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Impacts of Public Infrastructure on Productivity In Ontario

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Introduction

In this paper, we present a methodology that extends back Statistics Canada's official estimates for Ontario's productivity from 1997 to 1985. Using this extended series, we examine the role of public capital contribution to productivity with particular emphasis on transportation capital. We follow growth accounting framework first introduced by Robert Solow in 1957 (Solow, 1957) and currently used by Statistics Canada and the OECD (OECD, 2001). We make adjustment for the lack of disaggregated data for the province of Ontario and we estimate productivity at the business sector level.

Estimation of public capital contribution to productivity uses elasticity estimates of output with respect to public capital from Macdonald (2008). Other Canadian researchers have found a similar magnitude of the relationship between public infrastructure and productivity of the business sector (Harchaoui & Tarkhani, 2002; Brox & Fader, 2005). Estimates of elasticity of transit infrastructure were taken from Vafa & Georgiev (2013). However, we note that there may be important differences between business cost savings from public infrastructure and transportation. This question will be a subject of further study.

Background

In this section, we provide a brief non-technical overview of the growth accounting framework, its ideas, and use in modern macroeconomics.

Modern macroeconomics is concerned with the study of how raw resources can be used to produce consumption goods. It traces the process of extraction of the raw resources to completion of the final good. A handy tool that simplifies and abstracts that process and is yet powerful enough to be used to study the underlying dynamics of the process is the production function. The production function describes how small numbers of inputs combine to produce a good. An example of a production function, is the process by which a business combines labour with machinery and materials to produce a car. In fact, the production function approach is so powerful that it has been used to study the economy as a whole. Every year Statistics Canada releases detailed structure of the Canadian economy through the lens of the production function. This product is called the Input-Output tables.

Because we can present output as number of intermediate inputs, we can break up output based on its input components – capital and labour. The simplest mathematical relationship between output and inputs is output being equal to the sum of all inputs. Growth accounting explores the relationships between input and output and looks at how they evolve over time.

If we are able to explain all the changes in output with the changes in inputs then we would have a perfect correlation between the inputs and output. Unfortunately, when we measure inputs and try to match them up to the output we do not always get a perfect match. Economists call the difference between the two the error term. The error term is small but significant. Unlike in most economic relationships, where the error term averages out to zero, in the growth accounting literature the error term does not. It is larger than zero and varies quite a bit over time. This is because the error term captures two distinct processes. The first process is the measurement error associated with inaccurate data collection by the statistical agency, and the second is technological change over time. The measurement error in the error term does average out to zero over time so that most of the variation in the term is caused by the technological process. In growth accounting literature, economists call that error term productivity growth. Productivity growth can be attributed to changes in how businesses are being operated, adoption of new technological processes or accumulation of experience in running a business.

Economists have found a relationship between productivity growth and government investment in public infrastructure. We explore this finding by building an index of Ontario's productivity from 1985 to 2010 in order to estimate the contribution government investments have had on the growth of output.

Public capital contributions to MFP

Multifactor productivity (MFP) growth is measured as the difference between the growth of output and the growth of inputs (K for capital and L for labour).

$$\dot{MFP} = \dot{Y} - s_k\dot{K} - s_l\dot{L}$$

The sum of all factors must equal 1 therefore $s_k + s_l = 1 \Rightarrow s_l = (1 - s_k)$[i]. We can rewrite the previous equation as:

$$\dot{MFP} = \dot{Y} - s_k\dot{K} - (1 - s_k)\dot{L}. (1)$$

We can measure the growth of GDP $(\dot{Y})$, labour $(\dot{L})$ and capital $(\dot{K})$ using data from Statistics Canada. There is an inherent heterogeneity between different types of labour and capital. We cannot just add the capital and labour stock to create the capital and labour indices. We need to find the services that are produced by the capital and labour stock. To do this, Canadian Productivity Accounts (Statistics Canada; as well as OECD and others) break down capital (28 asset types in the Canadian Productivity accounts see Harchaoui & Tarkhani, 2003; Oulton & Srinivasan (2003) and Schreyer (2004)) and labour into sub-types (labour consists of 42 worker types; see Gu, Kaci, Maynard & Sillamaa, 2002)). To aggregate asset sub-types we use a weighted average of individual asset type growth rates so that Equation (1) becomes

$$\dot{MFP} = \dot{Y} - s_k\sum_i \frac{u_i K_i}{\sum_i u_i K_i}\dot{K}_\iota - s_l\sum_j \frac{w_j L_j}{\sum_j w_j L_j}\dot{L}_j \quad (2)$$

where *u* and *w* are the user cost of capital and labour wage (labour income) respectively.
Statistics Canada through their productivity program has measured MFP for Canada and Ontario starting in the year 1997. Because our interest is in the long-term variability and trend of MFP, we would like to measure it back to the 1980s to provide a statistically robust sample.

