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The Canadian Productivity Review

The Impact of Public Infrastructure on Canadian Multifactor Productivity Estimates

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Abstract

This paper makes use of a growth accounting framework to examine the importance of public capital for private sector productivity growth. Most measures of multifactor productivity consider only the inputs of the business sector. This paper produces an alternate measure of multifactor productivity for the business sector that incorporates the impact of public capital. It uses the estimate of the elasticity of business sector output with respect to public capital derived from Macdonald (2008). Over the period, the conventional estimate of MFP growth averages 0.4% per year. About half of this growth is attributable to public capital.

Keywords: rate of return, public infrastructure, productivity

Executive Summary

Public capital provides a vital input for private sector production. It consists primarily of roads, bridges, sewer systems and water treatment facilities. Public capital enables geographic concentrations of economic resources and provides wider and deeper markets for output and employment.

Despite public capital's importance, its impact on business sector productivity growth or total economy GDP has not been widely analyzed. The omission largely results from a dearth of comprehensive data on infrastructure and the lack of a consensus about how best to estimate the impact of public capital. Public capital in North America tends to be publicly owned and financed through taxation so no markets exist for its output. Additionally, public capital in North America lacks close substitutes in the private sector making it infeasible to use private sector information as a proxy for the public sector. As a result, estimates of public capital's impact are not easily obtained.

Consequently, the role of public capital in business sector productivity growth has not been thoroughly investigated. This paper asks how much of labour productivity and multifactor productivity (MFP) growth can be attributed to investments in infrastructure.

The growth accounting framework currently employed for productivity analysis focuses on private sector inputs and outputs. MFP is calculated as the difference between the rate of growth of business sector output and a weighted sum of the growth in labour and capital that are applied by the business sector to the production process. The impact public capital at present is subsumed in MFP.

This paper makes use of a growth accounting framework and an estimate of the elasticity of business sector output with respect to public capital to examine the impact of public capital on productivity growth in the Canadian business sector. It does so by extending the inputs considered in the standard framework that estimates multifactor productivity to include both private sector inputs (labour and capital) but to also include public sector capital.

The paper examines several questions:

1. How much of labour productivity growth came from public capital deepening?

   Public capital's contribution to labour productivity averaged 0.2 percentage points per year from 1962 to 2006. Although modest when compared with the average contribution of 1.3 percentage points from private capital deepening, public capital nonetheless accounted for an average of 9 percent of labour productivity growth during the sample period.

2. How much of the conventional MFP growth estimate is due to public capital?

   The conventional MFP growth estimate is measured as a residual after accounting for changes in private sector inputs. It, therefore, includes the contribution that public capital makes to private sector production. The conventional MFP growth estimate averages 0.4 percent per year.

The experimental MFP estimate calculated in this paper comes from analysis that explicitly includes a contribution to private sector value added from public capital. It, therefore, excludes the contribution of public capital from MFP growth. The experimental estimate averages 0.2 percent per year, half of the conventional estimate. Thus, 50% of the conventional estimate was due to the growth in public infrastructure.

3. Is public capital's contribution to productivity growth constant over time?

No. It was considerably larger in the earlier post-war period when investments in public infrastructure were largest. The largest contributions to labour productivity growth from public capital occurred in the 1962-1966 and 1967-1973 periods. During these years, public capital contributed 0.4 and 0.3 percentage points respectively to labour productivity growth. After 1980, public capital's contribution to labour productivity averaged only 0.1 percentage points per year.

Analysts using conventional multifactor productivity estimates have long been faced with the conundrum that productivity growth was much higher before 1980 than afterwards. The new measures that take into account the impact of public infrastructure substantially reduce the difference between the two periods, thereby demonstrating that part of the higher growth in the earlier period came from the very substantial growth in public infrastructure before 1980.

4. Did a reduction in government capital investment cause the productivity slowdown?

While the slowdown in productivity growth experienced in Canada coincided with slower growth in the stock of public capital, it is not possible to infer causality based on the analysis reported here. The slowdown in public capital investment occurred as decades of cross-country highway expansion came to an end and scheduled projects came to a conclusion. The investment opportunities for the public sector were lessened as a result, leading to a natural decline in public sector investment.

5. How robust are the rate of return estimates used to gauge the impact of public capital on output?

The impact of public infrastructure is derived from the rate of return estimates of public infrastructure in Macdonald (2008). Because this rate of return estimate is derived from econometric techniques, it is subject to statistical error. The true rate of return lies within a range around the estimate derived from the econometric technique. To address the uncertainty surrounding the true rate of return, a sensitivity analysis is performed which uses several approaches to gauge the robustness of results to alternate estimates of the rate of return:

1. Rate of return estimates of plus/minus 10 percentage points around the 17% value used in the main calculations are used to assess the sensitivity of results to alternate values of the rate of return. The magnitude of the average contribution of public capital to labour productivity growth varies from 0.1 to 0.3 percentage points as the rate of return changes; however, the conclusion that public capital makes an important contribution to productivity growth remains unchanged.

2. The base method used in the paper assumes that public capital's impact is constant over time. Analyses are performed to assess the sensitivity of the results to the use of a rate of return that varies over time. The time varying rate of return leads to results that generally agree with the results from the fixed rate of return. Public capital continues to be an important input into the private production process, and continues to be subsumed in traditional MFP estimates.

3. Finally, a more comprehensive view of the impact of public infrastructure has a second benefit. It also allows for a more accurate depiction of the manner in which output in the public sector is derived from labour as opposed to capital inputs. Estimates of the labour share of income for the public sector are re-calculated assuming a 17% return on public capital, and are compared with their business sector counterparts. When the 17% return is included in public sector GDP, labour share of income in the public sector becomes similar to business sector calculations, declining from 0.8 before inclusion of the impact of public infrastructure to between 0.5 and 0.6 afterwards, depending on the year chosen for the calculation. The labour share of income in the business sector averages 0.6 from 1961 to 2006.

1 Introduction

Public capital constitutes a vital input for private sector production. It consists primarily of roads, bridges, sewer systems and water treatment facilities (Baldwin and Dixon 2007). Public capital enables concentrations of economic resources and provides wider and deeper markets for output and employment. It constitutes a broad system that is provided at low cost to individual users.

Despite public capital's importance, its impact on business sector productivity growth or total economy gross domestic product (GDP) has not been widely analysed. The omission largely stems from the lack of information about the impact of public capital. Public capital in North America tends to be publicly owned and financed through taxation, so no markets exist for its output. Additionally, public capital in North America lacks close substitutes in the private sector, thus making it infeasible to use private sector information as a proxy for the public sector. As a result, estimates of public capital's impact are not easily obtained.

Consequently, the role of public capital in business sector productivity growth is not well documented. The growth accounting framework currently employed for productivity analysis focuses on private sector inputs and outputs. Inputs that are difficult to measure or include, such as research and development, changes in management structure and public capital are folded into estimates of multifactor productivity (MFP). Because public capital is subsumed in MFP, it is unclear how large an effect public capital has on productivity growth or whether the impact varies over time. This paper attempts to measure its contribution.

Multifactor productivity is the difference between the rate of growth of business sector output and a weighted sum of the growth in labour and capital that are applied by the business sector to the production process. These weights approximate the elasticity of output that is normally expected from the increase in these inputs. Since the weighted sum of inputs is constructed so as to approximate the increase in business sector output expected from the application of business sector inputs (using existing technology), the estimate of MFP is just the increase in output that occurs beyond that which is to be expected from existing production techniques. It comes from all inputs that are not measured—among other things, from organizational change and from new techniques not embedded in the increase in capital applied to the production process. It also comes from inputs outside of the business sector—such as public sector capital.

Public sector inputs are not easily accommodated by the growth accounting framework for several reasons. First, it is difficult to find reliable elasticity estimates for public capital that can be used to apply to the increase in public capital or that can be used to approximate just how much business sector output should be expected to increase as a result of additions to public capital. Research has not led to a consensus view about what a reasonable elasticity should be (see, for example, Aschaeur 1989, Munnel 1990a and 1990b, Shah 1992, Berndt and Hanson 1992, Lynde and Richmond 1992, Nadiri and Mamuneas 1994, Conrad and Seitz 1994, Morrison and Schwartz 1996, Harchaoui 1997, Fernald 1999, Pereira 2000, Harchaoui and Tarkhani 2003, Ramirez 2004, Bader and Faden 2005, Macdonald 2008).

