THE MEASUREMENTS OF TOTAL FACTOR PRODUCTIVITY GROWTH FOR CANADIAN RAILWAYS

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INTRODUCTION

Productivity is a measure of how a firm, such as a railway company, uses inputs like labour, material, capital, etc., to produce outputs such as transportation movements and services. An increase in productivity occurs if the company produces a greater quantity of its outputs with the same quantity of inputs, or uses less quantity of inputs to produce the same volume of outputs. Productivity can be compared between firms, industry sectors, regions, countries, or even groups of countries in economic or political blocks.

The aim of this paper is to present a new method to calculate an index related to the Canadian Railways Total Factor Productivity.

Literature specific to Canadian Railways:

Freeman, Oum, Tretheway, and Waters (1987) investigated the growth and performance of Canadian railways over the period 1956 to 1981. Though the authors claim that the choice of specific starting and ending years was dictated by data, availability, the authors also note the period coincided with a profound change in the railway industry, including major transformations in technology, traffic mix, corporate organization, and the regulatory environment.

Tretheway, Waters, and Fok (1994) extended the study by FOTW using essentially the same methodology, but covering the period 1956-1991.

Differences in the two studies, other the additional 10-year period covered by TWF, involved differences in the measurement of input and output prices and quantities.

TWF (1987) and TWF (1994) were both direct applications of C.C.D (1982)

James Uguccioni's analysis (2016) is a direct application of C.C.D (1982) and Smith (2006). The author used publically available data from Statistic Canada up to 2009.

PROPOSED NEW AGENCY METHODOLOGY

We propose to study the productivity growth of CN and CP using three new methodologies that numerous assumptions, which should result in more realistic and therefore more accurate measures of total factor productivities for CP and CN.

Solow Productivity Index

Following Harrison (1994), staff estimates the Solow Residual using a formulation that does not assume perfectly competitive markets or constant return to scale. Agency staff's Solow Productivity Index (SPI) is estimated from the equation:

$$TFP_{t-1}^{t} = (lny^{t} - lny^{t-1}) - \frac{1}{2}\sum_{n=1}^{N}\left[\frac{w_n^{t-1}x_n^{t-1}}{P^{t-1}(I-m^{t-1}).y^{t-1}} + \frac{w_n^{t}x_n^{t}}{P^{t}(I-m^{t}).y^{t}}\right](lnx_n^{t} - lnx_n^{t-1})$$

where:

- TFP^{t}_{t-1} is the ratio of Total Factor Productivity between time periods t and t-1;
- $\ln y^{t}$ and $\ln y^{t-1}$ are the logarithms of a single aggregate output in periods t and t-1;
- $\ln x_n^{t}$ and $\ln x_n^{t-1}$ are the logarithms of n^{th} input in periods t and t-1;
- w_n^{t} and w_n^{t-1} are the prices of the n^{th} input in periods t and t-1;
- P^{t} and P^{t-1} are the prices of the aggregate output prices in periods t and t-1; and
- m is the markup factor by which marginal product exceeds factor cost.

It is important to note that the theoretical formulation of the SPI allows for productivity to be calculated in conditions where there is a single output with multiple inputs.

Malmquist Productivity Index

Using the analytical approach proposed by Chambers (2002) and Hudgins and Primont (2004), Agency staff has re-formulated the Diewert & Fox extension of the traditional CCD model, to derive a fully deterministic productivity equation that allows for imperfect competition and non-constant returns to scale. Agency staff's Malmquist Productivity Index (MPI) is estimated from the equation:

$$TFP_{t-1}^{t} = \frac{1}{2}\sum_{i=1}^{I}\left[\frac{P_i^{t-1}\left(1-m_i^{t-1}\right)y_i^{t-1}}{\sum_{i=1}^{I}P_i^{t-1}\left(I-m_i^{t-1}\right)y_i^{t-1}}+\frac{P_i^{t}\left(1-m_i^{t}\right)y_i^{t}}{\sum_{i=1}^{I}P_i^{t}\left(I-m_i^{t}\right)y_i^{t}}\right]\left(lny_i^{t}-lny_i^{t-1}\right) - \frac{1}{2}\sum_{n=1}^{N}\left[\frac{w_n^{t-1}x_n^{t-1}}{\sum_{i=1}^{I}P_i^{t-1}\left(I-m_i^{t-1}\right)y_i^{t-1}}+\frac{w_n^{t}x_n^{t}}{\sum_{i=1}^{I}P_i^{t}\left(I-m_i^{t}\right)y_i^{t}}\right]\left(lnx_n^{t}-lnx_n^{t-1}\right)$$

where:

