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The Canadian Productivity Review

Integrated Productivity Accounts: Contributions to the Measurement of Capital

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Integrated Productivity Accounts: Contributions to the Measurement of Capital

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Symbols

The following standard symbols are used in Statistics Canada publications:

. not available for any reference period
.. not available for a specific reference period
… not applicable
0 true zero or a value rounded to zero
0^s value rounded to 0 (zero) where there is a meaningful distinction between true zero and the value that was rounded
^{p} preliminary
^{r} revised
x suppressed to meet the confidentiality requirements of the *Statistics Act*
^{E} use with caution
F too unreliable to be published

1 Introduction

Measures of productivity are derived by comparing outputs and inputs. The System of National Accounts (SNA) in Canada provides a useful framework for organizing the information required for comparisons of this type. Integrated systems of economic accounts provide coherent, consistent alternate estimates of the various concepts that can be used to measure productivity.

In Canada, multifactor productivity (MFP) measures are derived from a set of industry accounts. These industry accounts are integrated and consistent with the expenditure side of the National Accounts of Canada (see Wilson 2006). This provides for a variety of productivity series at the industry level based on alternate measures of output along with their corresponding inputs. This approach permits the construction of MFP measures for the aggregate business sector as a weighted average of industry productivity growth rates, where the weights are defined in terms of the ratio of industry current dollar 'output' to the current dollar bottom-up GDP. Furthermore, these estimates can be reconciled completely to estimates derived from the final expenditure accounts.

The bottom-up industry approach relies on a detailed set of production accounts. In Canada, the expenditure accounts and the production accounts are integrated within a unified framework defined by the input-output tables (IOT). These IOT are used to derive the estimates of output and inputs by industry and by major sector, in current and constant prices; they also allow for the construction of final-demand GDP and provide the cost of primary inputs for the aggregate business sector.

In the SNA, these various components are brought together into a consistent whole that facilitates productivity estimation. These integrated systems also support studies that advance our understanding of the role of capital—both tangible and intangible—in the production process. This paper describes how the integrated productivity accounts and the analytical program behind them have made progress in several different areas.

2 The Canadian Productivity Accounts (CPA)[1]

The Canadian Productivity Accounts (CPA) begin with the available production and expenditure accounts for the business sector that are available from the SNA and supplement them with coherent measures of labour services and capital services.

2.1 Output and GDP

Data on output and inputs in current and constant prices are obtained from the existing production and expenditure accounts available from the IOT. The Canadian IOT consist of five matrices that outline the disposition or production, on the one hand, and the use, on the other hand, of goods and services and primary inputs (see Lal 1986 and Statistics Canada 1989). The make matrix shows the details of the industries and the commodities they produce. The use and

1. For more information on methodology, see Appendix 1, "The Statistics Canada Productivity Program: Concepts and Methods" by T.M. Harchaoui, M. Kaci and J.-P. Maynard, in *Productivity Growth in Canada*, No. 15-204-XIE, published in 2001.

the final-demand matrices provide information on the goods and services purchased for intermediate use and final demand, respectively. The remaining two matrices show the details of the primary inputs used, by industry, and purchased, by final demand.

These tables cover about 300 industries with data on gross output, value added, materials inputs, energy, and services—both in current dollars and in constant dollars. These data are created mainly from establishment surveys and are establishment-based. They also contain compensation data that consist of the following: a) labour income; b) mixed income of unincorporated business enterprises; c) other operating surplus; d) taxes on products; e) other taxes on production; f) subsidies on products; and g) other subsidies on production. Sources here come mainly from enterprise tax files that are then spread to industries in order to make them compatible with the establishment production data. Accompanying the industry data are make and use commodity tables that contain about 700 commodities. The final demand tables include about 170 categories of final demand.[2]

For the CPA, time series are created in order to provide a consistent long-run time series for a smaller set of industries. For the period 1961-1997, the labour productivity estimates are generated at various levels of detail available from the IOT for business or commercial industries. Business-sector MFP estimates were generated at the P (123 industries), M (47 industries), and S (16 industries) levels.[3] With the introduction of the North American Industrial Classification system (NAICS), the granularity of the industry divisions changed somewhat so that, for the 1961-to-2007 period, MFP estimates correspond to the P-level (88 industries measured at 4-digit NAICS), M-level (52 industries measured at 3-digit NAICS), and S-level (17 industries measured at 2 digit NAICS).

Categories for final-demand commodities include personal expenditure, gross fixed capital formation, additions to (the value of physical change in) inventories, government expenditure on goods and services, and exports. Data on imports are also available.

The production accounts are constructed so as to meet several basic identities. These are:

1. Industry accounts: The gross output of any industry equals its total intermediate inputs plus its total primary inputs.

2. Commodity accounts: The total output of any commodity equals the sum of its total use as an intermediate input and its total use for final demand.

3. Primary inputs and final demand: Given that gross supply and disposition of commodities are equal and that interindustry intermediate purchases and sales of commodities are identical, it follows that final demand is equal to cost of primary inputs. The former is derived by subtracting intermediate inputs from total use of commodities and the latter by deducting intermediate inputs from total supply of commodities. Hence, total gross domestic product at market prices (income-based) equals total gross domestic product at market prices (expenditure-based).

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2. The number of industries and commodities in the input-output tables has changed over time with the use of different industry- and commodity-classification systems.
3. The most detailed level of industry for MFP estimates is less than that for labor productivity because investment data are not available for the L level.

All of these identities hold for both current-price and constant-price tables.

Industry value added is calculated as the difference between the gross output of industries and the total of intermediate inputs and taxes, less subsidies on production (net taxes on production). These components of income include all personal income taxes and all corporate income taxes. Summed across all industries, these estimates of value added are equal to the GDP calculated from market-price final expenditures less taxes on products less subsidies on production.

The set of industry accounts represented by the IOT is valuable for several reasons. First, it benchmarks the rest of the National Accounts, including the final-demand GDP. As such, the CPA productivity estimates at the industry level are consistent with those at the more aggregate level. Second, considerable effort is spent in checking the concordance of industry-level measures of outputs and inputs and in valuing outputs and inputs consistently. Since the IOT are at the core of the statistical system, they provide an audit tool that allows the statistical system to monitor the various sources used in different parts of the process that builds data on expenditure, on factor income, and on commodity production and use. Third, as we point out here, these data, when combined with information on labour, capital, and other series, provide the base for analytical studies aimed at providing new statistical products—either in the form of data products or an understanding of issues that suggests directions for the statistical system to take.

2.2 Labour

The CPA are responsible for constructing labour estimates from various sources that accord with the recommendations of the SNA 1993 and that are consistent with the data generated by the production accounts. Estimates of jobs and hours worked are produced at a detailed industry level and by class of workers (see Baldwin *et al.* 2005). Changes in the skill level of the labour force are not captured in a simple sum of hours worked across all workers. To obtain a measure of productivity that excludes the effect of changing skill levels, the CPA adjust hours worked for changes in the quality or composition of the labour force, by making use of relative wages as aggregation weights in order to take into account differences in relative productivity of different groups of workers. Its labour estimate therefore takes into account changes in labour composition or labour "quality."

Details on the construction of the labour data can be found in Gu *et al.* (2003). Briefly, the Censuses of Population, conducted by Statistics Canada every five years, provides detailed benchmark data on employment, hours, and labour compensation across demographic groups in census years. The annual Labour Force Survey (LFS), conducted by Statistics Canada, and other data are used to interpolate across intervening years.

The demographic groups include 56 different types of workers, cross-classified by class of workers (employee, self-employed, or unpaid), age (15-17, 18-24, 25-34, 35-44, 45-54, 55-64, 65+), and education (0-8 years grade school, some or completed high school, post-secondary education below a bachelor's degree, and a bachelor's degree or above). Adjustments to the data include allocations of multiple job-holders and an estimation procedure to maintain consistent definitions of demographic groups over time. These detailed data allow us to estimate the quality of labour input for the private business sector as well as for individual industries down to the three-digit (L) level of the IOT.

2.3 Capital Services

The CPA are also responsible for developing internally consistent, coherent estimates of capital services. The CPA take investment data and modify them to meet the boundaries of the National Accounts. Here, the CPA rely on investment data first from the Income and Expenditure Accounts for final-demand GDP and then from input-output accounts that are built from industry survey data obtained from the Investment and Capital Stock Division of Statistics Canada. Investment expenditures are acquired from the latter Division in the form of an establishment survey that provides more extensive detail than is available from the Industry Accounts. This establishment survey is used to produce detailed industry data, which are reconciled to the aggregate data.

The CPA begin with investment data, estimates capital stocks using the perpetual inventory method, and aggregate capital stocks using rental prices as weights. This approach, originated by Jorgenson and Griliches (1967), is based on the identification of rental prices with marginal products of different types of capital. The estimates of these prices incorporate differences in asset prices, service lives and depreciation rates, and the tax treatment of capital incomes. Service lives are derived from special questions included in the *Investment Survey*. Depreciation rates are derived from used-asset prices (Micro-economic Analysis Division 2007). A broad definition of capital is employed, which includes tangible assets such as equipment and structures, as well as land and inventories. A service flow is then estimated from the installed capital stock.[4]

The CPA approach to capital services generates a complete time series of investment derived from over 150 investment types reclassified into 28 private assets (18 types of equipment and software, 6 types of non-residential structures, and 4 types of residential structures). To estimate capital stocks, the CPA use the perpetual-inventory method and a geometric depreciation rate based on age-price profiles developed in *Depreciation Rates for the Productivity Accounts,* a 2007 publication also in The Canadian Productivity Review series.

Capital services at the industry level are then estimated as the weighted sum of capital stock, with rental prices as weights. Capital services for the aggregate business sector are constructed by aggregating capital services at the industry level on the basis of the industry share of total user costs.

3 Testing the Assumptions Used to Estimate Capital Services

An integrated set of productivity accounts such as the CPA is useful not just for estimating productivity statistics: it also permits a statistical agency to monitor the internal consistency of the data used for the estimates. In this section, we demonstrate that an integrated set of productivity accounts can be used both to test the sensitivity of the estimates to alternate assumptions and to ask whether the estimates are internally consistent. We do so by assessing how sensitive MFP estimates are to alternate ways of estimating the user cost of capital.

MFP growth measures have been developed as summary statistics to measure the amount of this progress. They do so by comparing actual growth rates in GDP with the increase in GDP

4. See Harchaoui and Tarkhani (2003) for methodology.

that would have been expected from an increase in inputs using pre-existing or current production techniques.