Second, even if estimates of the impact of public inputs are included in the growth accounting framework, issues arise as to how to treat the private sector production function that is traditionally used—whether it should still incorporate the traditional assumption of constant returns to scale.

Public capital's effect on the level of GDP in the public sector is, for similar reasons, problematic in present treatments. Within the private sector, capital must earn enough to cover, among other things, its depreciation and its opportunity cost. It must generate an economic return. When private sector output and GDP are measured, the return associated with the private capital stock constitutes an important component of income and affects the level of GDP.

On the other hand, the System of National Accounts 1993 does not presently include a return for publicly owned physical assets for its estimates of public sector GDP, because it is unclear what rate of return should be chosen. Therefore, only depreciation of public assets is included in public-sector GDP estimates. Since it is likely that public capital generates a positive return, it is also likely that current public-sector value-added estimates are too low, unless all benefits are captured as rents in the private sector. In addition to its effects on the level of GDP, underestimating public sector GDP also affects estimates of the shares of income accruing to labour and capital as well as public sector productivity estimates.

This paper investigates the effect of including an economic rate of return to public capital in Canada on both the estimate of MFP in the business sector and on estimates of public sector GDP. It is similar to Mas's (2007) study for Spain, except that this paper employs the econometrically generated rate of return estimates from Macdonald (2008) rather than using a private sector rate of return as a proxy for public capital's return as is done in Mas (2007). It examines the impact of public capital on private sector labour productivity, and investigates the impact of imputing an economic rate of return to the use of public capital on estimates of GDP in the business sector and the total economy.

The remainder of the paper is organized as follows. Section 2 describes the growth accounting framework used for productivity analysis. Section 3 details how public capital's rate of return is included in GDP estimates. Section 4 demonstrates how public capital affects business sector productivity; in doing so, it provides an analysis of the sensitivity of the conclusions to a range of estimates of public capital's rate of return. Section 5 describes the data employed and the estimates of public capital's rate of return and elasticity. Section 6 presents the change in GDP that ensues from including an economic rate of return from public capital. It also presents estimates of how the modified measure affects the share of total income accruing to labour. Section 7 concludes.

2 Growth accounting

2.1 Estimating multifactor productivity

The growth accounting framework is a non-parametric approach to productivity analysis. Estimates for the output elasticities of private capital and labour (β_L, β_K) are generated under the assumptions that markets are competitive, that inputs are paid their marginal revenue product, and that the business sector production function exhibits constant returns to scale (i.e., $\beta_L + \beta_K = 1$). Under these conditions, it is possible to estimate the elasticity of labour as labour's

share of income and the elasticity of capital as one minus labour's share (Baldwin and Gu 2007).[1]

Estimates of multifactor productivity (MFP) growth are derived as the residual portion of output growth after changes in inputs are accounted for—that is, the difference in achieved output minus the change in output that would have been expected given the increase in inputs that were devoted to the production process. MFP growth estimates are often interpreted as originating from technological change, but they also are caused by changes in other variables that are omitted from the production function, such as public capital or changes in organizational structure.

The traditional growth accounting framework decomposes changes in gross domestic product (GDP) into the portion that is caused by changes in labour, changes in capital and a residual called MFP, that is

$$\Delta \ln GDP_t = \Delta \ln MFP_t + \beta_L \Delta \ln L_t + \beta_K \Delta \ln K_t . \quad (1)$$

All variables in Equation (1) can be directly measured, given the assumptions outlined above, from existing data, except for MFP. MFP is measured as the residual change in GDP after accounting for changes in inputs. The growth accounting equation can be re-written to estimate MFP as shown in Equation (2)

$$\Delta \ln MFP_t = \Delta \ln GDP_t - \beta_L \Delta \ln L_t - \beta_K \Delta \ln K_t . \quad (2)$$

In Equation (2), the influence of public capital is subsumed in the MFP term.

Equation (2) is based on calculating MFP using value added as a measure of output. An alternative approach uses gross output and introduces intermediate inputs, such as energy, into the analysis. This paper employs the value-added approach because it matches the procedure in Macdonald (2008), from which the elasticity and rate of return estimates for public capital are taken.

To explicitly analyse public capital's influence, changes in MFP are decomposed into the contribution from public capital and from technology. This approach adopts the usual assumptions about constant returns to scale across private inputs ($\beta_L + \beta_K = 1$) and private factors being paid their marginal revenue product. Moreover, the private input elasticities (β_L and β_K) continue to be estimated as the share of income accruing to labour and capital. By doing so, we implicitly assume that public capital affects output growth, but not the share of income earned by labour and capital. This is in keeping with the assumption of a competitive economy—

1. For an analysis of the effect of utilizing an alternative parametric framework on the estimates of multifactor productivity, see Baldwin, Gaudreault and Harchaoui (2001).

because it presupposes that the benefits of public capital are competed away by the private sector.[2]

Estimates of MFP net of public capital's contribution to output growth are calculated as

$$\Delta \ln MFP^*_t = \Delta \ln GDP_t - \beta_L \Delta \ln L_t - \beta_K \Delta \ln K_t - \beta_g \Delta \ln G \,. \tag{3}$$

The term MFP* represents MFP net of public capital. Because MFP is estimated as the residual after accounting for identifiable inputs, including an additional input while holding the previous terms constant, will reduce the estimate. MFP* is used throughout the paper when comparisons are made between MFP, which includes public capital and MFP, which is estimated net of public capital. Empirically, Equations (2) and (3) are related through the identity

$$\Delta \ln MFP_t = \Delta \ln MFP^*_t + \beta_g \Delta \ln G_t \,. \tag{4}$$

2.2 Decomposing labour productivity

For purposes of exposition, differences in MFP estimates are related to labour productivity growth. Within the growth accounting framework, it is possible to re-write Equation (1) as (see Baldwin, Gu and Yan 2007)

$$\Delta \ln\left(GDP_t / Hours_t\right) = \Delta \ln MFP_t + \beta_K \Delta \ln\left(L_t / Hours_t\right) + \beta_K \Delta \ln\left(K_t / Hours_t\right), \tag{5}$$

where

$\Delta \ln\left(GDP_t / Hours_t\right)$ = Labour productivity

$\beta_K \Delta \ln\left(L_t / Hours_t\right)$ = Contribution from labour composition changes

$\beta_K \Delta \ln\left(K_t / Hours_t\right)$ = Contribution from increased capital intensity (capital deepening)

$\Delta \ln MFP_t$ = Contribution from all other factors than labour or capital.

2. While it is possible that public capital provision affects the return on private capital investment, and may influence income shares, sufficient data are not currently available to test this supposition. It is not currently clear how business sector incomes should be distributed if the elasticities of public capital, private capital and labour should be divided if they exhibit constant returns to scale. While previous studies have used capital and labour share of income to split the return on public capital between business sector inputs, this approach raises capital and labour income, but it does not change their shares. Consequently, there does not appear to be a large penalty from maintaining currently held assumptions about business sector income shares.

As noted above, $\Delta \ln MFP_t$ can be decomposed further into $\Delta \ln MFP^*_t + \beta_g \Delta \ln G_t$ to illuminate the impact of public capital provision on labour productivity.

3 Public sector gross domestic product measurement

Calculating public sector gross domestic product (GDP) is more challenging than calculating GDP in many business sector industries because there are no explicit markets for most of the services provided by governments. Consequently, it is not possible to calculate GDP using final sales. Rather, public-sector GDP is calculated using factor payments: the value of labour and capital services (earnings).

While this approach circumvents the problems that stem from the lack of markets for government services, it suffers from a different problem—finding a way to calculate the capital services provided by public infrastructure. Capital services represent the flow of payments that would have to be made to cover the rental of an asset—and is composed of payments for depreciation (δ) and the rate of return (r) that would have to be paid on the capital investment. Competitive markets equate borrowing costs and rates earned. But the lack of a market for the services of public capital makes it difficult to ascertain what public capital's rate of return actually is and public borrowing costs may be quite different from actual returns because there is less likelihood that the two will be equated in the political domain. As a result, public sector GDP in Canada only includes labour income and depreciation of the capital stock. The estimate of public sector GDP does not include an estimate of a return on public investment

This issue is resolved by Mas (2007), who uses a private sector rate of return as a proxy for the public sector rate of return. The Mas study focuses on Spain, where both private and public sector investors provide infrastructure items such as roads or highways. By using the return from private companies engaged in infrastructure investment, Mas adjusts total economy GDP figures to include a rate of return attributed to publicly owned infrastructure.