- TFP^{t}_{t-1} is the ratio of Total Factor Productivity between time periods t and t-1;
- $\ln y_i^{t}$ and $\ln y_i^{t-1}$ are the logarithms of the i^{th} output in periods t and t-1;
- $\ln x_n^{t}$ and $\ln x_n^{t-1}$ are the logarithms of n^{th} input in periods t and t-1;
- w_n^{t} and w_n^{t-1} are the prices of the n^{th} input in periods t and t-1;
- P_i^{t} and P_i^{t-1} are the prices of the i^{th} output in periods t and t-1; and
- m_i^{t} and m_i^{t-1} are the markup factors by which marginal product exceeds factor cost for the i^{th} output in periods t and t-1.

Luenberger Productivity Index

Following Chambers (2002) and Hudgins and Primont (2004), Agency staff has developed a fully deterministic Luenberger productivity indicator that is directly computed and not estimated using DEA or stochastic empirical estimation techniques. The Agency staff Luenberger productivity indicator, which allows for imperfect competition and non-constant returns to scale, is estimated from the equation:

$$TFP_{t-1}^{t} = \frac{1}{2}\sum_{i=1}^{I}\left[\frac{P_i^{t-1}(1-m_i^{t-1})}{\sum_{i=1}^{I} P_i^{t-1}\left(I-m_i^{t-1}\right) y_i^{t-1} + \sum_{n=1}^{N} w_n^{t-1}\, x_n^{t-1}} + \frac{P_i^{t}(1-m_i^{t})}{\sum_{i=1}^{I} P_i^{t}\left(I-m_i^{t}\right) y_i^{t} + \sum_{n=1}^{N} w_n^{t}\, x_n^{t}}\right]\left(lny_i^t - lny_i^{t-1}\right) - \frac{1}{2}\sum_{n=1}^{N}\left[\frac{w_n^{t-1}}{\sum_{i=1}^{I} P_i^{t-1}\left(I-m_i^{t-1}\right) y_i^{t-1} + \sum_{n=1}^{N} w_n^{t-1}\, x_n^{t-1}} + \frac{w_n^{t}}{\sum_{i=1}^{I} P_i^{t}\left(I-m_i^{t}\right) y_i^{t} + \sum_{n=1}^{N} w_n^{t}\, x_n^{t}}\right](lnx_n^t - lnx_n^{t-1})$$

where all symbols retain the same meanings as for the MPI.

The Luenberger productivity indicator is then converted into a Luenberger Productivity Index (LPI) using the transformation:

$$TFP_t = TFP_{t-1}\, D_t^{t-1} = TFP_{t-1}\,[1+\beta]$$

where β is the Luenberger productivity indicator calculated for the period t to t-1.

DATA USED

The data needed to estimate all three productivity models comprises output prices and quantities and input prices and quantities as described below.

Output Quantities

Both FOTW and TWF studied a single aggregated freight output represented by revenue tonne-miles performed by CN and CP in each year, though FOTW included revenue passenger miles as an additional output. For estimation of the Solow Productivity Index this study uses a single aggregate output, revenue tonne-miles. For estimation of the Malmquist and Luenberger productivity indices this study uses a more disaggregated measure of outputs, comprising the revenue tonne-miles performed by CN and CP of 14 commodity groups based on CN and CP's lines of business.

The annual revenue ton-miles (RTM) of each commodity group moved by CN and CP are determined from the confidential annual rail traffic database submitted to the Agency by CN and CP. Quantity indices are derived for each of the 14 commodity groups from 1992 to 2014, with the value of the 1992 RTM of each group set to 1.