The basic production model on which productivity estimates are based is written:

$$GDP_t = A(t)F(K_t, L_t) \tag{1}$$

By taking the total derivative with respect to time and assuming competitive markets, the change in GDP with respect to time can be represented:

$$G\dot{D}P_t = \dot{A}_t + \omega_{l,t}\dot{L}_t + \omega_{k,t}\dot{K}_t \tag{2}$$

where the elasticities of capital and labour growth are their respective income shares.

MFP growth, $\dot{A}_t$, is measured as a residual:

$$MFP_t = \dot{A}_t = G\dot{D}P - \omega_{l,t}\dot{L}_t - \omega_{k,t}\dot{K}_t \tag{3}$$

Rewriting this is in terms of income shares gives

$$M\dot{F}P = \dot{Q} - \sum \frac{P_i X_i}{PQ}\dot{X}_i = \dot{Q} - \sum s_i \dot{X}_i \tag{4}$$

where s_i is the factor *i*'s share in value of GDP (PQ).

Estimates of MFP from (4) require measures of the change in GDP (Q), capital (K), and labour (L) and factor shares. In a world where all assets have the same marginal product, changes in capital may be estimated by simply summing the value of all assets and calculating changes therein over time. However, factors (either workers or types of capital assets) may differ in terms of their marginal product; it is consequently inappropriate to simply sum the factors. If there are *m* types of factor *i*, each with a different marginal product, then the appropriate formula for estimating the effect of a change in a factor is

$$s_i \dot{X}_i = \sum_{k=1}^{m} s_{ik} \dot{X}_{ik} \tag{5}$$

where s_{ik} can be approximated by the share of total GDP that goes to each type of the factor *i* and

$$s_i = \sum_{k=1}^{m} s_{ik} \tag{6}$$

This can be transformed to

$$\dot{X}_i = \sum_{k=1}^{m} (s_{ik} / s_i) \dot{X}_{ik} \tag{7}$$

and then substituted into equation 5.

Consequently, the appropriate weights to aggregate changes in a type of factor are the relative shares of each type of factor in the total compensation received by that factor. In order to estimate these shares, we need to calculate the unit price of each type of factor. In the case of prices for labour, the task is relatively straightforward. Transactions are observed continuously in labour markets that can be used for this purpose. In the case of capital, we need comparable prices. While the price of the capital good is available, the price of the services that the capital good yields, when it is used over a period that is shorter than its length of life, is not usually observed and needs to be inferred.

The user cost of capital can be thought of as the price that a well functioning market would produce for an asset that is being rented by an owner to a user of that asset. That price would comprise a term reflecting the opportunity cost of capital (r_t) (either the opportunity cost of using capital or the financing costs), a term reflecting the depreciation of the asset (δ), and a term reflecting capital gains or losses from holding the asset (reflecting changes in the market price of an asset, $q_t - q_{t-1}$). Jorgenson and Griliches (1967) demonstrate that the formula for the rental price of a unit of capital that costs q is

$$c_t = q_{t-1} r_t + q_t \delta - (q_t - q_{t-1}) \tag{8}$$

The implementation of this formula requires estimates of depreciation, capital gains resulting from holding the asset, and the rate of return expected. Depreciation rates can be estimated from trajectories of used asset prices and capital gains from the price indices of different assets collected by the agency. However, one area in which practice has not coalesced is that of the measure of the rate of return.

The debate here has revolved around whether the rate of return should be calculated endogenously or taken from exogenous sources.[5]

Rates that are calculated endogenously make use of data from the National Accounts on capital income as well as estimates of capital stock to solve for the rate of return.

Alternatively, the rate of return can be drawn from other sources—a rate of return observed in financial markets, for example. Here, there are several choices—a risk-free rate of return such as a government-bond rate, a corporate-debt rate that takes into account the risk of the business sector, or a weighted average of corporate debt and corporate equity rates that recognizes that the corporate sector is financed by a mixture of debt and equity.

The benefit of using the method that employs endogenous rates is that it is provides a fully integrated set of accounts. The surplus is taken directly from the National Accounts, which

5. See Schreyer, Diewert, and Harrison (2005).

provide the underlying data for the CPA. Capital is directly estimated from the investment flows that are also part of the SNA. In Canada, investment flows are integrated with the IOT and are thus consistent with GDP at the industry level. These flows can serve to estimate capital stock through the perpetual-inventory method and, together with the surplus, yield a rate of return earned in each industry.

Equally important, the assumptions that are required to be made in order to make use of the surplus in estimating capital services are fully compatible with the assumptions that underlie the non-parametric productivity estimates—namely, a competitive economy with a production process subject to constant returns to scale.

Choosing an exogenous rate of return allows for the assumption of constant returns to scale to be relaxed. This approach does not require that the assets used completely exhaust capital, thereby recognizing that some assets may be excluded in existing estimates. This also allows an analyst to presume that the economic system is not perfectly competitive and that the corporate surplus may include more than just the cost of capital services—for example, that it may also include monopoly profits.

Since the use of an exogenous rate of return does not guarantee that the corporate surplus is completely exhausted, it permits the estimation of a residual (the difference between corporate surplus and capital services). This difference could be the result of monopoly profits. It could arise because the list of factors included in the MFP estimates is incomplete (for example, assets such as land, inventories, natural resources, or intangibles are excluded). It could arise because there are economies of scale, and, therefore, paying factors their marginal revenue product does not completely exhaust total product.

While using the exogenous rate overcomes several potential problems, doing so gives rise to other problems. The difficulty with using the exogenous rate is that it is not obvious what rate should be used, and choice of an incorrect rate will lead to an error in the estimates of MFP.

In the case of an exogenous rate, a wide range of rates have been suggested—from short to long rates, from lending to borrowing rates (Diewert 1980). The interest rate in the cost-of-capital formula should reflect risk-adjusted rates of return (since it is these that govern investment decisions). This requires a variation in the return by industry or by asset in order to reflect varying degrees of risk.[6] This problem, in turn, requires that the analyst make use of information that would help to adjudicate differences in risk. When this is done, there may, in the end, be little difference between the rates yielded by an endogenous system and those yielded by an exogenous system.

In this paper, as in the CPA, we use capital income from the National Accounts to derive the internal rate of return. Capital income is defined here as current-dollar gross domestic product except for labor compensation (wages, salaries, supplementary compensation, and a portion of proprietors' income attributable to labour). We drew capital stock estimates from the CPA database of Statistics Canada. This database applies the perpetual-inventory method to investment flows.

6. See Schreyer, Diewert, and Harrison (2005, p. 43), who stress that practitioners should therefore use industry-specific rates of return that reflect the fact that some investment in fixed capital is riskier than others.

For the exogenous rate of return, we have used a weighted average of debt costs and the equity rate of return, where the weights are the proportion of debt and equity that is used to finance business capital.[7] For the debt rate, we have used the 90-day commercial-paper rate.[8] For the equity rate, we have used the rate of return on equity as derived from the gain in the index of the Toronto Stock Exchange to which we added the dividend yield.[9] The resulting exogenous rates of return are inclusive of the overall inflation rate and thus represent the nominal rates of return. These nominal rates are then deflated with the consumer price index. The resulting series of real exogenous rates are averaged over the period 1961 to 2001, to yield a constant rate of return of 4.7%. For the user cost specification (8) based on the exogenous rate of return, we will set the real rate of return r_t^* to a constant 4.7%.

3.1 Alternate Specifications of Rate of Return

To examine the effect of alternative approaches to the estimation of capital services and MFP, we compare two sets of estimates. The first (M1) applies the instantaneous change in asset prices to an estimate of capital gains. The second (M3) ignores the capital gains term since it is not clear whether there are ways that holding-period gains arising from differential rates of inflation can be harvested—especially for investment goods. Both variants include the impact of taxes. (See Baldwin and Gu 2007a).

Table 1
A comparison of alternative capital-rental cost formulae in the business sector, 1961 to 1981

	Endogenous		Exogenous	
	M1	M3	M1	M3
Mean statistics over years 1961-1981				
Average nominal rate of return	0.15	0.13	0.11	0.11
Annual MFP growth (%)	1.00	1.24	1.48	1.50
Mean statistics over years 1981-2001				
Average nominal rate of return	0.10	0.11	0.09	0.09
Annual MFP growth (%)	0.12	0.21	0.25	0.38

Source: Canadian Productivity Accounts.

In order to assess the effect of the alternate scenarios, we compare the average rates of return produced by each, and the growth in MFP. The scenarios differ by the choice of the rate of return and the choice of expected capital gains. Summary statistics in each of these areas can be found for the periods 1961 to 1981 and 1981 to 2001 in Table 1.

The nominal rates of return produced by the endogenous method are generally higher than those yielded through the exogenous method.[10] Over the 1961-to-1981 period, the endogenous

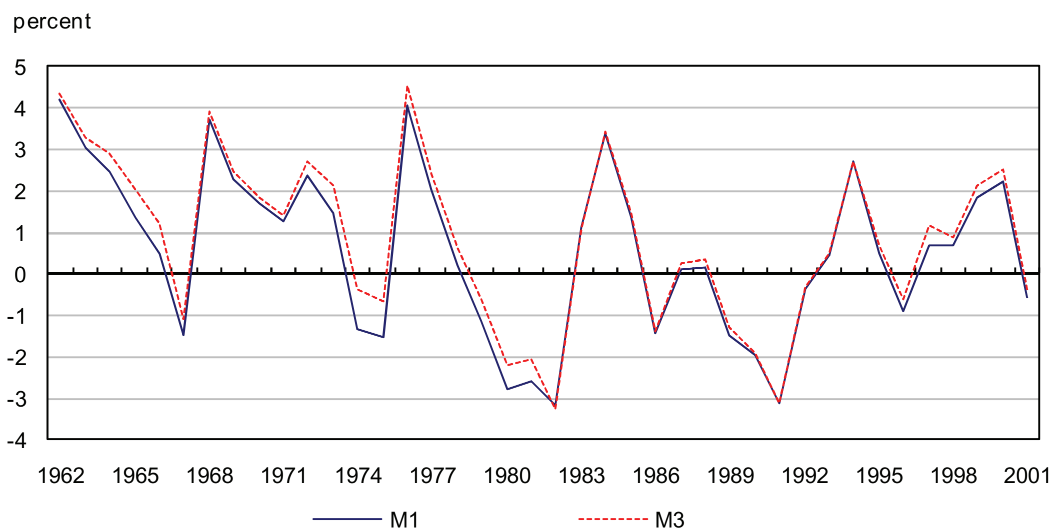
7. These proportions are taken from the Industrial Organization and Finance Division of Statistics Canada.
8. See CANSIM, series 122491. We use the commercial rate rather than the long-term corporate bond rate to reflect the fact that it is the after-tax rate that is required, and the commercial rate, which is below the corporate rate, allows us to capture the tax effect. Future versions of this paper will explore alternatives.
9. See CANSIM, series 122620 and 122628.
10. We have employed the user cost formula based on real rates in estimating the exogenous user cost of capital. For the presentation of the results, we use nominal rates of return. The nominal rates of return are computed as the sum of the real rates of return plus a five-year moving average of the change in the consumer price index.

rate that excludes asset price changes as a measure of capital gains (M3) is 13%, while the comparable exogenous rate averages only 11%. Over the 1981-to-2001 period, the endogenous rate estimated from M3 is 11% while the comparable exogenous rate averages 9%. The difference is not large—around two percentage points in both periods when we consider M3 the method that excludes asset price changes as measures of capital gains.

