm's disposal. While neither of these claims are directly measurable, their productivity improvements ought to be captured in the TFP series estimated by reducing the inputs required to produce an output. Some of these gains were likely captured in fuel productivity growth over the period.

Harrison (2000) touts the operational successes CN experienced under his precision railroad regimen, and our results indicate that there was a statistically significant difference in productivity after 1999. Other than slight accelerations in the declines of operational locomotives and freight cars at CN around 1998, there is little cursory evidence of his strong operational management in the data. This, however, is not surprising, as operational efficiency is primarily captured in the residual output growth which TFP measures.

VII Conclusion

Ultimately, labour productivity growth at CN and CP from 1986 to 2009 was sustained by capital deepening, improvements in the stock of capital, and robust TFP growth. Operational changes, especially the introduction of precision railroading, were central contributors to TFP growth during the period. There is little evidence that the privatization of CN in 1995 changed the trajectory of its TFP growth. However, TFP growth at CN systematically improved following the installation of Tellier as CEO in 1992. As Tellier's marching orders were to prepare the firm for privatization, the fundamental changes to productivity that were results of privatization may well have have occurred in 1992. The advent of precision railroading in 1999 was also a major turning point for productivity growth at CN.

Using indices, we estimate productivity growth to be 4.42 per cent per year at CN and 3.12 per cent per year at CP. At the industry level, we estimate annual TFP growth of 3.94 per cent per year. Econometric estimates put annual productivity growth throughout the period at 4.23 per cent per year at CN and 3.52 per cent per year at CP.

Our findings provide evidence of productivity drivers from the industry level holding true at the firm level (e.g. capital deepening or core operational improvements). Future research into Canadian railways should strive to extend the period of analysis to include the years of sluggish economic growth which followed the 2008 financial crisis and investigate whether the quickly falling operating ration at CP under Harrison was in fact driven by rapid TFP growth. Future research using alternative estimation methods with the *Railway Transport Survey* dataset would help enhance the understanding of the successes of Canadian freight railways.

Further research should also expand the breadth of analysis into studies of passenger railways (e.g. VIA rail) and shortlines, the data for which is also available from the *Railway Transport Survey* dataset. Statistics Canada should consider making the microdata from the *Railway Transport Survey* on shortlines publicly available to fuel future research. They should also consider the addition of throughput variables and land variables in the *Railway Transport Survey*, to allow researchers estimate returns to density and generate TFP estimates which include land inputs.

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Appendix I: Data Tables

Appendix Table 1: Partial Productivity Measures

Year	CP RTK per employee	CN RTK per employee	CP RTK per 1000L of diesel	CP RTK per 1000L of diesel
1986	3574.5	2779.7	111.0	124.4
1987	4313.1	3235.9	122.0	137.2
1988	4323.4	3577.8	118.7	136.1
1989	3933.9	3551.0	114.0	143.0
1990	4370.0	3714.8	118.9	145.4
1991	4630.0	4231.3	120.4	148.4
1992	4482.3	4366.4	117.7	150.4
1993	5013.2	4655.3	122.1	153.4
1994	5904.0	5657.4	129.1	169.2
1995	6072.9	5932.3	128.0	158.7
1996	6457.4	6564.1	135.3	155.4
1997	7322.5	7354.2	135.3	150.0
1998	7209.8	7513.5	140.6	153.6
1999	7328.1	8292.6	141.2	179.9
2000	8648.9	9249.3	153.0	192.0
2001	9201.2	9677.1	159.1	185.8
2002	9401.4	10690.3	153.5	188.3
2003	10035.1	10569.3	156.5	180.0
2004	10926.7	11543.9	163.6	177.5
2005	10935.6	12126.6	165.4	178.3
2006	11022.6	12787.7	161.9	181.0
2007	11875.0	12313.9	160.4	180.9
2008	11281.7	11776.9	159.5	178.5
2009	10417.7	11807.4	163.1	187.6

Appendix Tabel 2: Multifactor Productivity Indices				
Year	CP VFP	CN VFP	CP TFP	CN TFP
1986	100	100	100	100
1987	116.32	111.93	117.03	112.33
1988	114.64	119.02	111.67	120.90
1989	103.77	116.09	102.11	119.31
1990	111.40	118.91	110.97	123.25
1991	116.49	129.75	116.79	135.07
1992	110.81	131.65	111.92	137.46
1993	119.75	137.44	122.07	143.80
1994	136.67	158.00	139.67	165.40
1995	138.30	157.87	142.03	167.72
1996	142.40	168.27	146.89	179.79
1997	154.44	182.27	158.92	199.51
1998	153.02	183.18	158.96	204.93
1999	153.71	198.92	163.03	224.42
2000	173.41	215.24	185.47	244.10
2001	179.45	219.52	191.29	250.63
2002	178.56	232.80	192.91	266.98
2003	188.91	225.94	203.54	259.20
2004	203.23	238.25	217.51	273.38
2005	204.94	247.18	216.39	275.65
2006	202.06	255.90	213.91	283.75
2007	211.27	249.07	225.24	278.24
2008	202.16	237.30	218.07	264.66
2009	185.49	239.16	202.79	270.50