Output Prices

The output price for each commodity group is derived from the confidential rail traffic database as the average revenue obtained by CN or CP for that commodity group divided by the RTM performed of that group. Revenue shares for each commodity group are obtained directly from the same database.

Input Quantities

The inputs used in this study follow the classical KLEMS (capital, labour, energy, materials, services) used in most productivity studies and by both FOTW and WTF.

Labour

Annual Labour quantities are derived from the annual reports submitted to the Agency by CN and CP on compensation and actual hours worked for each of 79 categories of labour (Schedule S-12). For each railway, a labour quantity index is constructed of the annual total labour hours worked, with the 1992 value set to 1. Before constructing the quantity index, the total hours worked are reduced by the labour hours spent on capital projects, as those hours are included in the capital quantities. This is done by comparing the total labour expenses in the Expense Reports submitted to the Agency for unit cost determination purposes, which excludes expenses on capital projects, with the labour expenses submitted to the Agency for price indexation purposes, which includes labour expenses on all projects, to obtain a factor that reflects the proportion of labour-related capital in all expenses. This factor is then applied to total quantities of hours worked to identify and remove the labour hours spent on capital projects.

Fuel

Annual fuel quantities are derived from the annual reports submitted to the Agency by CN and CP on the total litres of fuel consumed in rail operations in each province (Schedule S-13). For each railway, a fuel quantity index is constructed of the annual total fuel consumed, with the 1992 value set to 1

Capital

This study constructed quantity indices for four categories of capital assets: land, infrastructure, owned equipment, and rented and leased equipment. Both railways use the perpetual inventory method to keep track of the value of reasonably homogeneous groups (for example, locomotives, freight cars, rail, ballast, etc.) of their owned capital assets, in each year. For each class of assets, the railways record the gross value of the capital stock at the beginning of the year, the additions to capital assets (new investments) during the year, the reductions to capital assets (retirements and depreciation) during the year, and the gross value at the end of the year. This information is provided in Schedule F-49 annually to the Agency by CN and CP.

The data in Schedule F-49 allows the Agency to calculate quantity indices for capital assets that are more accurate than those used in previous studies, which had to apply the perpetual inventory method to construct estimates of the actual quantity series using a base year capital investment, annual investment series, and assumed depreciation curves.

The quantity of infrastructure capital is the net book value (gross value of the capital stock less accumulated depreciation) of way & structures assets in constant 1992 dollars, for each of the assets in accounts 102-163 (investment) and 202-263 (accumulated depreciation) of the Uniform Classification of Accounts (UCA). The aggregate net book value of infrastructure stock is deflated to constant 1992 dollars using the Statistics Canada price indices for rail Buildings and Engineering Construction. A quantity index of infrastructure capital is then constructed from the resulting constant dollar series by setting the 1992 value to 1.

Similarly, the annual amounts of the aggregate net book value of owned equipment, derived from accounts 171–195 (investment) and 271-295 (accumulated depreciation) in the UCA, are deflated to constant 1992 values using the Statistics Canada price index for rail industry Machinery and Equipment, and a quantity index of owned equipment is constructed from the resulting constant dollar series by setting the 1992 value to 1.

Because land is not a depreciable asset, the gross amounts for land (account 101 in the UCA) are deflated to constant 1992 dollars using the GDP deflator, and a quantity index of land is constructed from the resulting constant dollar series by setting the 1992 value to 1.

The railways report their annual expenditures on equipment leasing and rentals in accounts 551-566 of the UCA. Estimates of the dollar values of the quantities of equipment capital rented or leased are obtained by dividing the annual expenditures by the Statistics Canada rail industry Machinery and Equipment price index.

Materials
Materials comprise thousands of parts and supplies which, as with capital, makes it impractical to develop an aggregate quantity index based on the quantities of the material items. Instead, a quantity index for materials is developed by dividing annual expenditures on materials by a materials price index approved by the Agency for use for regulatory purposes, then converting the resulting quantity series into an index with 1992 value set to 1. Material expenses are developed from Expense Reports, which excludes the materials used in capital projects.

Services
Services include all other expenses incurred by the railway excluding labour, fuel, capital and materials. It includes engineering, legal, accounting, consulting, contracting, and other services purchased by the railway. A quantity index for services is developed by dividing annual expenditures on services by the GDP deflator, then converting the resulting quantity series into an index with 1992 value set to 1. Services expenses are developed from Expense Reports and include no capital-related expenses.