Measuring business sector GDP

Measurement of GDP $(\dot{Y})$ in Equation (2) is provided by Statistics Canada Provincial Economic Accounts (CANSIM 384-0002). Since MFP is strictly a measure of the private sector productivity[ii], we have to remove the government sectors from the measure of GDP. The specific sectors that are removed: Public Administration [NAICS 91], Education [NAICS 61] and Health [NAICS 62]. Statistics Canada does not provide breakdowns of those industries before 1997; we use Ontario Ministry of Finance estimates for those sectors from 1984 to 1997. This forms our estimate of business sector GDP. To get an estimate of business sector GDP in current dollars, we use the implicit price deflator for total GDP.

Measuring capital services

Capital Stock

Economic theory suggests using capital stock to measure MFP will not be appropriate. This is because the output produced in any given year (see Equation (1)) is not based on the amount of capital, but on how we use that capital to produce output. This is, by definition, the flow of capital services. We use the rental price of capital to measure the flow of capital services that comes from capital stock. Rental prices are observed for some capital types but not others. For example, rental prices for buildings are readily observable in the market place while rental prices for machinery can be hard to obtain. Because some prices are not observed in the market place, they are considered implicit costs that the owners of capital pay themselves as the users of that capital. Therefore, these prices are named the user cost of capital.

An important aspect of any capital investment is that it loses value over time, because of wear and tear or because more productive technology has taken its place. The capital stock data provided by Statistics Canada includes physical depreciation that is geometrically declining over time. Because the categories that Statistics Canada presents are an amalgamation of lower level series in the Stocks and Flows dataset, we had to estimate some of the depreciation rates by averaging the relevant asset types. Due to requirements for the length of this paper, we have omitted the estimates.[iii]

Calculating the user cost of capital

To calculate the user cost of capital we follow Harchaoui & Tarkhani (2003), Schreyer (2004) and Oulton & Srinivasan (2003). The formulation is as follows:

$$u_{i,t} = (p_{i,t-1}r_t + p_{i,t}\delta_{i,t} - \Delta p_i) \times \frac{1 - \tau_{corp,t}\zeta_{i,t} - e_{i,t}}{1 - \tau_{corp,t}}$$

where $p_{i,t-1}$ is the price of a new unit of capital type i in period t, r_t is the rate of return on capital in year t, Δp_i is price change of asset i, $\tau_{corp,t}$ is the corporate income tax rate in period t, $\zeta_{i,t}$ is the present value of depreciation deductions from $1 investment capital type i, and $e_{i,t}$ is the effective rate of the investment tax credit for capital type i in period t.

The implicit price index of investment capital is calculated by dividing the current dollar investment by the constant dollar investment (volume series) for a given capital type. For some of the capital types (Marine Engineering Construction, Communication Engineering Construction, Electric Power and Oil and Gas Engineering Construction) investment series didn't exist because of confidentiality suppression by Statistics Canada. For those series, the stock price instead was used of the investment price. The stock prices series is a close substitute for the investment price series as it includes the growth rate of prices for new capital and the growth rate of prices for used capital.

For the purposes of this paper, we are going to ignore the taxation component of the user cost of capital because we don't have enough data to calculate it reliably. We provide a treatment of the possible impacts on the estimates of MFP in the full paper.