For Canada, using a private sector rate of return for a proxy is less than ideal because the majority of public sector infrastructure in Canada does not have close private–sector equivalents. Consequently, this paper uses a rate of return for public capital that is generated econometrically.

In addition to estimating new multifactor productivity estimates that take into account public capital, this paper also modifies public-sector GDP estimates so as to investigate the impact of including an economic rate of return from public capital to provide a more comprehensive estimate of the value of capital services. Currently public sector GDP estimates are formed using labour payments and only capital consumption associated with public capital:

$$GDP_t = \sum_i w_t L_t + U_t K_t \,, \tag{6}$$

where w and L are the wage rate and hours worked, respectively, K_t is the real public-sector capital stock (net of depreciation) and U_t is the user cost of capital.

The user cost of capital provides an estimate of the flow of services provided by the stock of public capital. For the purposes of this paper, it is written in a form that excludes taxes and capital gains:

$$U_t = P_t(r + \delta). \tag{7}$$

Current estimation of public sector GDP only includes the depreciation portion of the user cost (7). By including the rate of return earned by public capital, the estimate of GDP in the public sector will be raised by rP_tK_t dollars. The new estimate of GDP in the public sector will then be compared to the existing estimate.

4 The impact of public capital on business sector output

Because public capital in Canada does not have a market price, it is not possible to use non-parametric estimates for its elasticity (β_g) in a production function. As a result, parametric estimates must be generated.

This study employs the estimates derived in Macdonald (2008). Mindful of the need to evaluate the sensitivity of the parameters derived from multivariate analyses, Macdonald uses several different approaches.

The first makes use of a production-function approach and treats firms as viewing public capital as an unpaid factor of production when maximizing profit. Their output is assumed to be a function of private capital (*K*), labour input (*L*), public capital (*G*), and multifactor productivity $MFP(t)$:

$$Y = MFP(t)F(K, L, G). \tag{8}$$

A Cobb-Douglas function is used to generate parameter estimates of $MFP(t)F(K, L, G)$. The Cobb-Douglas function is employed because it is commonly used in the literature, making estimates comparable with previous studies. Additionally, the resulting elasticity estimates should be similar to the share of income accruing to labour and capital, and this provides a transparent, widely understood set of prior expectations against which the impact of including public capital can be examined.
The second approach uses a cost function

$$C = MFP(t)F(p, G), \tag{9}$$

where *C* is cost, *MFP* is multifactor productivity, *p* are factor costs and *G* is an estimate of public capital. The cost-function approach uses input prices as explanatory variables. Prices are more likely to be exogenous than the input variables used in a production function and this permits more accurate parameter estimates of the production function. As a result, the cost-function approach is viewed by many economists as a better way to estimate the impact of public capital. In the cost-function approach, public capital is assumed to be an unpaid factor of production that affects the level of the variable cost curve.

We have two separate cost-function estimates of the impact of public capital derived from Statistics Canada's Capital, Labour, Energy, Materials and Services (KLEMS) database. The first comes from the work by Harchaoui and Tarkhani (2003), who used industry data. Macdonald (2008) extends this analysis using provincial data and an alternate approach to modeling the impact of public capital derived from Fernald (1999). In the latter approach, the effect of public capital is subsumed in the transport-cost share of each industry.

Using production function and cost function estimates, Macdonald (2008) 'triangulates' on an estimate for the elasticity of public capital that is consistent across the different data sets and methodologies and that best overcome estimation problems.

Public capital and MFP behave similarly over time, making it difficult to econometrically disentangle their marginal impacts (Macdonald 2008). Using the production-function approach, Macdonald finds the point estimate for the elasticity of public capital (β_g) to be very sensitive to the manner used to derive an estimate of MFP. Estimates of MFP and the elasticity of public capital derived from the production-function approach are difficult to disentangle because they both track real GDP quite closely. This is a data, not an econometric or theoretical problem. In order to gain greater precision with regards to estimates of the output elasticity of public capital, either better data sets or an alternate cost function approach is needed for calculating the impact of public capital services.

Cost functions provide an alternative that have generated more robust estimates of the output elasticity of public capital. Using a cost function, Harchaoui and Tarkhani (2003) report that the private-cost elasticity of public capital is 0.06. Their model allows for the existence of economies of scale and the expansion of public capital in response to increases in output that come from lower prices as the economy expands along a production function with economies of scale. Summing the two effects, Harchaoui and Tarkhani (2003) report that, on average, a one-dollar increase in public capital reduces private production costs by 17 cents.

The approach adopted by Macdonald also uses a cost function approach to estimate the effect of public infrastructure (β_g) by considering its impact on transportation costs. He also takes into account a number of data problems that were not considered in the Harchaoui and Tarkhani (2003) study. Several different estimation techniques are employed to control for possible unit root issues and data sets that contain 'aberrant' observations because of macroeconomic shocks and possible discontinuities, either in product or industry taxonomies, that exist in the input–output tables.

Macdonald (2008) reports an estimate of the elasticity of the output with respect to increases in public infrastructure capital of around 0.1. To account for uncertainty surrounding the optimal estimation technique, this paper employs a sensitivity analysis using elasticity estimates of 0.05, 0.1 and 0.15.

The associated rate of return, which can be derived using the user-cost formula for the mid-point elasticity estimate, is 17%, which coincides with the total return reported in Harchaoui and Tarkhani (2003). The rate of return from the lower bound elasticity estimate of 0.05 is 7%, while for the upper bound elasticity estimate of 0.15, the rate of return is 26%. This range includes the private sector's rate of return being earned over the study period (Baldwin and Gu, 2007).

5 Data and estimates

In order to calculate the nonparametric estimates of multifactor productivity (MFP) net of the impact of infrastructure capital, using Equation (4) and our estimate of β_g, data for gross domestic product (GDP) and labour input are taken from the Capital, Labour, Energy, Materials and Services (KLEMS) dataset produced by the Micro-economic Analysis Division of Statistics Canada. Real business sector GDP is derived from the input–output tables produced by Statistics Canada.

The labour input variable employed is the labour services estimate from KLEMS. Labour services aggregates hours worked using wage rates as an indicator of the marginal product of labour. The labour services construct assumes that workers with higher marginal products earn higher incomes and, therefore, have a larger impact on output fluctuations.[3]

An analogous approach is used for private capital services. The user cost of capital is used as a weight to determine the relative importance of various types of capital stocks.[4]

Importantly, the capital services used here for the analysis do not include land services. Because public capital investment can significantly affect the value—hence service value—of land, it is removed to avoid possible double counting when the impact of public capital is investigated.

The public infrastructure stock is calculated using the perpetual inventory method from investment data supplied by the Investment and Capital Stock Division of Statistics Canada. The investment flows are those found in the North American Industry Classification System (NAICS) 91 industry, which is referred to as the public sector throughout the paper.[5] It should be noted that NAICS 91 excludes all industries in the health and education sectors, the majority of which are publicly financed. As a result, productivity estimates in this paper should not be used to draw conclusions about productivity in education or health care.

6 Impact of public capital on productivity growth

Public capital's expansion and, ultimately, its contribution to the business sector vary importantly over the 1961-to-2006 period (Table 1 and Chart 1). During the 1960s and 1970s, large-scale public works projects increased the network of inter- and intra-provincial highways. The centrepiece of this expansion was the Trans-Canada Highway—spanning approximately 7,800 kilometres—linking Canada's east and west coasts. Although the highway was officially opened in 1962, construction continued until the early 1970s. The highway has since had numerous upgrades that have twinned busy sections and have added extra lanes.