Input Prices

Labour
The annual price of labour is calculated as the average dollar of employee compensation per hour worked. Total compensation for employees includes salaries and wages, wage-related benefits (paid vacations, bonuses, share-purchase plans, etc.), employment benefits (CPP, QPP, EI, health & welfare payments, etc.), stock-based compensation, and pension benefits. Annual data on these expenses are provided in Schedule S12 (which details salaries and wages and wage-related benefits, along with hours worked and hours paid for, for 79 categories of railway employees) and accounts 820-839 of Schedule F46, submitted annually to the Agency by each railway. A labour price index is constructed from the annual price series by setting the price for 1992 to 1.

Fuel
The annual price of fuel is calculated as the fuel price per litre from Schedule S13, which details the litres of fuel consumed and corresponding fuel expense incurred by Province, submitted annually to the Agency by each railway. A fuel price index is constructed from the annual price series by setting the price for 1992 to 1.

Capital
Unlike, say fuel, a capital item is not fully consumed in the provision of a transportation service. A capital item is long-lived, and is best thought of as providing a flow of services over its useful life. The price of the service flow provided by a capital item in any given year is therefore very different from the purchase price of the capital item, and is related to many factors including the opportunity cost of capital, the rate of depreciation of the asset, property taxes, investment tax credits, and other factors.

Materials
The Agency approves annually material price indices calculated separately for CN and CP, using the purchase order database for each railway containing the quantity and price for all material purchase transactions during the year. The Agency-approved MPI is reset to 1992=1 and used as the price of materials in this study.

Services
The GDP deflator is used as the price index for the services purchased by the railways.

Markup Factors

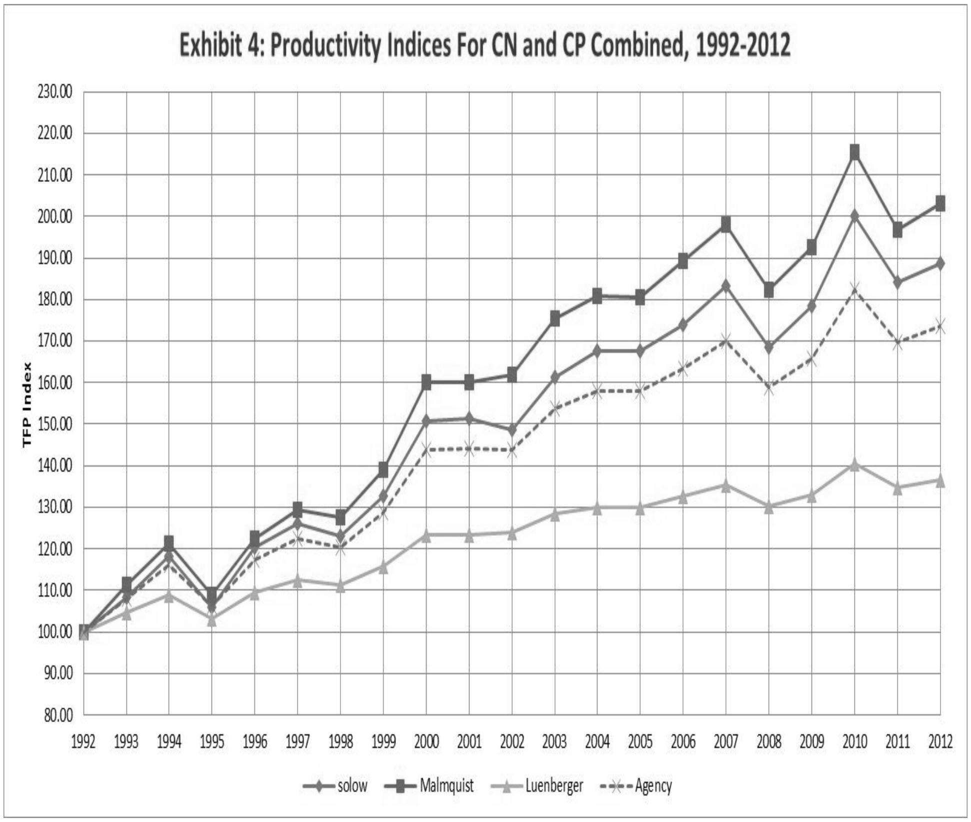
The markup factors by which marginal product exceeds factor cost, m_i in the productivity equations, are calculated from data on average revenue per RTM for each of the 14 commodity groups, representing marginal product, and long-run marginal cost per RTM for each of the 14 commodity groups, representing factor cost. Revenue per RTM is calculated from the freight traffic database submitted annually to the Agency by CN and CP, and long-run marginal costs are calculated using the Agency Regulatory Costing Model (ARCM).