Appendix Table 3: CN Expense Shares

Year	Track	Locomotives	Freight Cars	Deisel	Labour
1986	0.1404	0.0918	0.0807	0.1144	0.5727
1987	0.1452	0.0942	0.0753	0.1209	0.5644
1988	0.1421	0.0925	0.0778	0.1207	0.5669
1989	0.1422	0.0954	0.0690	0.1197	0.5737
1990	0.1390	0.0879	0.0797	0.1257	0.5678
1991	0.1377	0.0795	0.0786	0.1318	0.5724
1992	0.1362	0.0704	0.0767	0.1177	0.5991
1993	0.1519	0.0754	0.0867	0.1151	0.5709
1994	0.1539	0.0781	0.0774	0.1291	0.5615
1995	0.1536	0.0740	0.0733	0.1312	0.5679
1996	0.1540	0.0728	0.0729	0.1497	0.5505
1997	0.1589	0.0610	0.0744	0.1568	0.5488
1998	0.1728	0.0535	0.0735	0.1289	0.5713
1999	0.1859	0.0537	0.0739	0.1149	0.5716
2000	0.1744	0.0517	0.0735	0.1516	0.5488
2001	0.1660	0.0801	0.0588	0.1640	0.5311
2002	0.1775	0.0739	0.0675	0.1525	0.5286
2003	0.1701	0.0786	0.0802	0.1554	0.5157
2004	0.1806	0.0752	0.0756	0.1749	0.4936
2005	0.1652	0.0651	0.0759	0.2243	0.4695
2006	0.1706	0.0611	0.0712	0.2459	0.4512
2007	0.1822	0.0609	0.0625	0.2650	0.4295
2008	0.1766	0.0523	0.0482	0.3324	0.3905
2009	0.2132	0.0672	0.0531	0.2191	0.4475

Appendix Table 4: CP Expense Shares

Year	Track	Locomotives	Freight Cars	Diesel	Labour
1986	0.1386	0.1228	0.0849	0.1382	0.5154
1987	0.1422	0.1207	0.0909	0.1442	0.5020
1988	0.1422	0.1138	0.0917	0.1381	0.5141
1989	0.1484	0.1151	0.0946	0.1270	0.5149
1990	0.1442	0.1055	0.0929	0.1452	0.5122
1991	0.1492	0.0956	0.0882	0.1391	0.5280
1992	0.1624	0.0873	0.0897	0.1274	0.5332
1993	0.1545	0.0856	0.0916	0.1338	0.5345
1994	0.1461	0.0966	0.0815	0.1422	0.5336
1995	0.1433	0.1092	0.0745	0.1448	0.5282
1996	0.1380	0.1133	0.0823	0.1496	0.5169
1997	0.1442	0.1101	0.0851	0.1635	0.4972
1998	0.1464	0.1094	0.0773	0.1433	0.5238
1999	0.1352	0.1018	0.0759	0.1426	0.5446
2000	0.1430	0.1027	0.0734	0.1971	0.4839
2001	0.1345	0.1133	0.0876	0.1891	0.4755
2002	0.1444	0.1181	0.0633	0.1808	0.4933
2003	0.1379	0.1209	0.0671	0.1890	0.4850
2004	0.1501	0.1134	0.0576	0.2011	0.4777
2005	0.1413	0.1058	0.0567	0.2351	0.4611
2006	0.1373	0.1085	0.0534	0.2643	0.4366
2007	0.1516	0.1078	0.0535	0.2811	0.4061
2008	0.1498	0.0959	0.0417	0.3307	0.3819
2009	0.1558	0.1007	0.0549	0.2439	0.4448

Appendix Table 5: Econometric results
method: SUR

	N	DF	SSR	detRCov	OLS-R2
system	240	206	0.10601	0 0.96168	0.924675

	N	DF	SSR	MSE	R2	Adj R2
totalcost	48	24	0.036519	0.001522	0.985165	0.970949
locomotiveinput	48	42	0.007215	0.000172	0.653145	0.611853
freightcarsinput	48	42	0.008447	0.000201	-0.115659	-0.248475
fuelinput	48	42	0.017719	0.000422	0.879818	0.865510
labourinput	48	42	0.036110	0.000860	0.719924	0.686582