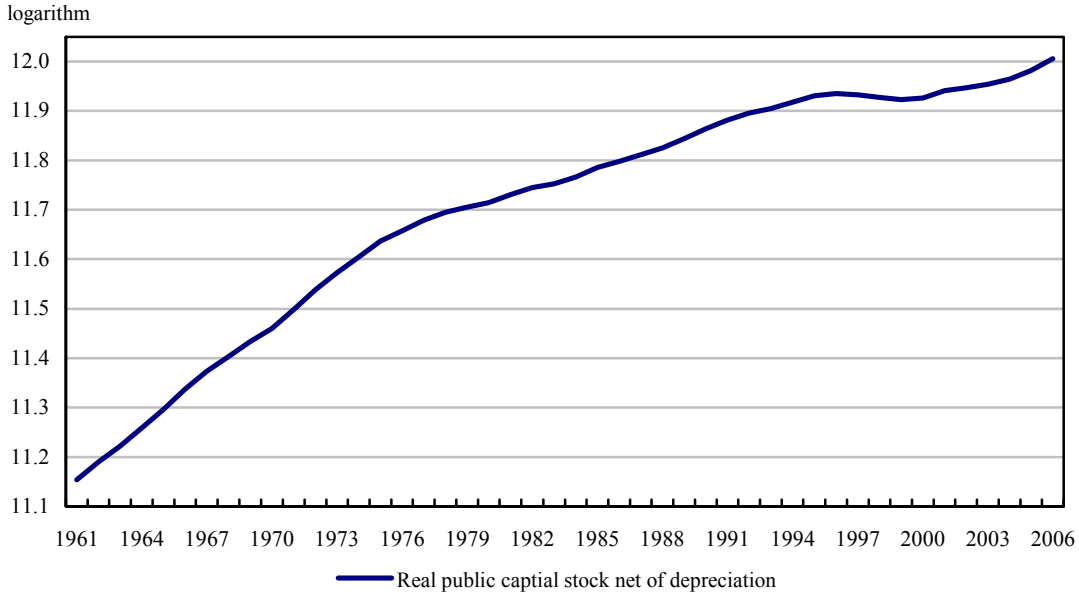
3. For more information see Gu et al. 2003.
4. For more information see Baldwin and Gu 2007; Gellatly, Tanguay and Yan 2003; and Harchaoui and Tarkhani 2003.
5. Our public capital stock includes all investment in fixed assets by governments. All asset classes are employed for the sake of completeness. However, public fixed investment is dominated by investment in roads and bridges. For more information see Baldwin and Dixon 2007.

During the 1960s, the net public capital stock grew by 3.6% on average. The expansion continued in the 1970s, when net stock of public assets rose on average 2.8% per annum. By the late 1970s, the expansion of the highway system was winding down and growth of the public capital stock slowed. Public capital stock expanded by 1.4% per year on average during the 1980s, half the average growth rate of the 1970s.

The slowdown continued into the 1990s, when governments sought to restrain deficits. During the 1990s, the net stock of public capital rose by only 0.8% per annum on average. However, when federal deficits were reversed in the mid-1990s, growth in the public capital stock turned negative–investment did not cover depreciation. By the late 1990s, investment and capital stock began growing again. After 2000, there was a resurgence in public infrastructure investment. From 2000 to 2006, the net public capital stock rose by 1.2% per annum, similar to growth in the 1980s.

The growth of real capital stock in the business sector follows a similar pattern over time. However, the slowdown of capital formation in the business sector was less pronounced than in the public sector. Business sector capital stock grew, on average, roughly 50% faster than public capital stock during the 1960s and 1970s. During the 1980s, 1990s and 2000s, growth in public capital declined more than the growth in business sector capital. Business–sector capital stock growth was double the growth in public–sector capital during the latter decades.

Chart 1
Log-level of real public capital



Source: Statistics Canada.

Table 1
Average annual capital stock growth by decade

	Public sector	Business sector
	percent	
1960s	3.6	4.7
1970s	2.8	4.6
1980s	1.4	2.8
1990s	0.8	1.7
2000s	1.2	2.4

Source: Statistics Canada.

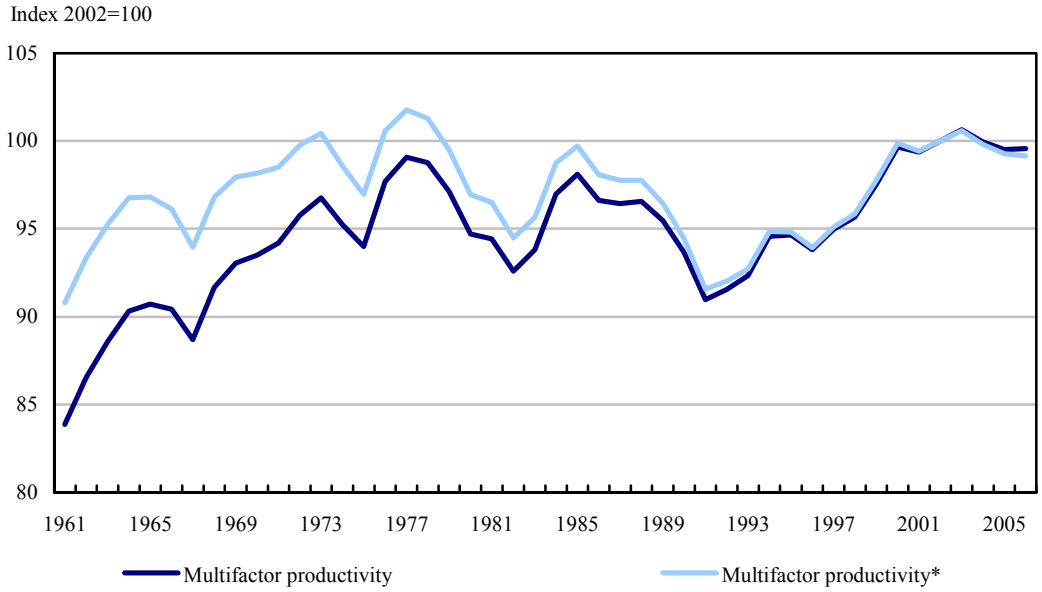
The contribution of public capital to multifactor productivity (MFP) and labour productivity growth are discussed below. Initially, the β_g elasticity estimate of 0.1 is employed for analysis. A second sub-section follows with a sensitivity analysis. In each section, MFP refers to the standard estimate while MFP* is calculated net of public capital.

6.1 What is the impact on multifactor productivity?

Measures of the impact of public infrastructure are provided by differences in the MFP estimates with and without public infrastructure (Chart 2). These differences are most pronounced in the earlier half of the sample period from 1961 to the early 1980s. The largest difference between MFP and MFP* occurs during the period when the inter-provincial highway system was being constructed. After the mid-1980s, and particularly following the 1991 recession, there is little difference between MFP and MFP*.

Once the impact of public capital is incorporated into the measures of MFP, productivity growth varies less over time. The conundrum of much more rapid productivity growth earlier than later in the period has concerned analysts for many years. It is partially explained by the omission from traditional MFP estimates of the impact of infrastructure capital.

Chart 2
Multifactor productivity index with and without public capital ($\beta_g = 0.1$)



Note: MFP stands for multifactor productivity.
Source: Statistics Canada.

Table 2
Labour productivity growth by source

	1962 to 2006	1962 to 1966	1967 to 1973	1974 to 1979	1980 to 1988	1989 to 1999	2000 to 2006
				percent			
Labour productivity	2.1	3.9	3.2	2.0	1.4	1.5	1.4
Capital contribution	1.3	1.6	1.7	1.7	1.1	1.0	0.9
Labour composition contribution	0.4	0.8	0.5	0.2	0.4	0.4	0.4
Multifactor productivity (MFP)	0.4	1.5	1.0	0.1	-0.1	0.1	0.2
Public capital contribution	0.2	0.4	0.3	0.2	0.1	0.1	0.1
Multifactor productivity (MFP*)[1]	0.2	1.2	0.7	-0.2	-0.2	0.0	0.0

1. MFP is decomposed into the changes arising from public capital provision and MFP*.
Source: Statistics Canada.

The quantitative effect of taking into account public capital for a number of subperiods is outlined in Table 2—along with a decomposition of changes in labour productivity into changes in capital intensity (capital contribution), labour composition changes, and MFP. The latter is also decomposed into the changes arising from public capital provision and MFP* (Table 2). The estimates in the first four rows are the same as in Baldwin and Gu (2004) except for capital which is calculated net of land in this study.

Over the entire 1962-to-2006 period, including the impact of public capital halves the contribution of MFP growth to labour productivity growth. MFP grows by an average of 0.4% per annum while MFP* grows only by 0.2% per annum. Thus half of the traditional MFP estimate is due to the growth of public capital.