As regards the difference in MFP growth rates across the two alternatives, it is apparent that MFP growth is faster when we use the exogenous rate of return rather than the endogenous rate of return—though, as Chart 1 demonstrates, it is difficult to distinguish one method from another in the annual data.

This difference arises for two reasons. The first reason is that the endogenous rate of return is higher than the exogenous rate of return. The level of the nominal rate of return affects MFP growth in two ways—via its effect on what is referred to as *capital composition* (the difference between the growth of the simple sum and the weighted sum of individual assets) and its effect on the measure of the cost share of capital. The use of a lower rate in the user cost estimation leads to higher growth of capital composition and a lower cost share of capital service in the MFP growth accounting framework. The former result leads to a decline in the MFP growth estimate while the latter leads to an increase in the MFP growth estimate. The overall effect of the two offsetting factors is an increase in the MFP growth rate, as the effect of changes in capital share tends to dominate the effect of changes in capital composition.

Chart 1
Multifactor productivity growth in the business sector



Source: Canadian Productivity Accounts.

The second reason is that the use of an exogenous rate of return imposes an equality in the rates of return across industries that does not exist for the endogenous method. Part of the growth in GDP in a world where returns differ across industries can come from the reallocation of resources from industries where the marginal product of capital is lower to industries where the marginal product of capital is higher. Baldwin and Gu (2007a) show that much of the difference between the endogenous and exogenous rate methods stems from this phenomenon. That is, if the average endogenous rate were to be applied across all industries, the resulting MFP would increase to about the same level as the MFP estimate from the exogenous method.

In conclusion, using the CPA in this way provides a validation of the internal consistency of the database. This method has shown that the rate of return that falls out of the exercise is very close to the actual rate of return earned by the business sector. More importantly, it has demonstrated why the alternate method sometimes used to estimate MFP when integrated industry accounts are not available (when exogenous rates of return are chosen) is likely to lead to upward biases in MFP estimates—because such estimates miss part of the causes of growth—the reallocation of resources across industries from less productive to more productive uses.

4 Infrastructure Capital

One of the benefits of having an integrated set of productivity accounts is the ability to generate productivity measures that incorporate different sources or types of capital. The CPA focus on the business sector and examine the efficiency with which that sector transforms the labour that it hires and the tangible capital (machinery and equipment; buildings) that it purchases into output. Recently, the CPA have been extended to examine what happens when public capital is incorporated in the analysis.

Public capital is comprised of assets such as roads, bridges, and water and sewage plants (Baldwin and Dixon 2008). In Canada, roads are the largest component of the public capital stock. These assets are currently not treated as an input for the business sector and do not explicitly contribute to productivity, because investments in roads are not performed by the business sector.

4.1 Incorporating the Impact of Infrastructure on Multifactor Productivity

The standard index number approach to measuring MFP starts with a production function that uses capital services, K_t, and labour services, L_t, to transform inputs into outputs. The MFP term is incorporated as a shift parameter, $A(t)$, that represents changes to the level of the production function as technology changes (see for example: Baldwin, Gu, and Yan 2007).

As noted in the previous section, the conventional estimate of MFP is written:

$$MFP_t = G\dot{D}P - \omega_{l,t}\dot{L}_t - \omega_{k,t}\dot{K}_t \tag{9}$$

where the elasticities of capital and labour growth are their respective income shares.

In order to extend this framework to take into account infrastructure investment, public capital can be assumed to enter the production process as an exogenous input that leads to increasing returns to scale across all input but leaves private-sector agents facing constant returns to scale. The resulting experimental estimate of MFP is written:

$$MFP_t^* = G\dot{D}P - \omega_{l,t}\dot{L}_t - \omega_{k,t}\dot{K}_t - \varpi_g\dot{G}_t \tag{10}$$

$$\omega_{l,t} + \omega_{k,t} = 1 \quad \omega_{l,t} + \omega_{k,t} + \varpi_g \geq 1$$

The model that includes public capital is related to the standard MFP estimate produced by the CPA through the identity:

$$MFP_t = MFP_t^* + \varpi_g \dot{G} \tag{11}$$

The MFP estimates from (9) and (10), therefore, provide a method for assessing the extent to which current MFP estimates are biased as a result of the fact that they include not just technological change but also the contribution from public-sector investment.

4.2 Estimating the Output Elasticity of Public Infrastructure

In order to take into account the impact of public infrastructure on business-sector GDP, an estimate of the elasticity of public capital is required. While shares can be used to estimate private inputs, this is not possible for public capital. It is difficult for statistical systems to measure the value of government GDP because there are only limited, if any, markets for government services.

Without markets for the sale of outputs, it is difficult to find reliable elasticity estimates for public capital that can be applied to the growth in public capital or that can be used to approximate by just how much business-sector GDP should be expected to increase as a result of additions to public capital. To date, there is no consensus about what constitutes a reasonable output elasticity for public infrastructure, or what estimation method is most appropriate (see for example: Aschauer 1989; Munnell 1990; Munnell and Cook 1990; Shah 1992; Berndt and Hansson 1992; Lynde and Richmond 1992; Nadiri and Mamuneas 1994; Conrad and Seitz 1994; Morrison and Schwartz 1996; Harchaoui 1997; Fernald 1999; Pereira 2000; Ramirez 2004; Brox and Fader 2005; and Macdonald 2008).

To pursue this issue, we addressed two areas using the integrated CPA. In the first instance, we derived estimates for the elasticity of the business sector with respect to public capital; in the second instance, we introduced public capital as an explicit argument in the production function of the Canadian business sector and produced an experimental MFP estimate that excludes the effect of the input of public capital.

The input-output system that lies behind the GDP, as well as estimates of gross output and intermediate input that form the basis of the CPA, allow us to do this in two ways. The first method employs cost function estimates to derive a return from increases in public capital. Harchaoui and Tarkhani (2003) used industry data and a translog cost function. This approach makes use of share equations and demand functions to estimate a system of equations. These authors' paper drew on data from the CPA with regard to the values of gross output, the cost of labour, capital services, and intermediate inputs for 37 Standard Industry Classification (SIC) industries in the Canadian business sector with respect to the period 1961-1997. The authors combined the data from the CPA with public-capital data derived from the same investment source as was used for building the business-sector capital stock.

The second method is found in Macdonald (2008), where the author employs a cost function to examine the impact of public investment on private costs. Macdonald explores the sensitivity of estimation procedures to aberrant observations like outliers and to different time-series specifications by means of a GDP function. Macdonald followed Fernald (1999) in assuming that public-capital expenses are proportional to transportation costs. This assumption allowed

Macdonald to calculate an instrumental variable for public-capital costs of businesses by industry. The author drew on the commodity data of the input-output accounts from which the CPA are constructed.

In addition to cost-function estimates, Macdonald (2008) also estimates the dual production function. The production function estimates are formed from a panel of provincial data where GDP, capital, and labour variables are consistent with the data used to produce the CPA and consistent with a public-capital variable derived from the same investment data as that used by Harchaoui and Tarkhani (2003).

The two approaches are used to 'triangulate' on a likely range of values for the elasticity of public infrastructure. Macdonald (2008) compares the cost function to the production function estimates and the respective average rates of return derived therefrom, as well as to other estimates in the literature. This produces an elasticity of business-sector GDP with respect to increases in public capital of 0.05 to 0.15 that is centered on 0.1. These values correspond to a range for the rate of return to government capital that spans values from 5 percent to 29 percent, centered on 17 percent. The range of the estimates includes the average rate of return on public debt and the combined average return on private debt and equity.

Through the integrated set of productivity accounts, the elasticity and rate-of-return estimates can be incorporated into productivity measures either to create total-economy productivity measures or to re-estimate productivity measures such as MFP after including public capital as an explicit argument in the business sector's production function. Here an experimental MFP measure for the business sector is discussed because it represents an adjustment of the currently produced MFP measure widely used in Canada (see Gu and Macdonald 2009 for more information). Moving to a total economy MFP measure produces a similar result when a positive rate of return to public capital is included.

For purposes of examining how public infrastructure affects productivity growth, estimates of labour productivity growth are decomposed into their component sources. Within the growth accounting framework, equation 9 can be written in discrete time where all variables are measured in logarithms as:

$$\Delta\left({GDP_t}/{Hours_t} \right) = \Delta MFP_t + \beta_L \Delta\left({L_t}/{Hours_t} \right) + \beta_K \Delta\left({K_t}/{Hours_t} \right) \tag{12}$$

Where:

${GDP_t}/{Hours_t}$ = Labour productivity

$\beta_L \Delta\left({L_t}/{Hours_t} \right)$ = Contribution from labour-composition changes

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

MFP_t = Contribution from technology change and factors difficult to measure or include

When examining the role that public capital growth plays in private-sector productivity growth, the results are presented following the components in equation 12. However, MFP growth is decomposed as:

$$MFP_t = MFP^*_t + \varpi_g \Delta G_t \qquad (13)$$

Initially, the ϖ_g elasticity estimate of 0.1 is employed. Later, a sensitivity analysis based on the 0.05 to 0.15 elasticities obtained from Macdonald (2008) is provided. Throughout this section, the assumption of a competitive economy is maintained. The competitive assumption coincides with assumptions imposed on the traditional MFP estimates from the CPA, where an internal rate of return is employed for calculating capital services. This assumption is, therefore, a natural starting point.

4.3 Results

The effect of removing the influence of public capital on MFP is seen most strongly in the earlier half of the sample period, from 1961 to the early 1980s (Chart 2). After the mid-1980s, and particularly following the 1991 recession, there is little difference between MFP and MFP*.

The difference between MFP and MFP* occurs largely during the period when Canada's inter-provincial highway system is constructed. Once the impact of public capital is accounted for, the estimate of MFP* shows less growth over time than the standard estimate of MFP that includes the impact of public capital.