Estimating internal rate of return (r_t)

We can estimate r_t (the nominal rate of return to capital) from capital income known as gross operating surplus (GOS) before tax and depreciation. GOS before tax and depreciation is the total rents generated by all capital assets. The gross operating surplus is simply GDP minus the total labour income, minus the portion of mixed income [iv] attributed to labour (s_{ml}), minus the portion of tax on factors of production attributed to labour (s_{tl})[v].[vi]

$$capitalincome_t = GDP_t - labourinc_t - s_{ml}mixedinc_t - s_{tl}taxpro\,duction_t$$
$$Capitalincome_t = \sum_i (p_{i,t-1}r_t + p_{i,t}\delta_{i,t} - \Delta p_i)A_{i,t} \quad (3)$$

The total mixed income attributed to labour is the proportion of labour income attributed to self-employed individuals. Because self-employment income in Ontario is not observable, we can use the ratio of labour income of self-employed and employed individuals for Canada and assume the self-employed income portion of labour income will be similar across Canada. The data on employment income is taken from CANSIM table 383-0024. We use business sector income to estimate mixed income.

$$s_{ml}mixedinc_t = business\ sector\ income_t \times \frac{total\ labour\ income_{self-employeed,t}}{total\ labour\ income_{employeed,t}}$$

The portion of taxes on production that are attributable to labour ($s_{tl}taxpro\,duction_t$) is:

$$taxpro\,duction_t \times \frac{labourincome_t + s_{ml}mixedincome_t}{labourincome_t + mixedincome_t + capitalincome_t} \quad (4)$$

The fraction in Equation (4) represents the labour income as portion of total income without taxes. The data on taxes related to production is taken from CANSIM table 384-0001.

Endogenous vs. exogenous rates of return

We use an endogenous rate of return to estimate MFP. In the full paper, we present estimates of MFP using an exogenous rate of return. We find that using an exogenous rate of return the MFP estimates increase by an average of 0.11% over the period. Details are presented in the full paper.

Calculating labour income

An estimate for labour income is required to calculate capital income and MFP (see Equation (2))
We calculate labour income by multiplying the total hours worked by the wage rate per hour.

$$Income_t = H_t * W_t$$

The wage rate for the business sector is assumed to be identical to the wage rate in the total economy. We can use Statistics Canada's data on wages, salaries and supplemental labour income for Ontario from the Provincial and Territorial Economic Accounts (CANSIM 384-0001), and divide it by the total hours worked for all industries (and all jobs), from the Labour Force Survey (LFS) for Ontario (CANSIM 282-0018), to get the effective wage per hour.

$$W_t = \frac{Wages + Supplementary\ labour\ income}{H_{t,all,LFS}}$$

Data on hours worked at the industry level is available from Statistics Canada for the period 1987 to 2011. In order to get estimates for the period 1984-1987, for the business sector, we use the LFS data on hours worked in the business sector and establish a statistical relationship between that (CANSIM 282-0022) and the hours worked in all industries (CANSIM 282-0028):

$$\log\left(\frac{H_{t,business,LFS}}{H_{t-1,business,LFS}}\right) = const + \beta * \log\left(\frac{H_{t,all\ industries,LFS}}{H_{t-1,all\ industries,LFS}}\right)$$

Parametric estimates are presented in the full paper. This relationship gives us a good estimate of hours worked in the business sector and all sectors before 1987.

In addition, we use a factor for converting the hours worked on the main job with the hours worked in all jobs. Details about calculation of this factor are presented full paper.

Finally, to calculate the labour income, we combine the above calculations to arrive at

$$Income_{t,business} = H_{t,business,LFS,main} * F_{maintoall} * W_t$$

which we can calculate from the data provided by Statistics Canada and our estimates.

Calculating mixed income

After we have calculated labour income, we can turn our attention to mixed income. By definition, mixed income is the sum of income that cannot be attributed directly to our two inputs of production. Mixed income is defined as the sum of *Accrued net income of farm operators from farm production* and *Net income of non-farm, unincorporated business, including rent*. Data on both of these variables can be found in CANSIM Table 384-0001. The estimation of the labour share of mixed income and the labour share of taxes on production is discussed in the section titled *Estimating* r_t of this paper.

Land

Land is not included in our capital services estimation. Because public investment can significantly affect the value of public land, it is ignored to avoid possible double counting. This is similar to the strategy Gu & Macdonald (2009) employ in their analysis.