RESULTS

Exhibits 3 shows the estimates of total factor productivity for CN and CP combined over the period 1992-2012, using the Solow, Malmquist and Luenberger index methodologies. The results show that the two railways combined experienced positive productivity growth for most years over the period.

Exhibit 3: Productivity Indices for CN and CP Combined, 1992-2012					
	Solow	**Malmquist**	**Luenberger**	**Agency**	**Productivity**
Year	**Index**	**Index**	**Index**	**Index**	**Growth**
1992	100.00	100.00	100.00	100.00	
1993	108.21	111.40	104.84	108.11	1.08
1994	118.26	121.32	108.98	116.06	1.07
1995	106.06	109.07	103.19	106.08	0.91
1996	120.49	122.56	109.57	117.40	1.11
1997	126.11	129.35	112.39	122.39	1.04
1998	122.96	127.55	111.22	120.38	0.98
1999	132.68	138.98	115.89	128.81	1.07
2000	150.69	160.02	123.28	143.79	1.12
2001	151.31	160.08	123.30	144.01	1.00
2002	148.59	161.99	123.95	143.96	1.00
2003	161.18	175.53	128.54	153.78	1.07
2004	167.72	180.69	130.13	157.99	1.03
2005	167.56	180.57	130.05	157.87	1.00
2006	173.93	189.37	132.76	163.53	1.04
2007	183.33	198.07	135.43	170.06	1.04
2008	168.63	182.33	130.31	158.83	0.93
2009	178.58	192.56	132.87	165.94	1.04
2010	200.23	215.34	140.65	182.36	1.10
2011	184.14	196.67	134.89	169.68	0.93
2012	188.67	203.21	136.60	173.66	1.02
Mean Annual Productivity Growth Factor, 1992-2012:					**1.0280**

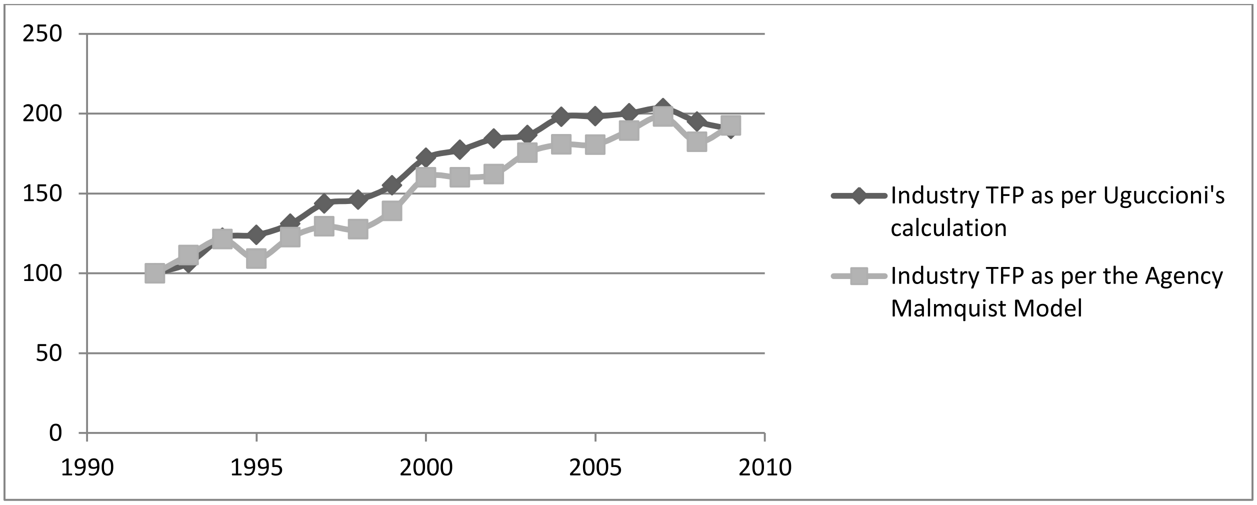
Exhibit 4 shows that the three alternative measures of productivity exhibit identical patterns of year over year productivity changes over the study period, the only difference between the three measures being in the magnitude of the year over year productivity changes.