The difference in MFP growth rates can be seen succinctly when changes in labour productivity are decomposed into changes in capital intensity (capital contribution), labour composition changes, changes in public capital provision, and MFP*. This is done in Table 2, where the first three rows show labour-productivity growth, the capital contribution, and the labour-composition contribution, respectively. They are the same as produced by earlier studies examining the CPA and are presented for completeness. The last three rows contain the decomposition of MFP. They show the decomposed effects of public capital and MFP. The traditional MFP growth estimate is the sum of the contribution from public capital and the revised MFP growth estimate MFP*.

Chart 2
Multifactor productivity indexes (elasticity estimate = 0.1)

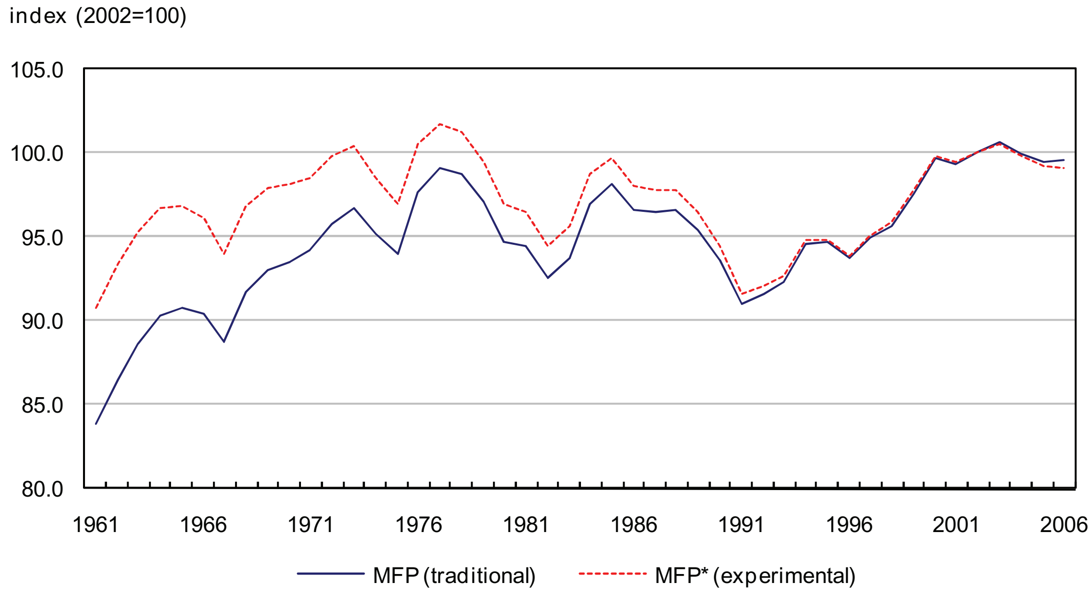


Table 2
Average annual contribution to labour productivity growth by source

	1962 to 2006	1962 to 1966	1967 to 1973	1974 to 1979	1978 to 1988	1989 to 1999	2000 to 2006
				percentage points			
Labour productivity	2.1	3.9	3.2	2.0	1.1	1.5	1.4
Capital contribution	1.3	1.6	1.7	1.7	1.0	1.0	0.9
Labour composition contribution	0.4	0.8	0.5	0.2	0.4	0.4	0.4
Public capital contribution	0.2	0.4	0.3	0.2	0.1	0.1	0.1
MFP*	0.2	1.2	0.6	-0.2	-0.4	0.0	0.0
MFP	0.4	1.5	1.0	0.1	-0.2	0.1	0.2

Note: MFP* stands for the experimental MFP.

Over the entire period, 1962-2006, including the impact of public capital halves the contribution of MFP growth to labour productivity growth. MFP rises by an average of 0.36% per annum while MFP* rises by 0.17% per annum. Public capital contributes importantly, adding 0.19% per annum to labour productivity growth from 1962 to 2006.

The contribution of public capital to labour productivity growth varies over time. Public capital had the largest contributions in the 1960s and 1970s. Those decades saw a sizeable expansion of the intra/inter-provincial highway system as well as the construction of the Trans-Canada Highway. They constitute a period during which the network of public capital expanded rapidly.

In subsequent years, public capital stock growth slows as the highway expansion ends and governments eliminate operating deficits. The contribution to labour productivity from public investment slowed in tandem. Estimates of MFP and MFP* both slow in the late 1970s, and are on average negative.

During the 1990s, and into the 2000s, MFP* grows at approximately the same rate as MFP. Estimates of both MFP* and MFP show the resurgence in productivity growth that occurred in the late 1990s and reflect a similar post-2000 slowdown.

4.4 Robustness Checks

The elasticity estimate employed to investigate the contribution of public capital to labour productivity is measured with uncertainty. Estimates of the elasticity of public capital are subject to normal statistical uncertainty, as well as to uncertainty arising from errors in variables associated with estimating its depreciation rate and its rate of return, and to uncertainty resulting from the estimation methodology. This uncertainty can significantly affect the associated elasticity estimates.

To assess the magnitude of the uncertainty, the elasticity estimate of 0.1 from Macdonald (2008) is adjusted up and down by 0.05. Macdonald (2008) argues that this represents a reasonable range for the elasticity of public capital that is consistent with most estimates from cost-function based studies.

The long-term rate for government bonds can be employed as an alternative method for calculating the marginal product of public capital. When the return on public capital is assumed to equal the average long-term rate for government bonds, the corresponding elasticity estimate is around 0.06. This estimate of the elasticity is consistent with the lower end of the confidence interval outlined above.

Estimates of the contribution of public capital and estimates of MFP* are influenced by the elasticity estimate employed (Chart 3 and Table 3). The influence is greatest during the period spanning approximately 1961 to 1980. This is the period when the conventionally derived estimates of MFP were highest. After 1980, only minor differences occur.

For each 0.05 increase in the elasticity estimate, the contribution of public capital to labour productivity growth is about 0.1 percentage points for the 1962-2006 period. The effect of increasing the elasticity estimate is larger during the earlier half of the period than during the latter half; this result is consistent with the growth rates of public capital stock.

For all three elasticity estimates, the contribution of MFP to labour productivity growth is lower during the 1960s and 1970s. Regardless of the estimate used, the MFP growth slowdown in the post-1980 period becomes less pronounced. In effect, when the impact of public capital is disentangled from MFP growth, MFP growth is lower and has less of trend, but continues to show cyclicality across eras.

Chart 3
Multifactor productivity indexes across public-capital elasticity assumption

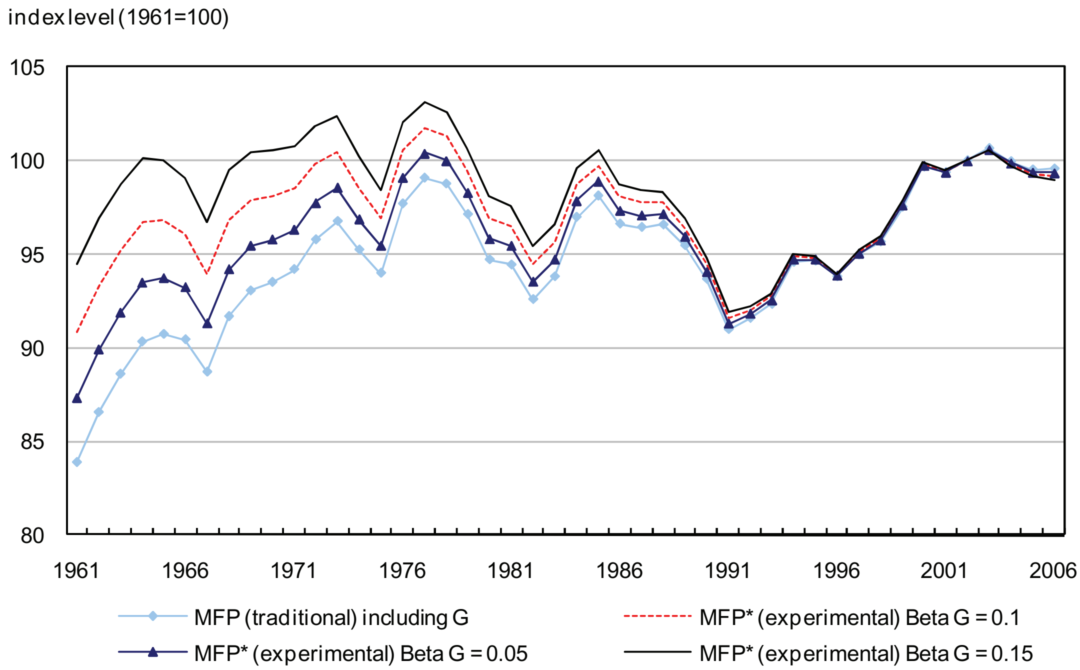


Table 3
Multifactor productivity and public capital contributions to labour productivity across elasticity estimates

	1962 to 2006	1962 to 1966	1967 to 1973	1974 to 1979	1978 to 1988	1989 to 1999	2000 to 2006
	percentage points						
Public capital contribution							
Beta = 0.05	0.09	0.18	0.17	0.11	0.07	0.04	0.06
Beta = 0.10	0.19	0.37	0.34	0.22	0.13	0.09	0.12
Beta = 0.15	0.28	0.55	0.50	0.33	0.20	0.13	0.18
MFP contribution							
Beta = 0.00	0.36	1.53	0.96	0.06	-0.22	0.09	0.16
Beta = 0.05	0.27	1.35	0.80	-0.05	-0.29	0.04	0.10
Beta = 0.10	0.17	1.17	0.63	-0.16	-0.36	0.00	0.04
Beta = 0.15	0.08	0.98	0.46	-0.27	-0.42	-0.05	-0.02

5 Intangible Capital

The integrated set of productivity accounts produced by Statistics Canada, the CPA, has also been used as a foundation for developing experimental estimates of investments that the Canadian economy makes in intangible assets. Intangible assets are broadly defined as knowledge-based assets, organizational assets, and assets relating to reputation.

Studies of the underlying factors behind growth have tended to focus on tangible assets such as machinery and equipment, buildings, and engineering construction (dams, railways, communication systems). However, most firms make expenditures in a wide range of other areas where the value of the expenditures to the firm lasts more than one year and therefore should be classified as an investment. Many of these are referred to as *knowledge assets* supporting the innovation process.

5.1 Types of Intangible Assets Investigated

One such intangible asset that has received much attention is research and development (R&D), which consists mainly of expenditures on the wages of R&D scientists—and produces knowledge capital that is critical for innovation. However, innovative activity is not restricted to this area. While R&D scientists create new knowledge that is embedded in brand-new products, other types of scientists—engineers—adapt new products and materials to the production process. Production engineering involves expenditures that are generally not classified as R&D but that have many of the same properties in that they create long-lived assets and involve substantial scientific effort.