6.2 How sensitive are the results to different elasticity estimates?

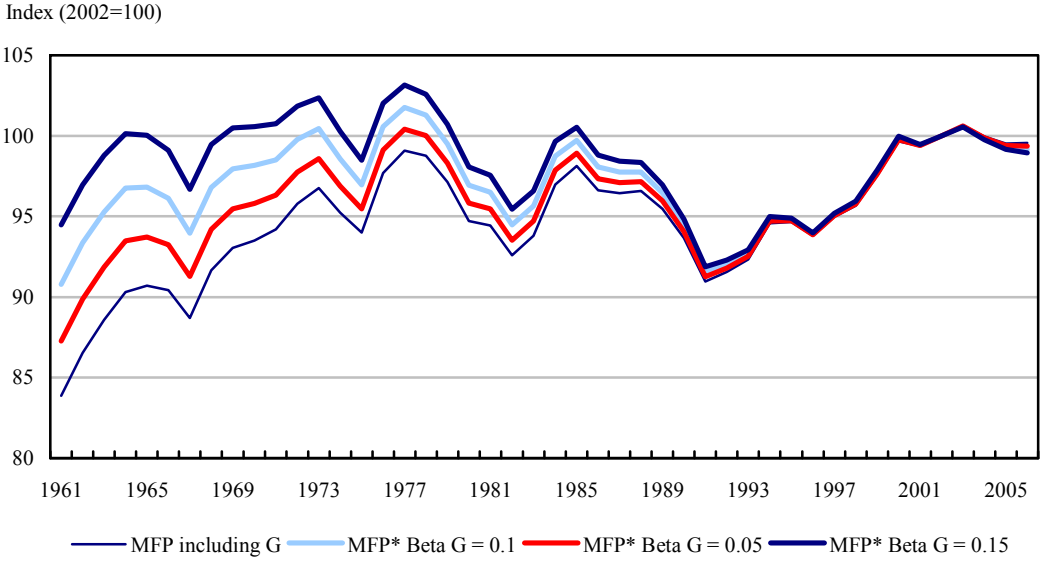
Estimates of public capital's elasticity are subject to the normal statistical uncertainty that is associated with the multivariate econometric procedures used for the estimation of this parameter.

To assess the importance of this uncertainty, the impact of public infrastructure is reestimated using a range of estimates of the elasticity of public capital—a confidence interval is derived by adding and subtracting 0.05 from the elasticity estimate of 0.1 taken from Macdonald (2008). This range encompasses most of the more reasonable estimates found in cost-function based studies.

This range also includes the elasticity estimate that corresponds to a value that would produce a rate of return to public capital that is about equal to the long-term government bond rate. The marginal product estimate that equates the rate of return to public capital and the average long-term government bond rate is 0.06. This falls within the lower end of the range outlined above.

Estimates of public capital's contribution and MFP* are affected by the elasticity estimate employed (Chart 3 and Table 3). The influence is greatest during the period spanning 1961 to 1980. After 1980, there are only minor differences.

Chart 3
Multifactor productivity index with and without public capital



Note: MFP stands for multifactor productivity.
Source: Statistics Canada.

For each 0.05 increase in the elasticity estimate, public capital's contribution to labour productivity growth rises by around 0.1 percentage points for the 1962-to-2006 period. The effect of increasing the elasticity estimate is larger during the earlier half of the period than the latter half, which is consistent with differences in the growth rates of public capital stock.

Table 3
Multifactor productivity and public capital contributions across elasticity estimates

	1962 to 2006	1962 to 1966	1967 to 1973	1974 to 1979	1980 to 1988	1989 to 1999	1999 to 2006
				percent			
Public capital contribution							
Beta = 0.05	0.1	0.2	0.2	0.1	0.1	0.0	0.1
Beta = 0.10	0.2	0.4	0.3	0.2	0.1	0.1	0.1
Beta = 0.15	0.3	0.6	0.5	0.3	0.2	0.1	0.2
Multifactor productivity contribution							
Beta = 0.00	0.4	1.5	1.0	0.1	-0.1	0.1	0.2
Beta = 0.05	0.3	1.3	0.8	-0.1	-0.1	0.0	0.1
Beta = 0.10	0.2	1.2	0.7	-0.2	-0.2	0.0	0.0
Beta = 0.15	0.1	1.0	0.5	-0.3	-0.3	0.0	0.0

Source: Statistics Canada.

For all three elasticity estimates, the contribution of public capital to productivity is higher during the 1960s and 1970s. Regardless of the estimate used, the productivity growth slowdown during the post-1980 period becomes less pronounced and the differences between the earlier and later periods are smallest for the highest estimates of the return on public infrastructure. When the impact of public capital is disentangled from MFP growth, MFP growth is lower and more consistent across time periods.

These results all presume that the elasticity of output with respect to investments in public capital remained constant over time. It has been argued (Fernald 1999) that the largest impact of building the North American highway system occurred in the earlier period when the network was first created. During this period, significant externalities could have been generated that accrued to private capital and that were not passed on to final prices via competition. If so, part of the return to private capital during the 1960s and 1970s would be due to the externality that private capital received from public sector investment. To allow for this possibility, the estimates of MFP* are re-estimated using time-varying elasticity estimates for public and private capital.

To calculate how elasticities varied over time, we estimated the proportion of the surplus accruing to the private sector that was due to the externality from public investment. Baldwin and Gu (2007) examine the difference between the endogenous and exogenous rates of return for private capital in the KLEMS dataset and found that the rate of return (i.e., the rate of return on capital derived from actual income) was larger than the average rate of return found in equity and debt markets early in the period, but not later. The difference between the rates is not large, around 1 percentage point, larger before 1980, and less thereafter.

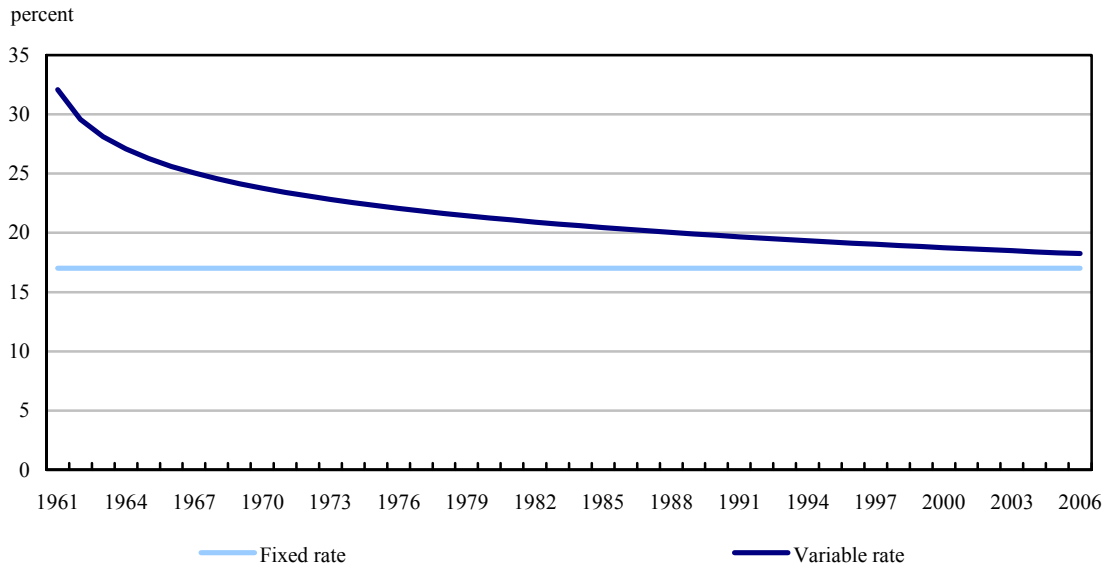
A trend measure of the difference is used to re-distribute a share of private sector returns to the public sector. A log-trend estimate is chosen to ensure that the externality generated by public capital in the 1960s and 1970s fades over time. In each year, the trend difference is employed to redistribute a share of private sector income to the public sector. The redistributed income is combined with the income that would be generated if public sector services were to be sold on a market—the income that is consistent with the 17% mean rate of return from Macdonald (2008).

The log-trend employed is consistent with the externality being essentially removed by the early 1980s (Chart 4). During the 1960s and 1970s, the time-varying rate of return is as much as 15

percentage points higher than the fixed rate, while during the 1980s and 1990s the gap shrinks to 2 percentage points. After 2000, the difference falls to around 1 percentage point.

The time-varying rate of return is used to generate a time-varying estimate for the elasticities of public and private capital. The elasticity of public capital now declines over time, beginning with a high of 0.15 in 1962 and reaching a low of 0.06 in 2003. Over the entire period, the elasticity averages 0.1, which is the same as the fixed rate estimate for this period used previously.