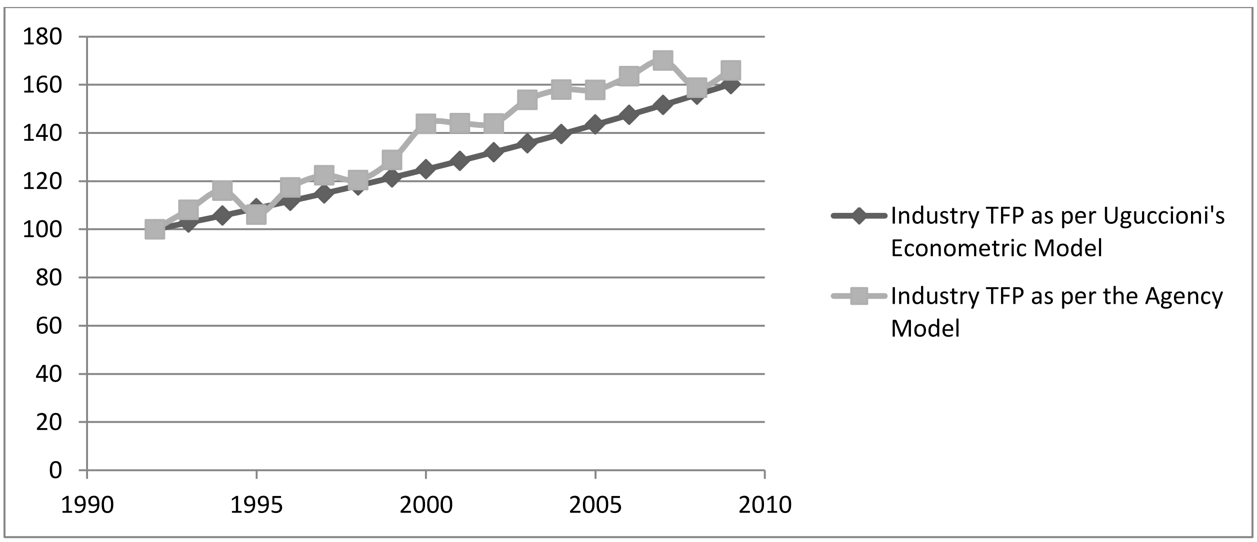


The results demonstrate the influence of the methodological approach on the measured productivity estimate, with the Solow and Malmquist indices estimating much higher productivity growths than the Luenberger index. Numerous researchers have reported similar results, in particular, that the Luenberger indicator tends to estimate significantly lower levels of productivity than the Malmquist index.

To avoid the problem of selecting a single index among the alternative approaches, all of whom are based on sound theoretical principles, Agency staff proposes a geometric mean of the three different estimates, shown in Exhibit 3 as the Agency Index, as the single best productivity measure.

Comparison with James Uguccioni's results:





Our result is between the two set of James Uguccioni's results which either overestimate or underestimate the Total Factor Productivity. In addition, Uguccioni's upper bound result and our Malmquist result are very close.

Conclusion:

We were able to compute a structural Luenberger productivity model without the need to use any reduced forms as D.E.A analysis did up to now. Moreover, we have introduced imperfect competition into the analysis of Canadian Railways and our results are the product of such a realistic hypothesis. Also, we have used recent data that were not publically available, but were submitted to the Agency and verified by our staff. Finally, our results were quite comparable with previous studies on Canadian railways, yet we believe we have improved these previous analysis.

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