Firms may invest in new scientific knowledge by hiring R&D- and production-oriented engineers and by producing this knowledge themselves—or may choose to buy this scientific knowledge. Knowledge investments are made by purchasing R&D, patents, licences, and technological know-how from other companies.

In the resource sector, exploration provides new information that becomes useful for production many years after it is acquired. Early-stage exploration expenditures serve to develop knowledge about where mineral resources are found and knowledge on the economic properties of mineral or petroleum reserves. R&D can be viewed as early-stage investments in innovation that are meant to reduce uncertainty. Exploration expenditures do the same for the resource sector of an economy.

Similarly, advertising expenditures provide firms with a reputation that, if it extends beyond the present and has an impact on the value of the firm, should be considered an investment in intangibles. Advertising expenditures build brand value, which has long been recognized as a valuable intangible asset.

The set of intangible assets that our research has examined for Canada cover several categories—i.e., advertising, mineral exploration, software, own-account research and development, purchased research and development, and own-account science and engineering expenditures. This research makes use of data that are derived from internally consistent, comprehensive, and reliable Statistics Canada data sources. For software and mineral exploration, the CPA already include the intangible asset in measures of capital input. For other assets, data are drawn from the IOT used as the basis for the CPA, from the Census of Population and from labour market surveys. The latter two sources use industry categories and definitions that make it possible to integrate the data into the industry accounts that underpin the CPA.

While other studies included a larger set of categories (in particular by extending the data to management and training),[11] the quality of the data in these areas make the evaluation of the conclusions derived therefrom somewhat problematic. In some cases, other studies have had to make use of third-party sources on R&D or advertising that are not integrated into the industry estimates coming from the SNA.

The estimates of intangible expenditures for Canada are linked directly to the industries in the CPA, which facilitates business-sector and industry-level analysis.[12] The integrated productivity measurement system provides a well established reference against which the intangible expenditures can be compared and allows for a straightforward reallocation of mineral exploration and software expenditures out of the currently used investment series and into intangibles expenditures.

5.2 Estimates of Investment in Intangibles

The shares of intangible investments are presented in Table 4 by three main categories: advertising; mineral exploration; and total science (we have subdivided the heading "Total science" into "Purchased science and engineering" and "Own-account," with the latter covering R&D, Software, and Other Science Own-Account). Science and innovation intangible expenditures are the most important—accounting for an average of 77.4% of total intangible investments over the period 1981 to 2001. Science-related innovation expenditures have increased their share over time, rising from 76.5% in 1981 to 78.4% in 2001. Advertising is second, with an average share of 18.3%, and its importance varies procyclically. Mineral exploration is third, making up on average 4.3% of intangible expenditures. The share of mineral exploration fell from its levels of the early 1980s to lower levels in the mid 1980s but has steadily grown since then (Chart 4). Investment in software is the smallest component of all intangibles for the sample period, having a share of 2.5% in 1981 and increasing to 6.7% by the end of the period. With the computer revolution taking place during this time, the share of this component more than doubles over the period.

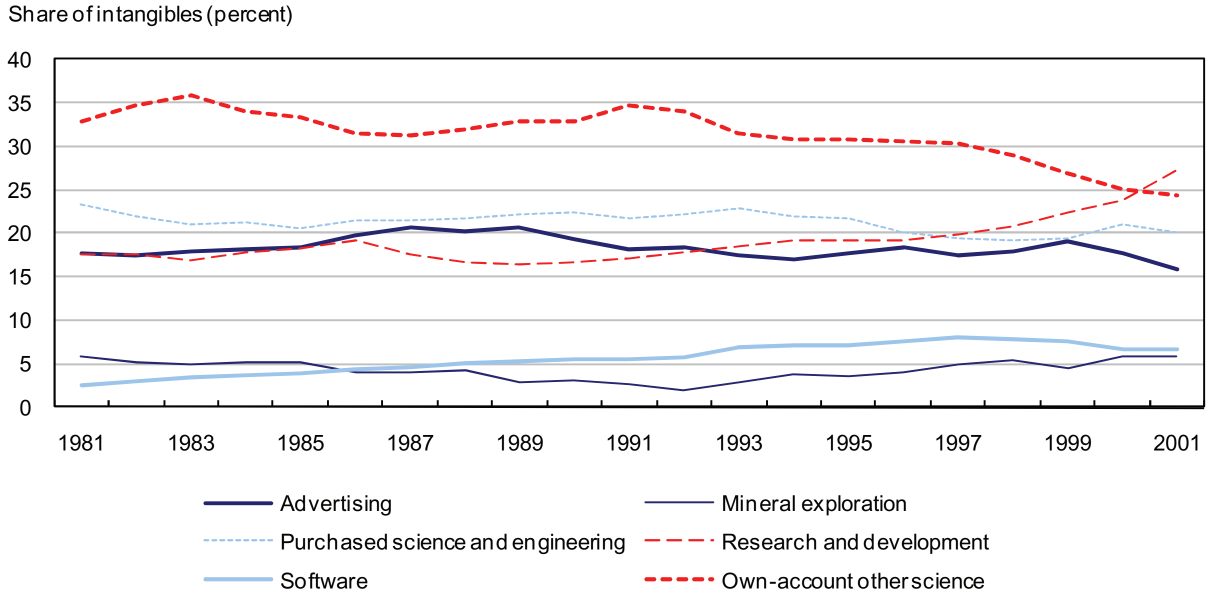
While R&D garners most of the attention in innovation studies, it accounts for only between 17.6 and 27.3 percentage points of total intangible investments, although its share grew in the late 1990s. The investments related to "Own-account other science" are considerably more important than R&D. Even the purchased science and engineering component is at least as large as R&D. A portion of this comes from imports of software.[13]

11. See for example Corrado, Hulten, and Sichel 2005, 2006.
12. The business sector defined here consists of all industries except NAICS 61 (Education), NAICS 62 (Health Care), and NAICS 91 (Public Administration).
13. The importance of R&D would be even less if exports of R&D were removed from the Own-account R&D expenditures, as is done in some satellite accounts of R&D.

Table 4
Share of intangible investments by asset category (current dollars)

	Advertising	Mineral exploration	Total science	Total science: Purchased science and engineering	Own-account: Research and development	Own-account: Software	Own-account: Own-account other science
				percent			
1981	17.7	5.8	76.5	23.4	17.6	2.5	33.0
1985	18.4	5.2	76.3	20.6	18.4	3.9	33.4
1990	19.4	3.1	77.6	22.5	16.6	5.5	32.9
1995	17.7	3.7	78.7	21.7	19.1	7.1	30.8
2001	15.8	5.8	78.4	20.1	27.3	6.7	24.4
Average	18.3	4.3	77.4	21.3	19.0	5.6	31.4

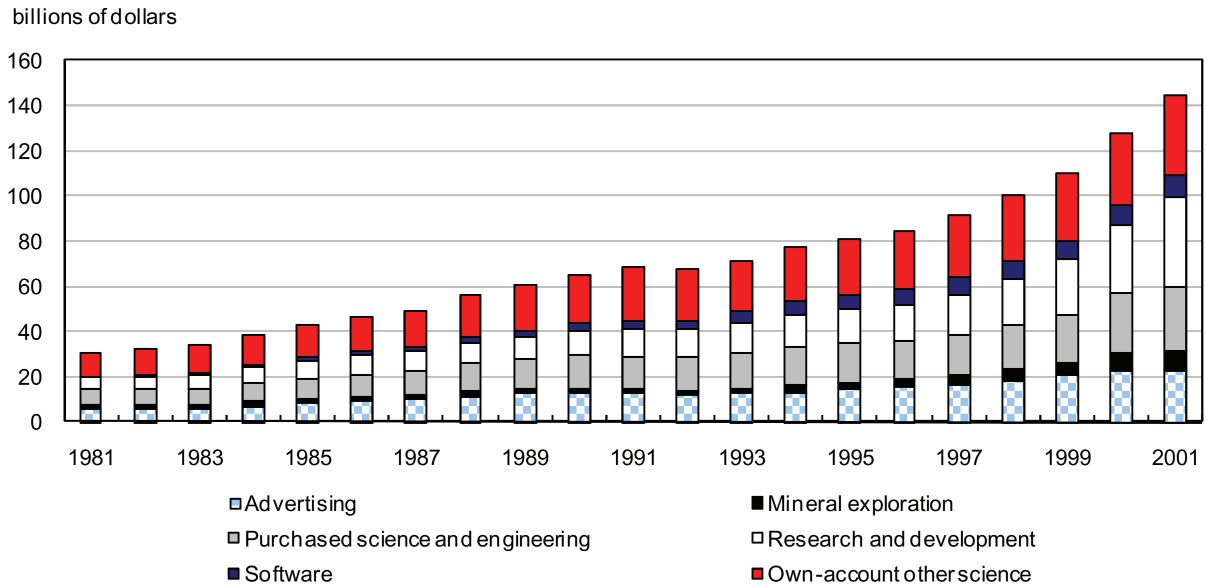
Chart 4
Share of intangible investments (1981-2001)



Intangible investment in Canada has expanded by an average of 8.2% per year from 1981 to 2001, rising four-fold from around $30 billion in 1981 to around $144 billion in 2001 (Chart 5). Software investment expanded most rapidly with an average annual growth of 13.9% per year. R&D investment had the second highest annual average growth rate (10.8%), followed by mineral exploration (10.4%), advertising (7.7%), purchased science and engineering services (7.5%), and Own-account science and engineering services (6.6%).

The own-account other science, after increasing in the early 1980s, fell slightly thereafter—going from 33.0% in 1981 to 24.4% by the end of the period. Investment in machinery and equipment (outside information and communications technologies (ICT)) has tracked expenditures with respect to other scientists closely over this period. Purchased engineering also declined slightly through the period—from 23.4% of the total in 1981 to 20.1% in 2001. Although the three categories (R&D, Software, and Own-account other science) have a relatively stable average share in the total over the time period, there has been a slight shift over the period. The share of "Own-account science" expenditures and "Purchased science" decreased during the 1990s while R&D and software increased slightly.