Chart 4
Fixed versus variable rates of return estimates



Source: Statistics Canada.

Because some of the return from private capital has been transferred to the public sector, the private sector now exhibits decreasing returns to scale. The largest proportional transfer of income occurs in 1961, when the scale economy estimate is 0.94. The scale estimate climbs quickly, however, reaching 0.98 in 1969 and 0.99 by the end of the 1970s. By 2000, the amount of income being reallocated is so small that the private sector scale estimate has, for practical purposes, returned to 1. There is no change to the estimate of labour's elasticity.

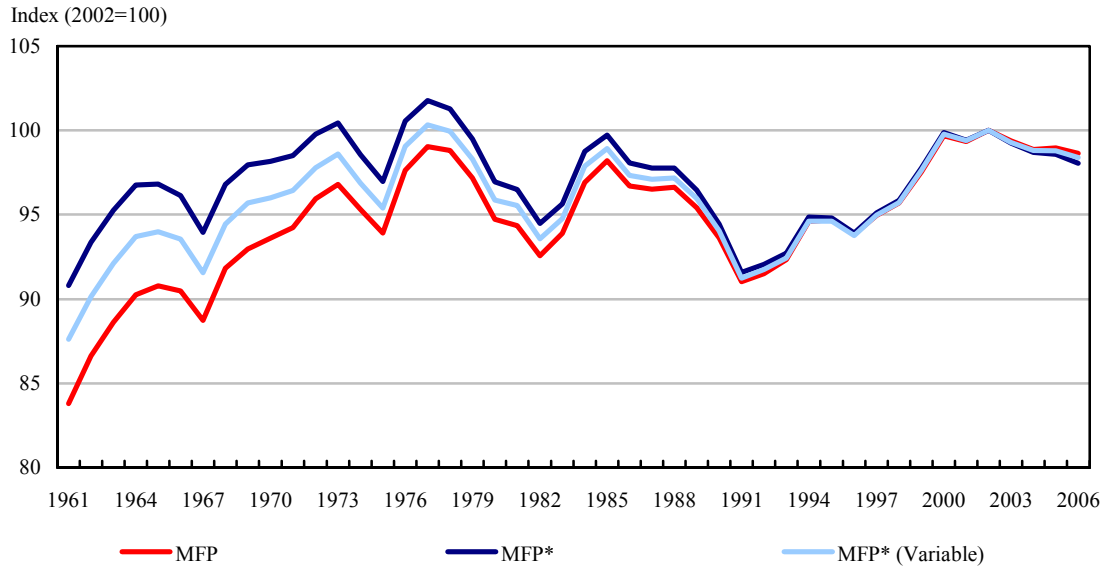
When the variable elasticity estimates of the impact of public capital are combined with the adjusted elasticity estimate for private capital and with labour's unchanged estimate, the new value of MFP*(variable) can be calculated using Equation (3). The estimates of the standard MFP estimate from (2), the estimate with the fixed elasticity of public capital, MFP*, and the estimate with the variable impact of public capital, MFP*(variable), are compared in Chart 5.

The largest difference between the MFP, MFP* and MFP*(variable) is found in the years prior to 1980. As noted, after 1980 the expansion of the road network was broadly completed. In the post-1980 years, there is little difference between the varying estimates of MFP growth.

Prior to 1980, however, the method for including public capital has important consequences for MFP estimates. The largest growth is seen in the traditional estimate that includes the impact of public capital while the smallest growth comes from MFP*, which uses the fixed rate of return for public capital. The MFP*(variable) falls in the middle. While it allows for an increased

impact from public capital, it simultaneously lowers the contribution from private capital investment. Because private capital investment outpaced public sector investment during the 1960s and 1970s, when the elasticity of private capital is lowered there is less explained growth and the MFP estimate rises.

Chart 5
Multifactor productivity estimates, with and without a variable rate of return



Note: MFP stands for multifactor productivity.
Source: Statistics Canada

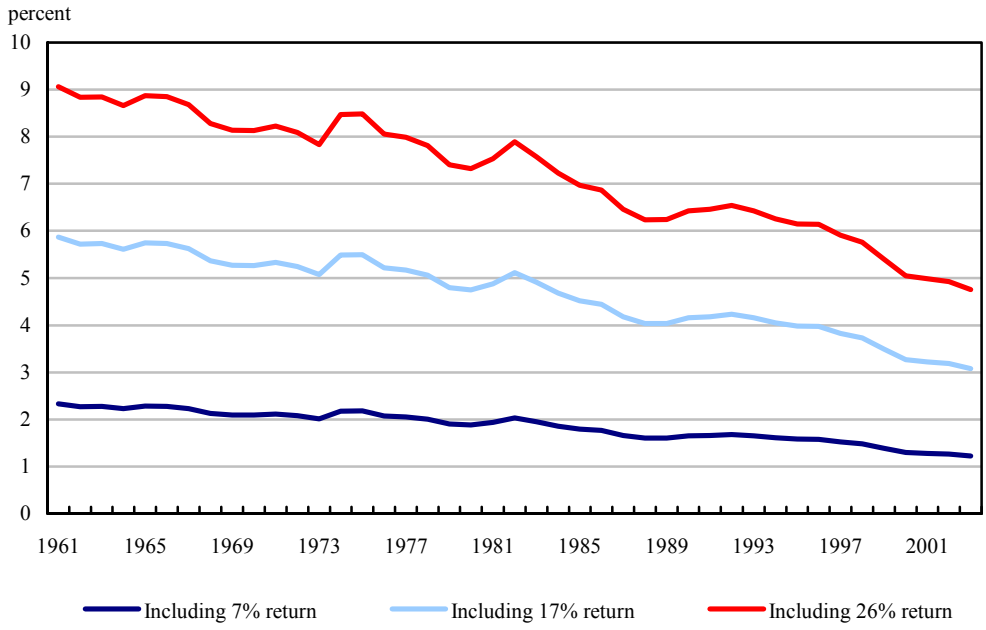
7 Changes to nominal gross domestic product and the labour share of income

Recognition that public capital provides a positive rate of return not only permits more precise estimates of productivity growth to be derived for the business sector, it also allows for a more accurate depiction of the manner in which output in the public sector is derived from labour as opposed to capital inputs. At the present time, government output appears to be far more dependent on labour input than is output in the business sector, since the share of income attributed to labour is far higher in the public sector.

The System of National Accounts currently calculates public sector gross domestic product (GDP) by adding up labour and capital income. However, because government outputs are not traded on well defined markets, it is not possible to calculate rates of return for government investment in a manner analogous to investments in the business sector. Moreover, government capital lacks close substitutes in the business sector in Canada that could be used as proxies for the rate of return earned by public capital. Consequently, the only income attributed to public capital in the estimates of public-sector GDP is the depreciation attributed to public capital—there is no return attributed to this capital. This potentially underestimates the amount of output that is derived from capital in the public sector.

One way to overcome this deficiency is to use the long-term government bond rate as the rate of return attributed to public capital—by arguing that this, at least, provides the opportunity cost of capital. In this paper, we use an alternative—the direct rate of return implied by the estimate of the elasticity of the reduction in private costs arising from an increase in public infrastructure. This rate of return can be derived from estimates of the output elasticity by employing a user cost of capital formula. Macdonald (2008) discusses the relationship between elasticity estimates and their associated rates of return. The rate of return estimates corresponding to the 0.05, 0.1 and 0.15 elasticity estimates used here are 7%, 17% and 26%, respectively.[6]

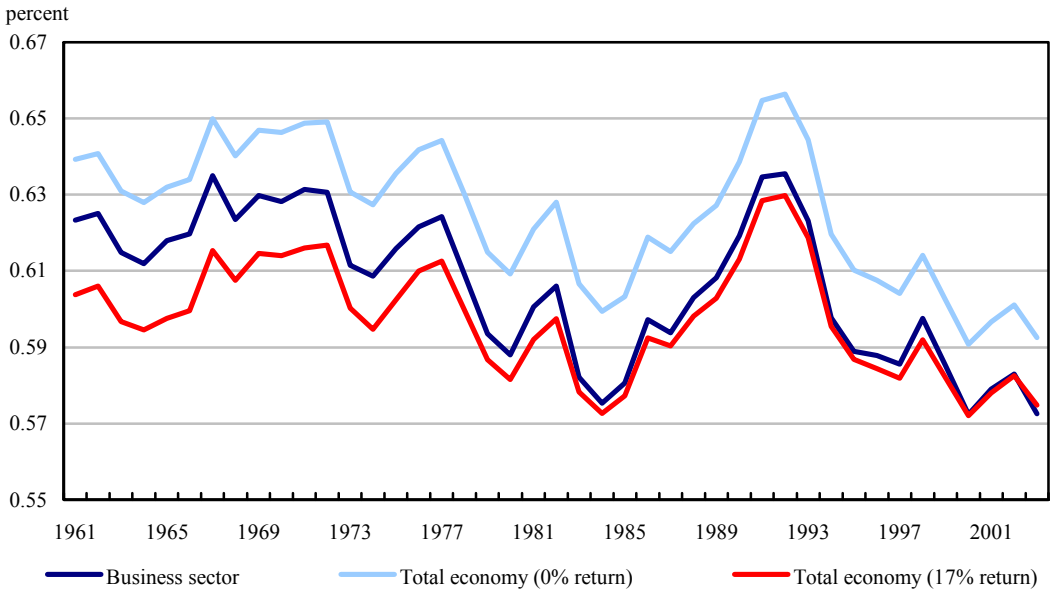
Chart 6
Percent increase in total economy nominal basic prices gross domestic product



Source: Statistics Canada.