Estimating capital services

Once we have estimates of capital income and the nominal rate of return on capital, according to Equation (3), we can proceed to estimate an index of capital services. We use a Törnqvist index to aggregate individual capital categories to the capital services index based on the average value share between two periods. A Törnqvist index is a discreet approximation of a continuous Divisia index (we assume that capital services is a continuous process). The Törnqvist capital services index is aggregated based on the following formula:

$$\dot{K}_t = \sum_i \frac{1}{2} \times \ln\left(\frac{A_{i,t}}{A_{i,t-1}}\right) \times weight_i$$

$$weight_i = \frac{p_{i,t-1}(r_t + \delta_{i,t}\frac{p_{i,t}}{p_{i,t-1}} + \frac{p_{i,t} - p_{i,t-1}}{p_{i,t-1}})A_{i,t}}{\sum_i p_{i,t-1}(r_t + \delta_{i,t}\frac{p_{i,t}}{p_{i,t-1}} + \frac{p_{i,t} - p_{i,t-1}}{p_{i,t-1}})A_{i,t}} + \frac{p_{i,t-2}(r_{t-1} + \delta_{i,t-1}\frac{p_{i,t-1}}{p_{i,t-2}} + \frac{p_{i,t-1} - p_{i,t-2}}{p_{i,t-2}})A_{i,t-1}}{\sum_i p_{i,t-2}(r_{t-1} + \delta_{i,t-1}\frac{p_{i,t-1}}{p_{i,t-2}} + \frac{p_{i,t-1} - p_{i,t-2}}{p_{i,t-2}})A_{i,t-1}}$$

Measuring labour services

Aggregation of labour services is done according to Equation (2). Detailed data of hours worked and compensation by labour category is only available for Canada. To get around this limitation, we use Statistics Canada labour services estimates for the period 1997-2010 (CANSIM 383-0026) and establish a statistical relationship with the stock series. There exists a statistical relation between the stock and services series because labour services growth is defined as the weighted sum of growth hours worked for each type of labour (Baldwin, Gu & Yan, 2007; OECD ,2001).

$$\dot{L}_{t,weighted,ontario} = \alpha + \beta_c \dot{L}_{t,unweighted,ontario} + \epsilon_t \quad \epsilon_t \sim N(0, \sigma^2) \text{ (5)}$$

We build the labour stock series from 1984 to 2010 using:

$$\dot{L}_{t,unweighted} = \ln\left(\frac{H_{t,bus,LFS,all}}{H_{t-1,bus,LFS,all}}\right)$$

The results are presented below. Using the estimates of Equation (5), we backcast the labour services growth in Ontario going back to 1984.

Labour services vs hours worked:OLS, using observations 1998-2010 (T = 13)
Dependent variable: ld_labour_input_index
HAC standard errors, bandwidth 1 (Bartlett kernel)

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	0.00468439	0.000543026	8.6264	<0.0001	***
ld_hours_worked	1.00663	0.0233759	43.0627	<0.0001	***

Mean dependent var	0.016682	S.D. dependent var	0.023150
Sum squared resid	0.000069	S.E. of regression	0.002503
R-squared	0.989285	Adjusted R-squared	0.988310
F(1, 11)	1854.392	P-value(F)	1.29e-13
Log-likelihood	60.51369	Akaike criterion	−117.0274
Schwarz criterion	−115.8975	Hannan-Quinn	−117.2596
rho	−0.270167	Durbin-Watson	2.486333

White's test for heteroskedasticity -
Null hypothesis: heteroskedasticity not present
Test statistic: LM = 1.1949
with p-value = P(Chi-square(2) > 1.1949) = 0.550213

Test for normality of residual -
Null hypothesis: error is normally distributed
Test statistic: Chi-square(2) = 1.79844
with p-value = 0.406888

Calculating MFP

In order to calculate the MFP index according to Equation (2), with a given index of labour and capital services, we need to calculate the labour share of GDP (capital share is 1-labour share). The labour share of GDP is labour income, plus mixed income attributable to labour, plus taxes on factors on production attributable to labour, divided by total GDP:

$$s_l = \frac{labourincome_t + s_{ml} mixedincome_t + s_{tl} taxonproduction_t}{GDP_t}$$

Public sector portion of MFP

Once we have estimates of MFP growth rates, we can use the growth accounting framework to estimate what portion of MFP can be attributed to public sector capital. Using Equation (2) we can split the MFP estimate using Macdonald (2008)'s estimate of the public capital contribution to cost savings (β_g) . The growth of MFP ex-public capital is therefore:

$$MF\dot{P}^{\star} = \dot{Y} - s_k\dot{K} - s_l\dot{L} - \beta_g\dot{G}$$

$$M\dot{F}P^{\star} = M\dot{F}P - \beta_g\dot{G}$$

Researchers at Statistics Canada take a similar approach and calculate the public capital contribution to the Canadian economy (Gu & Macdonald, 2009).