Chart 5
Intangibles composition (1981-2001)



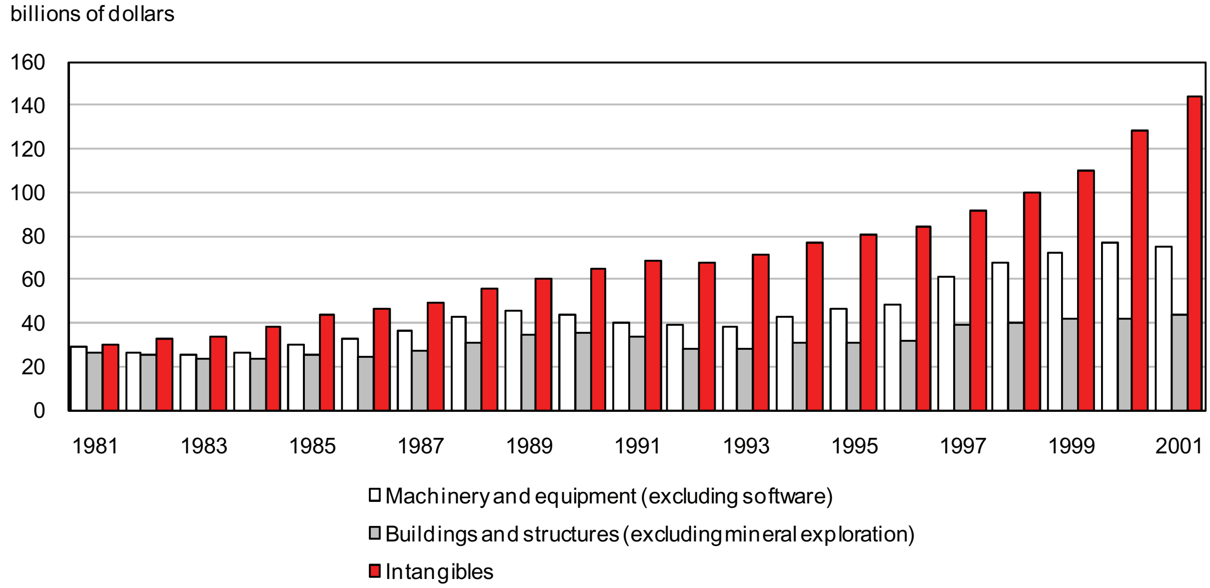
The decline of "Own-account other science" comes mainly from a switch in the proportion of total scientists to the software category. This is in keeping with other findings that investment in machinery and equipment over this period switched from more traditional investment goods to ITC (Baldwin and Gu 2007b).

Analysis of the determinants of economic growth often focuses exclusively on investment in tangibles. Recent studies on the knowledge economy suggest that expenditures on knowledge workers have grown more quickly than total employment (Beckstead and Vinodrai 2003; Baldwin and Beckstead 2003). Since many knowledge workers produce intangibles, growth in intangibles that comes from wage payments should also have been relatively high. At issue is the extent to which the growth in intangibles is larger than the growth in investments in tangible assets (such as machinery and equipment, buildings, and engineering structures). If it is, the omission of intangibles from total investment will underestimate the rate at which overall investment has been growing.

Investments in tangible capital, machinery and equipment, and buildings and structures has not kept pace with intangible investment. Investment in machinery and equipment rose at an average rate of 5.2%, while buildings and structures increased only at an annual average of

2.9% over the period (Chart 6). As a result, although expenditures on all three capital types are roughly equal in the early 1980s, the late 1990s, and early 2000s, investments in the intangible assets considered here stand at about double those in machinery and equipment, and are four times greater than investments in buildings and structures. Moreover, investments in intangibles are less cyclical than investments in tangibles. The recession of the early 1990s saw a relatively larger pullback in investment in tangibles than in investment in intangibles. By the end of the decade, the difference between the absolute level of investment in intangibles and investment in tangibles had widened considerably since the 1980s.

Chart 6
Investment by type (1981-2001)



In their study of the Canadian innovation system, Baldwin and Hanel (2003) stress that inputs to the innovation process differ by industry, with some inputs relying more on R&D scientists and others relying more on other people, such as engineers. Concomitant with the differences in the innovation profiles across industries, the type of intangible knowledge that is key to innovation in each industry also varies.

At the aggregate business-sector level, R&D is dominated by the other Own-account and “Purchased science" services categories. This is also generally true at the industry level, even in those industries that account for most of the R&D. Other Own-account science is most important in: agriculture and forestry; utilities; manufacturing; wholesale; information and culture; transportation; finance; and administrative support.

Professional, Scientific, and Technical Services is the one sector where R&D is the most important category—though even here “Own-account other science” comes second. R&D is also relatively important in manufacturing and wholesale.

Although all industries engage in intangible investments, when viewed as a share of total business sector expenditure, the intangible investments tend to be concentrated in a smaller number of industries. The largest share of total R&D is found in Manufacturing (39.2%), which is followed by Professional, Scientific, and Technical (26.7%), and FIREL (Finance, Insurance, Real Estate, and Leasing) (8.9%). Combined, these three industries account for 74.8% of all R&D expenditures. Similar concentrations are found in other intangible categories. The top three industries account for 60.1% of advertising investment; 84.5% of purchased science and engineering investment, 53.7% of software investment, and 68.1% of own-account other science investment.

Despite the concentration of intangible expenditures in particular industries, the innovative activities implied by those expenditures are spread across the entire business sector. Intangibles are prominent in both the goods and services sectors. A larger share of advertising and software investments is made by service-sector industries, while a larger share of expenditures relating to purchased science and engineering as well as mineral exploration takes place in the goods sector. The goods and services sectors account for about the same share in R&D and own-account other science.

The fastest growth in intangible expenditures comes from investments in software. In the overall business sector, investment in software has grown most rapidly, thereby increasing its share of total science expenditures. This is also the case in most industries. The rate of growth of software expenditures is as high or higher than that for most other categories (utilities; construction; manufacturing; transportation and warehousing; professional; scientific and technical; arts and entertainment; accommodation; food and beverages; and other services). Since software expenditures supported the introduction of ICT, the fact that growth was rapid everywhere bears testimony to the widespread impact of the ICT revolution.

At the aggregate level, expenditures on tangibles such as machinery and equipment are more cyclical than expenditures on intangibles. Intangibles grew more or less monotonically over the entire period, while tangibles fell back during the recession of the early 1990s. Inputs that involve higher adjustment costs have less cyclicality. Skilled labour tends to be hoarded in downturns, since it is costly to hire and train this type of worker, as a result of the non-codifiable knowledge that is embedded in a firm, which must be imparted to skilled labour in order for a given firm to take advantage of its capabilities. Intangibles also share some of the same properties, perhaps because they are complementary factors to skilled workers.

6 Human Capital

Counterparts to physical capital exist for the labour force, since substantial investments are made in developing skills. In addition, the CPA recognize the importance of skill upgrading in their estimates of labour inputs when they correct for the differential in labour productivity across worker groups (see Baldwin and Harchaoui 2006; Gu *et al.* 2003). The CPA construct a measure of labour input and labour composition that focuses on differences in educational attainment and experience of the Canadian workforce. This labour input is disaggregated by age, education attainment, and class of workers (paid vs. self-employed workers). These measures capture the increase in the flows of labour services that result from investments in human capital. Over the last forty-five years, increases in the ‘quality’ of the labour force as measured by these compositional shifts has accounted for one quarter of labour productivity growth in Canada (Baldwin and Gu 2007b).

Given the importance of human capital in productivity growth and sustainable development, there has been renewed interest in measuring the total stock of human capital in OECD countries (Wei 2004 for Australia; Le, Gibson, and Oxley 2002 for New Zealand; O'Mahony and Stevens 2004 for U.K; and Kokkinen 2008 for Finland).

Interest in the degree of capital invested in workers also stems from recent developments in the sustainable-development literature, where it has been suggested that a capital approach be used to provide statistical measures of sustainability. The capital approach is seen by some to provide objective measures of the degree to which an economy is maintaining and preserving capital assets of different forms for future generations. Those assets include physical capital, natural resources, human capital, and social capital.

Having an integrated set of productivity accounts gives us the ability to construct an estimate of human capital stock for Canada. The labour input data in the CPA provide data on hours worked, employment, and labour compensation for workers cross-classified by age, education attainment, and class of workers (paid vs. self-employed workers). The labour data provide the core database for this exercise, and are combined with data on student enrolment and population counts by different groups of the Canadian population to construct measures of human capital stock.

6.1 Methodology

For this exercise, we follow the methodology developed by Jorgenson and Fraumeni (1989, 1992a, and 1992b), who estimate the value of human capital stock as the expected future lifetime income of all individuals. This approach treats an individual as embodying capital with a "price" assigned to his or her lifetime labour income.[14]

The approach used to measure human capital is quite different from that used to measure physical capital—but both have their foundation in straightforward economic principles. For physical capital, the value of the asset is observed directly from market transactions in investment goods, and the cost of capital services with respect to the asset is derived from the equation for the user cost of capital. With well functioning markets, the net present value of the future stream of earnings should equal the cost of producing investment goods, and using the latter provides an estimate of discounted future earnings. In contrast, observable asset prices do not exist for human capital. Nevertheless, it is possible to observe the flow of services (the cost of labour services or wages), and the value of the asset can be estimated as the net present value of the wage trajectory over a lifetime (or lifetime labour income).

To provide an estimate of the stock of human capital in Canada, market lifetime labour income is estimated for all individuals aged 15 to 74 using cross-sectional data. Expected incomes of individuals in future periods are assumed to equal the incomes of individuals of the same gender and education, with future incomes being adjusted for increases in real income. Lifetime incomes can be calculated by a backward recursion, starting with age 74, which is assumed to be the oldest age before retirement. The expected income for a person of a given age is that person's current labour income plus that his or her expected lifetime income for the next period, times a probability of survival. For example, the present value of lifetime income of 74-year-olds is their current labour income. The lifetime income of 73-year-olds is equal to their current labour income plus the present value of lifetime income of a 74 year-old, adjusted for assumed increases in real income.

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14. Jorgenson and Fraumeni assume that human capital such as skills, knowledge, and competencies embodied in an individual of given gender, education, and age group does not change over time. To account for such change in "quality" of human capital in an individual would require the use of hedonic methods as in the estimation of price indexes for computers and semiconductors (Wei 2004).

The nominal value of human capital stock is the sum of lifetime labour incomes for all individuals in the working-age population. The volume index of human capital stock is constructed from data on numbers of individuals in the population and average lifetime income per capita of individuals, cross-classified by gender, age, and education.

This approach can be used to examine the effect of demographic changes in population, aging, and rising education levels on human capital per capita. Changes in human capital stock per capita occur as the composition of the population changes, either as a result of shifts in the average age or education of the population that are associated with changes in lifetime earnings.

Formally, human capital stock per capita (CK) is calculated as aggregate human capital per capita:

$$CK = K / L \tag{14}$$

where L is the number of individuals in the population and K is human capital.