6. The mid-point estimates of 17% are remarkably consistent with estimates of the internal rate of return to business sector capital investment in Canada. Using the Input/output estimates of industry surplus and the capital stock estimates in KLEMS, Baldwin and Gu (2007) calculate the internal rate of return for capital in the business sector as 15%. In light of the uncertainty surrounding the estimate of public capital's rate of return reported in Macdonald (2008), this suggests that the rates of return do not differ greatly between the business and public sectors.

Chart 7
Labour share of income in the business sector and total economy



Source: Statistics Canada.

These rate-of-return estimates are used here to modify currently published GDP estimates by adding a rate return to public capital. Estimates of nominal GDP are calculated in basic prices to provide consistency with the Canadian Productivity Accounts.

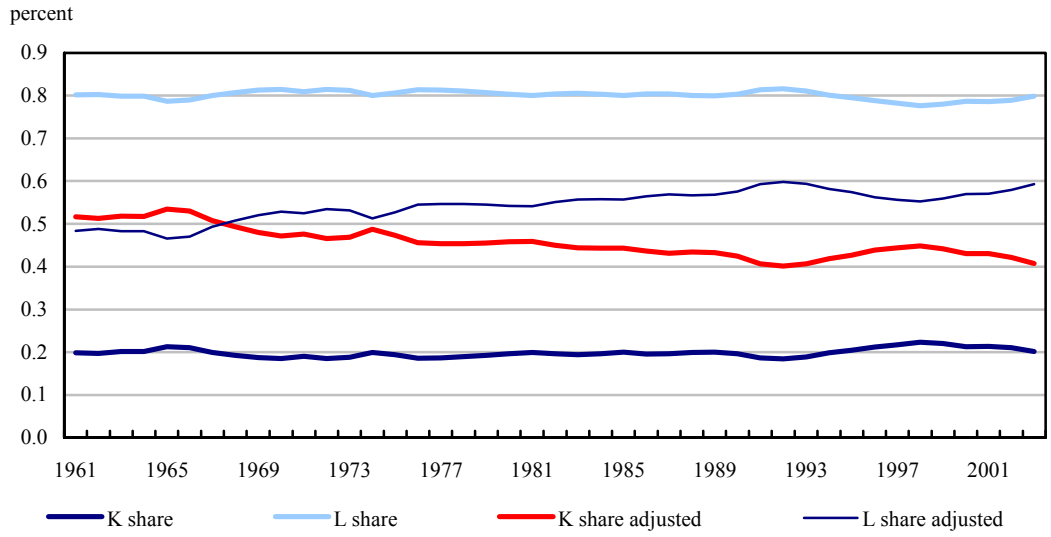
When this is done, the estimate of total GDP rises by as much as 9.1% or as little as 1.2%, depending on the year and the rate of return estimate used (Chart 6). For all three estimates, the addition to GDP provided by recognizing the return to public capital declines over time, since increases in the public capital stock fail to keep pace with business sector growth over the period. Using the mid-point estimate of a 17% return, nominal GDP rises by 5.9% in 1961 and trails off to an increase of 3.1% in 2003.

The inclusion of an economic rate of return to public capital, while tending to make a modest contribution to total economy value added, has more important implications for the share of income accruing to labour in the total economy. Because current estimates of the return to public capital only include capital depreciation, the labour share of income in the public sector is higher than in the business sector.

When the business and public sectors are combined to estimate labour share of income in the total economy, the estimate rises (Chart 7), because the return to capital income in the public sector is at present omitted. The labour share of income in the total economy averages 0.60 when the return on public capital is included, as opposed to 0.63 when the return on public capital is excluded. The labour share of income in the business sector is 0.61.

The inclusion of a return from public capital also changes the trend in the share of income accruing to labour. While labour share tends to decline each year when there is no return, or when the business sector is examined in isolation, the decline is less pronounced when a return to public capital is included.

Chart 8
Labour and capital share of income in the public sector



Source: Statistics Canada.

This difference stems from changes in the estimate of total income accruing to labour and capital in the public sector. Currently, estimates suggest that share of income accruing to labour in the public sector is around 0.8, while the share going to capital is around 0.2 (Chart 8). These shares are dramatically different from the average shares in the business sector.

By including a 17% return from public capital, these shares are altered considerably. In 1961, the share accruing to labour decreases from .80 before the correction to 0.48 after the correction. Labour's share increases over the period--moving from .48 in 1961 to reach 0.59 in 2003. The share accruing to capital declines over time--from 0.52 in 1961 to 0.41 in 2003. Governments supplied a larger proportion of services through the provision of capital earlier in the period and a larger proportion of services through labour later in the period.

8 Conclusion

Public capital provides a vital input for private sector production. Public capital facilitates concentrations of economic resources and enables the development of wider and deeper markets for output and employment.

Despite public capital's importance, its impact on business sector productivity growth or total economy gross domestic product has not been widely analysed. The omission largely stems from the lack of quantitative information about public capital's impact on production. Markets do not exist for its output. And without these markets, measures of the output of public capital are more difficult to derive than for the business sector. Additionally, public capital in North America lacks close substitutes in the private sector, making it infeasible to use private sector information as a proxy for the return on public investment. As a result, estimates of the output elasticity of the private sector in response to investments in public capital sector must be derived econometrically.

Elasticity estimates employed in this paper come from econometric estimates taken from Macdonald (2008). The estimates (0.05, 0.1, and 0.15) provide a range that includes the more credible found in cost-function based studies. These elasticity estimates are used to calculate the impact of infrastructure on productivity. The impact of public capital in Canada is normally subsumed into multifactor productivity (MFP) estimates, which makes MFP growth stronger during the 1960s and 1970s, when there was a significant expansion of the Canadian highway system. This occurs regardless of whether a fixed or variable rate of return on public infrastructure is employed.

While public capital is responsible for a large portion of the MFP growth experienced in the 1960s and 1970s, the slowdown in MFP growth in the 1980s and early 1990s should not be attributed to a reduction in infrastructure investment. It is possible that public sector investment slowed during this period only because the highway system had reached maturity, reducing the necessity of continued rapid expansion of the public capital stock.

When the impact of MFP and public capital are disentangled, public infrastructure is found to have accounted for half the estimate of productivity growth. Public capital's contribution to productivity growth varies over the last 47 years, with the largest impact found during the 1960s and 1970s. In the 1980s, 1990s and 2000s, the contribution of public capital is roughly two thirds lower than in the earlier period.

Analysts using conventional multifactor productivity estimates have long been faced with the conundrum that productivity growth was much higher before 1980 than afterwards. The alternate productivity measures that take into account the impact of public infrastructure substantially reduce the difference between the two periods, thereby demonstrating that part of the higher growth in the earlier period came from the very substantial growth in public infrastructure before 1980.

Including public capital in the private sector production function does not completely explain why productivity growth was stronger during the 1960s and 1970s than in subsequent decades. Nevertheless, recognizing its impact helps to explain why MFP growth was faster in the 1960s and 1970s than in the later decades of the 20th century.

Taking a more comprehensive view of the impact of public infrastructure has a second benefit. When the output elasticity of public infrastructure is used to estimate the return on public capital and re-estimate public sector GDP, the latter increases and the accompanying share of labour income in the total economy becomes more stable. It also more closely approximates estimates for the business sector.