The data on the growth rate of public capital ($\dot{G}$) was provided by Statistics Canada's Stocks and Flows dataset (CANSIM table 031-0002; NAICS 91 [Public Administration]). We consider only engineering capital to be productive public capital for the purposes of this paper. Engineering capital includes transportation (roads, bridges, etc.), water (reservoirs, pumping stations, filtration plants etc.), marine (docks, canals, etc.), sewage, electric power, communications, oil and gas, and other. It is the capital that millions of people use every day to conduct business in Ontario. Government buildings and machinery on the other hand are used by government to conduct government business and therefore do not contribute to the productivity of the private sector. We exclude government buildings, machinery & equipment from our estimates of productivity of the private sector. The productivity of transportation investments can be calculated by taking the transportation engineering category from the public capital dataset.

In order to estimate the productivity benefits of transit capital we use the engineering construction data from NAICS 485 (Transit and Ground Passenger Transportation). The data on transit engineering capital was provided to us by the Ontario Ministry of Finance and was taken from Statistics Canada's Stocks and Flows dataset.

Results

To calculate MFP for Ontario from 1985 to 2010, we use estimates of elasticity of public capital to output from Macdonald (2008) and assume that the productivity of transportation capital would have a similar impact. If we look at the infrastructure stock data, more than 80% of public infrastructure is transportation capital. Therefore, it is reasonable to assume that transportation will have an impact similar to broader public capital.

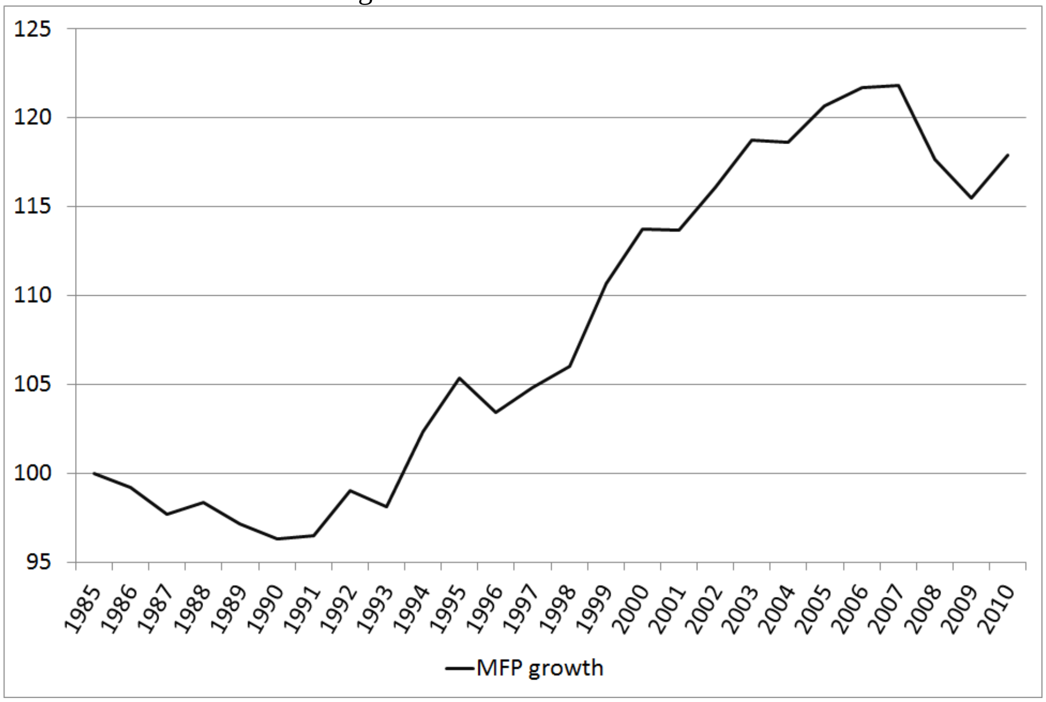
The elasticity of transit infrastructure with respect to GDP is estimated to be 0.02 (Vafa & Georgiev, 2013).