To examine the contribution to the change in human capital stock per capita from population characteristics such as gender, age, and education separately, partial indices of aggregate human capital stock are constructed that correspond to those characteristics. For example, a partial index of the volume of aggregate human capital stock corresponding to gender is defined as follows:

$$\begin{aligned} \Delta \ln K^{sex} &= \sum_s \bar{v}_s \Delta \ln L_s \\ &= \sum_s \bar{v}_s \Delta \ln \left(\sum_e \sum_a L_{s,e,a} \right) \end{aligned} \tag{15}$$

where K denotes the volume indices of aggregate human capital stock, $L_{s,e,a}$ denotes the number of individuals with gender s, age a, and educational level e, and Δ denotes a first difference, or change, between two consecutive periods, and where $\bar{v}_s$ is the two-period average human capital share of men or women in the nominal value of human capital stock:

$$\begin{aligned} \bar{v}_s &= \frac{1}{2}\left[v_s(t) + v_s(t-1) \right] \\ v_s &= \sum_e \sum_a v_{s,e,a} \end{aligned} \tag{16}$$

The partial volume index corresponding to gender captures the shift of the population between the two genders alone. Similarly the partial volume indices for education and age measure the shift between age groups, or between educational levels, respectively.

The difference between the growth of the partial indices of aggregate human capital for each characteristic (gender, age, and education) and the growth of the number of individuals in the population measures the contribution of that characteristic to the compositional change of human capital. The sum of the contribution that each characteristic makes to the compositional change of human capital will differ from the compositional change, as the sum of the contribution of characteristics represents the first-order approximation to the index of the compositional change.

Similar to physical capital stock, the change in human capital stock can be decomposed into three components: investment in human capital; depreciation on human capital; and revaluation of human capital (Jorgenson and Fraumeni 1989). The first component, human capital investments, includes the rearing of children, formal schooling, vocational and on-the-job training, health, and migration. This is estimated as the sum of changes in lifetime incomes resulting from education, lifetime incomes of all individuals that had reached working age, and the effect of immigration on human capital.

The second component of the change in human capital is the depreciation of human capital, which is the alteration of human capital stock resulting from aging, death, and emigration. It is calculated as the sum of: changes in lifetime labour incomes by age for all individuals that remain in the working-age population; and lifetime labour incomes of all individuals who die or emigrate.

The third component of the change in human capital is the revaluation of human capital that represents the change in human capital over time for individuals with a given set of demographic statistics—sex, education, and age. It is calculated as the sum of changes in lifetime labour incomes from period to period for individuals with a given set of demographic statistics. An example of such change is provided by Picot and Heisz (2000), who document a decline in participation rates and slow growth in worker earnings in Canada during the early 1990s, particularly among younger male cohort. This will give rise to a small or negative revaluation term for human capital in that period, particularly for the younger male cohort.

6.2 Results

The annual growth rates of aggregate human capital stock for Canada are presented in Table 5.

Table 5
Average annual growth in human capital, working-age population, and human capital per capita

	1970 to 2007	1970 to 1980	1980 to 2000	2000 to 2007
		percent		
Human capital stock	1.7	3.0	1.2	1.1
Working-age population	1.5	2.1	1.2	1.3
Human capital per capita	0.2	0.9	0.0	-0.2
First-order indices of human capital per capita				
Gender	0.0	0.0	0.0	0.0
Education	0.9	1.4	0.8	0.6
Age	-0.4	-0.1	-0.5	-0.6

Over the period 1970 to 2007, aggregate human capital rose at an annual rate of 1.7% in Canada. Most of the growth in human capital results from the increase in the number of individuals in the working-age population aged 15 to 74. Of the 1.7% growth in human capital, 1.5 percentage points is due to the growth in the working-age population, while the remaining 0.2 percentage points is attributable to the effect of the compositional shift or the growth in human capital per capita.

The growth of aggregate human capital was highest in the 1970s, a period that coincided with the entry of baby-boomers into the working-age population and higher education levels among Canadians. The increase in aggregate human capital was lower after 1980 as a result of the slowing of the growth in the working-age population and the fact that this population was aging. The aging of the working-age population has a negative effect on the growth of human capital per capita because it produces a shift towards older individuals who have lower lifetime incomes given that they have fewer working years remaining.

The relative contribution of age, gender, and education to changes in capital stock per capita is presented in the bottom half of Table 5. Rising education attainment in the Canadian population makes a positive contribution to the growth in aggregate human capital: it adds 0.9% to annual growth in human capital stock over the period 1970 to 2007.

The aging of the Canadian population after the early 1980s made a negative contribution to the growth in the human capital stock: it lowered the annual growth in human capital by 0.5% in the 1980-2000 period and by 0.6% in the 2000-2007 period.[15]

There are few changes in human capital per capita in Canada after 1980. This is the net result of rising education levels, which increased human capital per capita, and of population aging, which reduced human capital per capita.

The share of women in the working-age population was virtually constant over time. Consequently, gender has little effect on the growth in the composition of human capital stock, despite large increases in the labour force participation rates of women and increases in discounted lifetime labour income of women.

As described, the change in aggregate human capital stock is decomposed into investment in human capital, depreciation, and revaluation. Investment in human capital in a period is the sum of, and the result of changes in, lifetime incomes resulting from education, lifetime incomes for the individuals that reached working age, and the effect of immigration on human capital. Depreciation of human capital is the sum of: changes in lifetime labour incomes that are the result of aging for all individuals that remain in the working-age population; and lifetime labour incomes of all individuals who die or emigrate. Revaluation of human capital is the sum of changes in lifetime labour incomes from period to period for individuals with a given set of demographic statistics—sex, education, and age.

15. Boothby *et al.* (2003) discussed the effect of the aging of the Canadian population on the skill level of the working-age population in Canada.

Table 6 presents an account of human capital accumulation in current dollars. The change in human capital is equal to the sum of gross investment net of depreciation and revaluation. Both revaluation and the change in human capital stock show large fluctuations over time, which is due to the variations in the rate of change in the average lifetime income. The change in the value of human capital reflects mainly the revaluation of human capital stock. Gross investment in human capital made a smaller contribution to the change in human capital than did the revaluation of human capital. The revaluation term and change in human capital stock were relatively small in the early 1990s, as a result of decline in participation rates and slow growth in worker earnings in the period.

The nominal value of changes in human capital stock, human capital investment, depreciation, and revaluation can be divided into the price and volume components. Table 7 presents gross investment, depreciation, and revaluation in 2002 constant dollars. Gross investment in human capital in constant prices rose by 0.4% per year over the period 1971 to 2007. During that period, net investment in human capital declined at the rate of 3.1% per year as the growth of depreciation on human capital exceeded the growth of gross investment in human capital over the period.

Investment in human capital grew more slowly than investment in nonhuman capital. Over the period 1971 to 2007, the growth of investment in produced physical capital was 3.9% per year.

Table 6
Human capital accumulation

	Gross investment	Depreciation	Revaluation	Change in human capital
	billions of current dollars			
1971	121.9	63.4	130.3	188.8
1972	135.1	71.1	124.7	188.6
1973	149.4	78.9	170.1	240.6
1974	170.1	89.9	275.9	356.0
1975	189.8	100.4	278.2	367.6
1976	207.5	109.5	276.0	374.0
1977	213.7	118.1	143.2	238.9
1978	203.4	124.7	154.3	232.9
1979	219.0	131.4	229.3	316.8
1980	249.4	139.5	332.8	442.8
1981	251.3	162.5	644.5	733.3
1982	268.8	174.1	343.9	438.5
1983	251.9	170.4	84.6	166.0
1984	260.4	186.0	372.9	447.4
1985	270.0	188.9	307.8	388.9
1986	288.2	202.9	355.2	440.4
1987	309.2	212.9	373.1	469.4
1988	310.3	221.5	497.3	586.1
1989	344.4	245.9	423.8	522.2
1990	369.1	304.8	684.1	748.4
1991	425.3	315.0	338.9	449.3
1992	434.5	311.9	-27.0	95.7
1993	431.2	311.8	-313.7	-194.3
1994	443.4	310.6	-15.2	117.6
1995	454.9	321.4	211.9	345.3
1996	423.0	323.2	15.8	115.6
1997	465.5	336.9	164.7	293.3
1998	436.4	361.8	263.1	337.7
1999	456.7	376.0	297.9	378.7
2000	539.3	386.3	363.1	516.2
2001	580.7	414.8	311.6	477.5
2002	540.6	428.7	293.0	405.0
2003	572.1	428.3	281.4	425.2
2004	558.9	449.7	666.4	775.6
2005	635.5	455.8	544.6	724.3
2006	653.2	495.8	666.7	824.1
2007	676.9	518.7	630.7	788.8

Note: The change in human capital is equal to the sum of gross investment net of depreciation and revaluation.