9 Bibliography

Aschauer, David Alan. 1989. "Is public expenditure productive?" *Journal of Monetary Economics*. 23, 2: 177–200.

Aaron, Henry J. 1990. "Discussion of Why Is Infrastructure Important?" In *Is There a Shortfall of Public Capital Investment?* Alicia H. Munnel (ed.). Conference Series no. 34. Boston, Mass.: Federal Reserve Bank of Boston.

Baldwin, John R., and Jay Dixon. 2008. *Infrastructure Capital: What Is It? Where Is It? How Much of It Is There?* The Canadian Productivity Review. Catalogue no. 15-206-XIE2008016. Ottawa: Statistics Canada.

Baldwin, John R., Valérie Gaudreault and Tarek M. Harchaoui. 2001. "Productivity growth in the Canadian manufacturing sector: A departure from the standard framework." In *Productivity Growth in Canada*. Catalogue no. 15-204-XIE1999000. Ottawa: Statistics Canada.

Baldwin, John R., and Wulong Gu. 2007. *Multifactor Productivity in Canada: An Evaluation of Alternative Methods of Estimating Capital Services.* The Canadian Productivity Review. Catalogue no. 15-206 XIE2007009. Ottawa: Statistics Canada.

Baldwin, John R., and Wulong Gu. Forthcoming. *Relative Multifactor Productivity Levels in Canada and the United States: A Sectoral Analysis.* The Canadian Productivity Review. Catalogue no. 15-206 XIE. Ottawa: Statistics Canada.

Beckstead, Desmond, and Jean-Pierre Maynard. 2001. "Appendix 2—Industrial detail for productivity measures and related variables." In *Productivity Growth in Canada*. Catalogue Number 15-204-XPE. Ottawa: Statistics Canada.

Berndt, Ernst R., and Bengt Hansson. 1992. "Measuring the contribution of public infrastructure capital in Sweden." *The Scandinavian Journal of Economics.* 94, Supplement: S151–S168.

Brox, James A., and Christina A. Fader. 2005. "Infrastructure investment and Canadian manufacturing productivity." *Applied Economics.* 37, 11: 1247–1256.

Conrad, Klaus, and Helmut Seitz. 1994. "The economic benefits of public infrastructure." *Applied Economics.* 26, 4: 303–311.

da Silva Costa, Jose, Richard W. Ellson and Randolph C. Martin. 1987. "Public capital, regional output, and development: Some empirical evidence." *Journal of Regional Science*. 27, 3: 419–437.

Fernald, John G. 1999. "Roads to prosperity? Assessing the link between public capital and productivity." *American Economic Review.* 89, 3: 619–638.

Ford, Robert, and Pierre Poret. 1991. *Infrastructure and Private-sector Productivity*. OECD Economics Department Working Paper no. 91. Paris: Organisation for Economic Co-operation and Development.

Garcia-Milà, Teresa, Therese J. McGuire and Robert H. Porter. 1996. "The effect of public capital in state-level production functions reconsidered." *Review of Economics and Statistics.* 78, 1: 177–180.

Gellatly, Guy, Marc Tanguay and Beiling Yan. 2002. "An alternative method for estimating economic depreciation: New results using a survival model." In *Productivity Growth in Canada-2002*. John R. Baldwin and Tarek M. Harchaoui (eds.). Catalogue no. 15-204-XIE2001000. Ottawa: Statistics Canada.

Gramlich, Edward M. 1994. "Infrastructure investment: A review essay." *Journal of Economic Literature.* 32, 3: 1176–1196.

Grossman, Herschel I., and Robert F. Lucas. 1974. "The macro-economic effects of productive public expenditures." *The Manchester School of Economic and Social Studies.* 42, 2: 162–170.

Gu, Wulong, Mustapha Kaci, Jean-Pierre Maynard and Mary-Anne Sillamaa. 2002. "The changing composition of the Canadian workforce and its impact on productivity growth." In *Productivity Growth in Canada-2002*. John R. Baldwin and Tarek M. Harchaoui (eds.). Catalogue no. 15-204-XIE2001000. Ottawa: Statistics Canada.

Harchaoui, Tarek M. 1997. « Le capital public au Canada: Évolution historique et externalités. » In *Économétrie Appliquée.* Christian Gouriéroux and Claude Montmarquette (eds.). Numéro spécial de *L'actualité économique.* Paris: Economica.

Harchaoui, Tarek M., and Faouzi Tarkhani. 2002. "A comprehensive revision of the capital input methodology for Statistics Canada's multifactor productivity program." In *Productivity Growth in Canada-2002*. John R. Baldwin and Tarek M. Harchaoui (eds.). Catalogue no. 15-204-XIE2001000. Ottawa: Statistics Canada

Harchaoui, Tarek M., Jimmy Jean, and Faouzi Tarkhani. 2003. *Prosperity and Productivity: A Canada-Australia Comparison*. Economic Analysis (EA) Research Paper Series. Analytical Studies Branch. Catalogue no. 11F0027MIE2003018. Ottawa: Statistics Canada.

Harchaoui, Tarek M., and Faouzi Tarkhani. 2003. *Public Capital and Its Contribution to the Productivity Performance of the Canadian Business Sector*. Economic Analysis (EA) Research Paper Series. Analytical Studies Branch. Catalogue no. 11F0027MIE2003017. Ottawa: Statistics Canada.

Harchaoui, Tarek M., Faouzi Tarkhani and Paul Warren. 2003. *Public Infrastructure in Canada: Where Do We Stand?* Insights on the Canadian Economy. Analytical Studies Branch. Catalogue no. 11-624-MIE2003005. Ottawa: Statistics Canada.

Holtz-Eakin, Douglas. 1988. *Private Output, Government Capital, and the Infrastructure 'Crisis'.* Department of Economics, Discussion Paper 394. New York: Columbia University.

Holtz-Eakin, D. 1994. "Public-sector capital and the productivity puzzle." *The Review of Economics and Statistics.* 76, 1: 12–21.

Lynde, Catherine, and James Richmond. 1992. "The role of public capital in production." *The Review of Economics and Statistics.* 74, 1: 37–44.

Mas, Matilde. 2006. *Infrastructures and ICT: Measurement Issues and Impact on Economic Growth*. EU KLEMS working paper no 12.

Mera, Koichi. 1973. "II. Regional production functions and social overhead capital: An analysis of the Japanese case." *Regional and Urban Economics.* 3, 2: 157–186.

Morrison, Catherine J., and Amy Ellen Schwartz. 1996. "State infrastructure and productive performance." *American Economic Review.* 86, 5: 1095–1111.

Munnell, Alecia H. 1990a. "Why has productivity growth declined? Productivity and public investment." *New England Economic Review.* 1990, Jan.: 3–22. Boston, Mass.: Federal Reserve Bank of Boston.

Munnell, Alecia H. 1990b. "How does public infrastructure affect regional economic performance?" *New England Economic Review.* 1990, Sep.: 11–33. Boston, Mass.: Federal Reserve Bank of Boston.

Nadiri, M. Ishaq, and Theofanis P. Mamuneas. 1994. "The effects of public infrastructure and R&D capital on the cost structure and performance of U.S. manufacturing industries." *The Review of Economics and Statistics.* 76, 1: 22–37.

Pereira, Alfredo M. 2000. "Is all public capital created equal? *The Review of Economics and Statistics.* 82, 3: 513–518.

Ramirez, Miguel D. 2004. "Is public infrastructure spending productive in the Mexican case? A vector error correction analysis." *The Journal of International Trade & Economic Development.* 13, 2: 159–178.

Shah, Anwar. 1992. "Dynamics of public infrastructure, industrial productivity and profitability." *The Review of Economics and Statistics.* 74, 1: 28–36.

Statistics Canada. 2007. *Depreciation Rates for the Productivity Accounts*. The Canadian Productivity Review. Catalogue no. 15-206-XIE2007005. Ottawa: Statistics Canada.

Tatom, John A. 1991a. "Public capital and private sector performance." *Federal Reserve Bank of St. Louis Review.* 73, 3: 3–15.

Tatom, John A. 1991b. "Should government spending on capital goods be raised." *Federal Reserve Bank of St. Louis Review.* 73, 2: 3–15.

Tatom, John A. 1993. "Is an infrastructure crisis lowering the nation's productivity? *Federal Reserve Bank of St. Louis Review.* 75, 6: 3–21.