Table 1 – Public Sector MFP Growth Contributions

	Contribution to MFP growth	Contribution to GDP (2002$ Million)
Public capital	19%	$ 11,148
Transportation capital	16%	$ 9,307
Transit capital	1%	$ 356
MFP	**100%**	**$ 42,040**

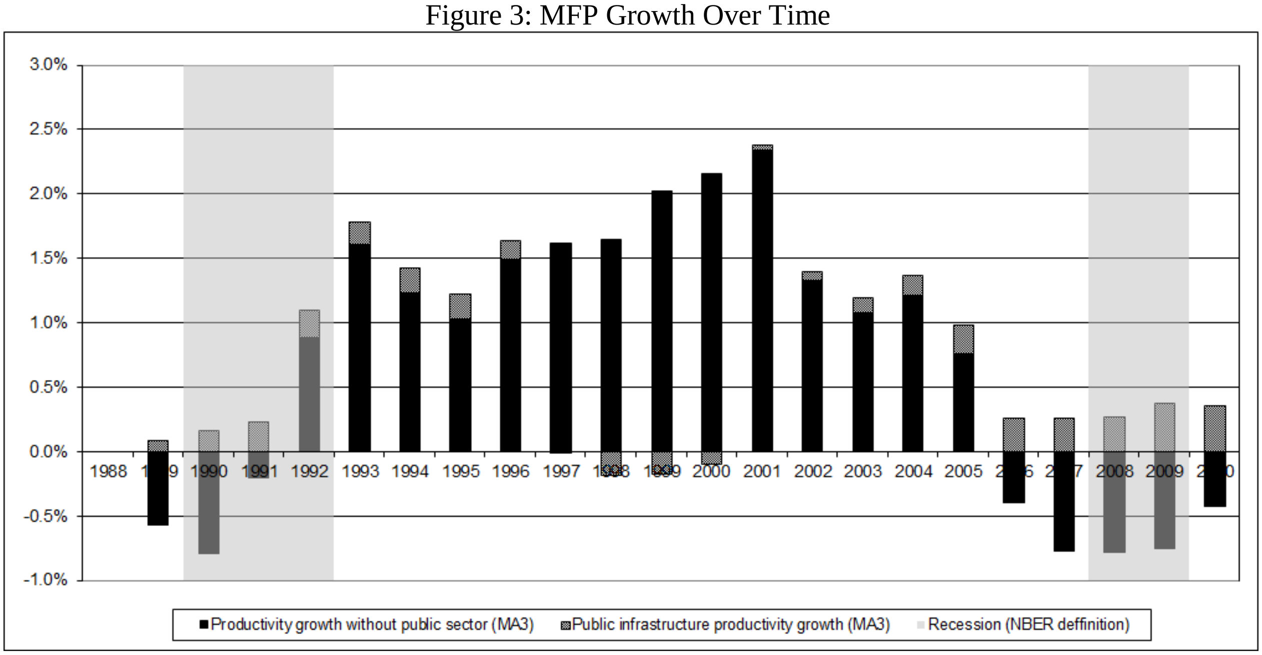
Table 1 shows that the public sector is responsible for small but significant portion of MFP growth in Ontario. Most of the MFP growth has been contributed by transportation capital. If we look at the investment data for the most recent decade, transportation capital accounts for most government investment in infrastructure. Between 2001 and 2010, the share of transportation infrastructure investments of all capital investment (excluding machinery and buildings) was 93% while during the previous decade 1990-2000 that share was 77%. All three levels of government have made significant investments in transportation that have had an impact on Ontario’s productivity.

Figure 2 – Ontario's MFP Index



This growing impact of public sector contribution to MFP can be most clearly seen in Figure 3. The impact of the public sector investments (gray bars) have been contributing significantly to MFP over the period 2002-2010 while virtually non-existent during the late 1990s.

Figure 3: MFP Growth Over Time



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Endnotes

[i]We make the simplifying assumption of constant returns to scale in the economy. For more information on parametric approaches that remove the scale effect on MFP for Canada please refer to Baldwin, Gaudreault & Harchaoui (2001). The MFP estimates without scale effects do differ slightly from the once estimates that include scale effects.

[ii] In the growth accounting framework the government sector is assumed to be non-productive. Since there is no strict market for government output, no price can be established; thus the output cannot be measured and therefore productivity cannot be calculated.

[iii] The full set of estimates, detailed calculations and sources can be obtained by contacting the author at cvetomir.georgiev@ontario.ca.

[iv] Income not attributable directly to labour or capital.

[v] Because taxes on factors of production are included in the calculation of GDP at basic prices, we assign them proportionally to both factors of production (labour and capital).

[vi] The data for GDP in Ontario was taken from CANSIM, with adjustments for business sector GDP as described in the *Measuring business sector GDP* section.