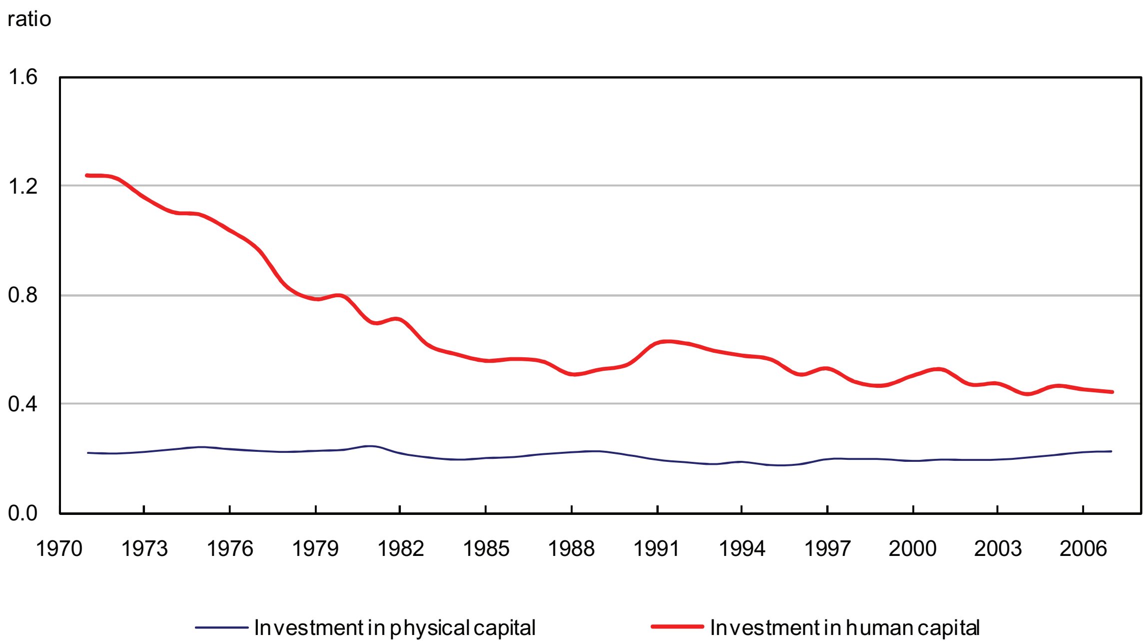
Table 7
Human capital accumulation

Year	Gross investment	Depreciation	Revaluation	Change in human capital
	billions of 2002 dollars			
1971	457.0	253.7	149.6	352.9
1972	460.9	259.1	156.8	358.6
1973	467.3	264.5	163.4	366.2
1974	474.3	269.7	169.5	374.2
1975	482.0	274.7	175.4	382.7
1976	488.9	277.7	181.1	392.4
1977	472.9	282.0	186.8	377.7
1978	437.5	288.6	191.8	340.8
1979	437.0	295.4	195.8	337.4
1980	470.3	303.2	199.8	366.8
1981	454.5	306.0	205.0	353.5
1982	441.4	313.0	209.0	337.4
1983	444.8	317.7	212.8	340.0
1984	435.6	320.8	214.0	328.8
1985	428.3	322.1	215.6	321.7
1986	445.3	323.4	217.5	339.5
1987	459.7	327.3	220.4	352.8
1988	459.3	333.6	223.0	348.6
1989	487.1	340.4	225.2	371.9
1990	514.1	343.7	226.0	396.5
1991	436.0	348.0	221.7	309.7
1992	459.8	355.1	224.5	329.2
1993	453.4	359.5	254.7	348.6
1994	521.1	365.4	244.7	400.4
1995	535.7	369.7	273.2	439.2
1996	492.8	370.4	303.8	426.2
1997	462.3	377.0	290.8	376.1
1998	497.6	388.5	282.0	391.2
1999	486.0	395.7	284.1	374.4
2000	489.5	404.3	285.8	370.9
2001	500.6	418.4	288.6	370.8
2002	540.6	428.7	293.0	405.0
2003	513.4	436.1	296.9	374.2
2004	467.3	443.6	301.1	324.8
2005	471.3	450.9	304.1	324.5
2006	510.9	460.7	308.0	358.2
2007.00	532.6	468.4	311.3	375.5

Note: The change in human capital in 2002 dollars is estimated as Tornqvist aggregation of gross investment net of depreciation and revaluation.

Chart 7 plots the ratio of investment in human capital to gross domestic product (GDP) in nominal value in Canada. To compare investments in human capital with investments in nonhuman capital, the investment to GDP ratio for physical capital is also plotted.[16] The ratio of investment in human capital to gross domestic product declined from 1971 to the mid-1990s, and changed little after the mid-1990s. The decline in the ratio of investment to GDP was fastest during the 1970s; the cause of this decline was the rapid growth in GDP in the period. The ratio of human capital investment to GDP was 1.26 in 1971, and it was 0.44 in 2007.[17]

Chart 7
Ratio of investment to gross domestic product in Canada



While the ratio of investment in human capital to gross domestic product declined over time, the ratio of investment in physical capital to GDP remained virtually unchanged. Investment in physical capital as a share of GDP was about 20% over the period.

In absolute terms, investments in human capital exceed the investment in physical, or nonhuman, capital. In 2007, investment in human capital was about twice the investment in physical capital in the Canadian economy. The magnitude of human capital investment relative to the investment in nonhuman capital was even larger in 1971. That year, human capital investment was about 5.7 times the investment in nonhuman capital.

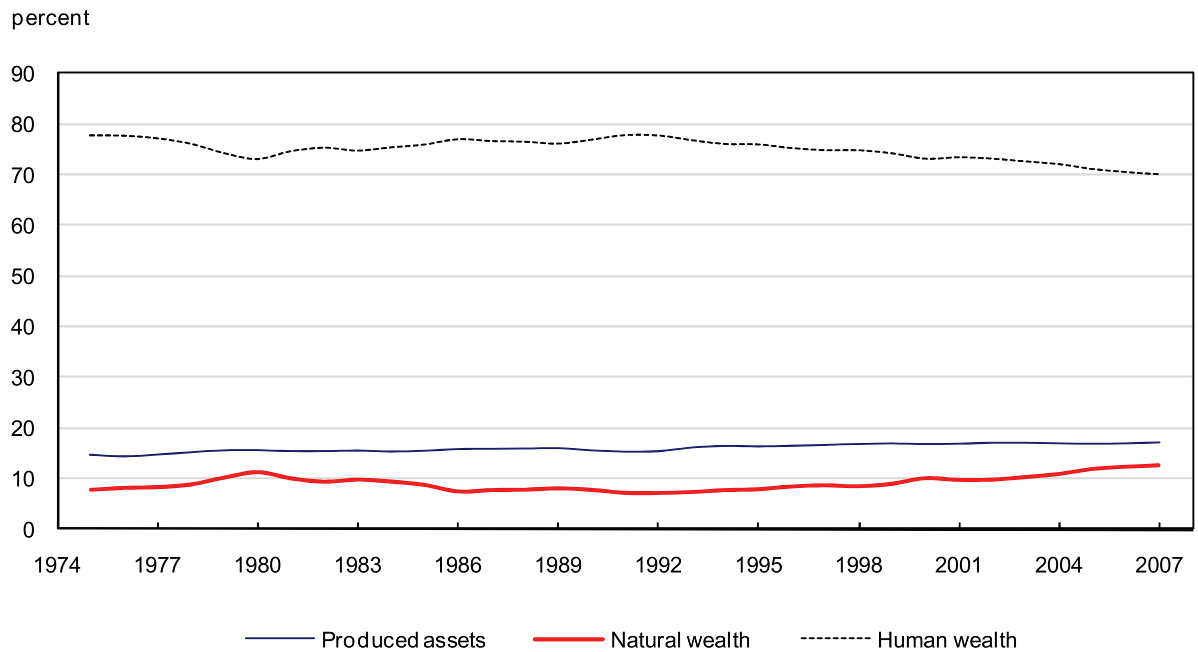
The share of human wealth, produced capital, and natural wealth is plotted in Chart 8. The largest component of total wealth in Canada is human wealth, which is followed by produced capital and natural capital. Human wealth accounted for 70% of total wealth in 2007, while

16. The data on investment and gross domestic product are obtained from the Income and Expenditure Accounts of Canada from Statistics Canada (CANSIM table 380-0017).
17. In the system of national accounts proposed by Jorgenson and Fraumeni, which include the accumulation of human capital, gross domestic product needs to be adjusted in order to include investment in human capital. When this is done, the ratio of human capital investment to the adjusted GDP was 0.55 in 1971. In the system of national accounts proposed by Jorgenson and Fraumeni, which include the accumulation of human capital, gross investment was 0.31 in 2007.

produced capital and natural capital accounted for 17% and 13% of total wealth, respectively, in that year.

Chart 8

The distribution of total wealth in Canada



Over the last forty years, the share of human capital in total wealth has declined slightly while the share of produced capital and natural capital has increased. The share of human capital declined from 78% in 1975 to 70% in 2007, while the share of produced capital increased from 15% to 17% and the share of natural capital grew from 8% to 13%.

The value of human capital exceeds the value of produced capital, but the ratio of human capital relative to produced capital has declined over time. In 2007, the value of human capital was about four times that of produced capital. In 1970, the ratio of human capital to produced capital was 5.7.

For the period 1970 to 2007, the growth of human capital in constant prices was slower than the growth of produced assets: human capital in constant prices increased 1.7% per year, while produced capital in constant prices rose at the rate of 2.8% per year.

7 Conclusion

The CPA consist of a set of integrated data that allow for the development of new statistical products**.** Ongoing debates about the nature of the growth process and the factors behind productivity growth have led to ongoing demands for new information regarding the nature of the inputs that contribute to long-run productivity growth.

This paper has described how the analytical program at Statistics Canada has contributed to the development of products in this area. The CPA build off a set of integrated data sets that start with the IOT but add coherent estimates of primary inputs—labour and capital—from other sources collected by Statistics Canada. These include the *Census of Population*, the *Labour Force Survey*, and special surveys.

This paper describes how the CPA can be used to construct various estimates of productivity in a way that tests both the coherence of the Accounts that are used to produce these estimates and the robustness of the estimates relating to alternate assumptions used in developing the analytical estimates of productivity growth. As an example, it discusses the extent to which using exogenous, as opposed to endogenous, rates of return yields different productivity estimates and at the same time asks whether the differences in the results serve to help us understand the nature of the economic system. The results show that in Canada the endogenous rates of return yielded by the integrated accounts are quite similar to the exogenous rates—but that the productivity growth rates derived from the two approaches differ because the former takes into account an important factor behind growth that the latter ignores. The exogenous approach does not count the reallocation process that redistributes resources from less productive to more productive uses over time.

The paper demonstrates not only how these Accounts can be extended to address ongoing productivity measurement issues but also how they can be used to extend analytical products into new areas.

In the first case, the conventional productivity estimates of the business sector that consider only the contribution made by labour and capital to business sector GDP are expanded in order to also consider the contribution of public infrastructure, which consists primarily of roads. The analysis indicates that almost half of MFP growth between 1961 and 2005 arose from the latter source.

The second example demonstrates how an integrated set of Accounts can be used to extend the boundaries of the productivity program into a different area. The most common measure of business-sector capital considers only machinery and equipment, buildings, and engineering capital, what is commonly referred to as *tangible capital*. Other forms of expenditures that are made by firms also yield assets that have a benefit to that firm of more than one year—and therefore should be classified as a form of investment. However, these other forms of investments have proven more difficult to measure. This research paper makes use of data from the IOT that are at the heart of the CPA and of data on wages and salaries that are integrated into the CPA, in order to provide estimates of several core elements of intangible investments. These are expenditures on science-related inputs to innovations, resources exploration, and advertising. Over the last thirty years, expenditures in these areas have surpassed those of tangible investments in Canada.

Finally, the paper describes a project that extends the CPA into the measurement of the investment that society makes in skills and people. It demonstrates how the data that are brought together on labour inputs in the CPA and related data can be used to measure the amount of investment that a society makes in what is known as *human capital*. Once more, our research confirms that a statistical base can be used to examine this concept from different dimensions—in terms of both inputs and outputs (life-time earnings)—and that these investments produce a capital stock that is large compared to physical or tangible capital.

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