Coefficients:

	Estimate	Std. Error	Pr(>|t|)
totalcost_CN	86.13993559	99.08141861	0.38564821
totalcost_CP	86.14083837	99.05543453	0.38551885
totalcost_CNprod	-0.03424049	0.00393706	1.1102e-15 ***
totalcost_CPprod	-0.02851169	0.00415587	7.8707e-11 ***
totalcost_log(grosskm)	-9.42442806	10.63219400	0.37643303
totalcost_log(price_loco)	0.43247569	0.12702216	0.00079600 ***
totalcost_log(price_freightcar)	0.49764158	0.13772726	0.00038002 ***
totalcost_log(price_diesel)	-1.27747132	0.22977388	8.3171e-08 ***
totalcost_log(price_labour)	0.91157586	0.29287629	0.00211856 **
totalcost_lint_kmlabour	-0.02073394	0.01576925	0.19002781
totalcost_lint_kmloco	-0.01751996	0.00685656	0.01133373 *
totalcost_lint_kmdiesel	0.07699865	0.01234726	2.5011e-09 ***
totalcost_lint_kmfreight	-0.02299786	0.00741065	0.00218207 **
totalcost_lint_locofreight	1.10553436	0.81381614	0.17580442
totalcost_lint_locodiesel	-1.51664471	0.34555530	1.8182e-05 ***
totalcost_lint_locolabour	1.44469984	0.72237111	0.04682008 *
totalcost_lint_freightdiesel	-1.77128918	0.51955966	0.00078372 ***
totalcost_lint_freightlabour	0.60861181	0.60688084	0.31710868
totalcost_lint_diesellabour	4.18390580	1.01816811	5.7284e-05 ***
totalcost_self_loco	0.36785501	0.32367921	0.25707598
totalcost_self_freight	0.03058799	0.38060330	0.93602331
totalcost_self_diesel	-0.23227850	0.25081396	0.35547832
totalcost_self_labour	-0.47828309	0.98848075	0.62900149
totalcost_self_km	0.51625027	0.57055133	0.36661402
locomotiveinput_(Intercept)	0.43247569	0.12702216	0.00079600 ***
locomotiveinput_log(grosskm)	-0.01751996	0.00685656	0.01133373 *
locomotiveinput_log(price_loco)	0.06949663	0.00728884	< 2.22e-16 ***

locomotiveinput_log(price_freightcar)	-0.02305688	0.00556593	5.0128e-05 ***
locomotiveinput_log(price_diesel)	-0.03393857	0.00651902	4.6551e-07 ***
locomotiveinput_log(price_labour)	0.03158663	0.01042327	0.00275535 **
freightcarsinput_(Intercept)	0.49764158	0.13772726	0.00038002 ***
freightcarsinput_log(grosskm)	-0.02299786	0.00741065	0.00218207 **
freightcarsinput_log(price_loco)	-0.02305688	0.00556593	5.0128e-05 ***

	Estimate	**Std. Error**	**Pr(>|t|)**
freightcarsinput_log(price_freightcar)	0.04165321	0.00709573	1.7209e-08 ***
freightcarsinput_log(price_diesel)	-0.05092685	0.00677446	1.6849e-12 ***
freightcarsinput_log(price_labour)	0.05563769	0.00959623	2.4965e-08 ***
fuelinput_(Intercept)	-1.27747132	0.22977388	8.3171e-08 ***
fuelinput_log(grosskm)	0.07699865	0.01234726	2.5011e-09 ***
fuelinput_log(price_loco)	-0.03393857	0.00651902	4.6551e-07 ***
fuelinput_log(price_freightcar)	-0.05092685	0.00677446	1.6849e-12 ***
fuelinput_log(price_diesel)	0.16635578	0.01164848	< 2.22e-16 ***
fuelinput_log(price_labour)	-0.10787525	0.01326082	3.8414e-14 ***
labourinput_(Intercept)	0.91157586	0.29287629	0.00211856 **
labourinput_log(grosskm)	-0.02073394	0.01576925	0.19002780
labourinput_log(price_loco)	0.03158663	0.01042327	0.00275535 **
labourinput_log(price_freightcar)	0.05563769	0.00959623	2.4965e-08 ***
labourinput_log(price_diesel)	-0.10787525	0.01326082	3.8414e-14 ***
labourinput_log(price_labour)	0.07178829	0.02831217	0.01196760 *

Signif. codes: ‘*’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1**