Catalogue no. 15-206-X — No. 031
ISSN 1710-5269
ISBN 978-1-100-22235-6

Research Paper

The Canadian Productivity Review

Multifactor Productivity Measurement at Statistics Canada

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.	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
*	significantly different from reference category ($p < 0.05$)

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May 2013

The Canadian Productivity Review

The Canadian Productivity Review is a series of applied studies that address issues involving the measurement, explanation, and improvement of productivity. Themes covered in the review include, but are not limited to, economic performance, capital formation, labour, prices, environment, trade, and efficiency at both national and provincial levels. The Review publishes empirical research, at different levels of aggregation, based on growth accounting, econometrics, index numbers and mathematical programming. The empirical research illustrates the application of theory and techniques to relevant public policy issues.

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Acknowledgements

We would like to thank Steve Rosenthal of the Bureau of Labor Statistics (BLS) for helpful discussions about the data and methodology used for the BLS multifactor productivity program. We would also like to thank Isabelle Amano, Sharon Kozicki, Jean-Pierre Maynard, Larry Shute, Jianmin Tang, and the participants at a Bank of Canada presentation for their helpful comments and discussions.

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Abstract

This paper describes the evolution of the Multifactor Productivity Program launched at Statistics Canada in 1987 and the improvements made in multifactor productivity measurement since then. The improvements were made in response to developments in the economic literature, better data sources, and the needs of the user community. The paper also summarizes research that uses alternate data and methodologies to assess the accuracy of the Multifactor Productivity Program and to provide insights into areas that traditional international multifactor productivity programs omit. Finally, the paper outlines future directions that are being contemplated to further improve the measurement of productivity at Statistics Canada.

Executive summary

Statistics Canada's productivity program was initiated in the late 1940s in response to demands from the user community to provide background summary statistics that would enable analysts to track Canada's economic progress. It was a result of recommendations from an interdepartmental committee on productivity analysis, who reviewed conceptual and measurement problems, and available data sources.

Initially, the program yielded only an estimate of labour productivity, measured as gross domestic product per worker. Statistics Canada recognized the desirability of including additional inputs and incorporating developments in the literature on productivity measurement. More comprehensive multifactor productivity measures were suggested that combined labour productivity with the productivity of other inputs (for example, capital) used in the production process. Following a feasibility study in the early 1980s, the Multifactor Productivity (MFP) Program was launched in 1987. The first MFP estimate published by Statistics Canada pertained to the 1961-to-1988 period.

Statistics Canada recognized that MFP estimates, unlike labour productivity estimates, require particular assumptions about the production process. In other words, such estimates are more of an analytical product than most other economic statistics. From the outset, the set of assumptions chosen by Statistics Canada for estimating MFP have been made explicit and documented along with the release of MFP measures.

This paper traces the evolution of the MFP Program at Statistics Canada and the improvements in MFP measurement that have been implemented over the past 25 years. Those improvements were in response to developments in the economic literature, the changing nature of the economy, better data sources, and the needs of the user community. Those changes have increased understanding of the process of economic growth in Canada and its relative productivity performance compared with its major trading partner—the United States.

This report also summarizes the research that uses alternate data and methodologies to assess the accuracy of the MFP Program and provide insights into areas that traditional international multifactor productivity programs omit. Finally, possible future directions that are being contemplated to improve the measurement of productivity at Statistics Canada are outlined.

Development of Multifactor Productivity Program at Statistics Canada

Statistics Canada uses the growth accounting framework to measure MFP growth. With this framework, economic growth can be divided into that coming from increases in capital and labour inputs, and the residual from that coming from all other sources—referred to as MFP growth. It can also be used to decompose labour productivity growth into MFP growth plus a term that depends on the growth in capital intensity (capital–labour ratios) as well as changes in the composition (quality) of labour. While the same framework continues to be used to measure MFP growth since the Program began, major improvements have been made to the measurement of capital and labour inputs.

When Statistics Canada first published MFP estimates, a simple summation of assets was used to measure capital stock, and in turn, capital input, and an aggregation of total hours worked was used to measure labour input. In 2002, the MFP measures were re-engineered. The constant quality index of capital and labour input, as proposed by Jorgenson and Griliches (1967), was introduced. The assets used to estimate capital were expanded to include land and inventories in addition to fixed reproducible assets (machinery and equipment and structures). New estimates of depreciation were introduced, which incorporated the rate of decline in asset prices after purchase; previous estimates had been based on expected lengths of lives and arbitrary assumptions about decay functions. These changes brought the Canadian practice in line with U.S. Bureau of Labor Statistics (BLS) estimates, which, in turn, were based on the work of Hulten and Wykoff (1981).

These revisions were consistent with international practice and with the recommendation of the Organisation of Economic Cooperation and Development productivity manual (OECD 2001). They also responded to users' need for greater comparability between MFP estimates for Canada and the United States.

The comprehensive 2002 revision had two major effects. First, it shifted the components of economic growth toward input growth (both labour and capital) and away from MFP growth.

Second, it yielded more methodologically sound comparisons of MFP growth in Canada and the United States. Previous comparisons that included the effect of changes in labour and capital quality in the Canadian MFP estimates found few differences between Canadian and U.S. MFP performance between 1961 and 1997. The revised estimates, which accounted for the growth that occurred from shifting toward higher-quality inputs, showed that MFP growth in the Canadian business sector was lower than that in the United States.

Understanding productivity growth

The accuracy of the MFP Program has been assessed by examining the sensitivity of the estimates to the use of alternate parameters and by using alternate data and methodologies. First, micro-data have been used to gain a better understanding of the dynamics of productivity growth. Second, the neoclassical assumptions underlying growth accounting have been relaxed in order to examine the roles of scale economies and short-run capacity utilization fluctuations in estimates of productivity growth. Third, the asset coverage has been expanded to include assets not normally included in estimates of investment by the regular programs of statistics agencies—items such as intangibles and infrastructure—in order to improve the understanding of the process of economic growth and of the degree to which conventional measures of MFP may have shortcomings. These studies provide users with guidance on whether or how the standard measures should be used.

Future directions for the multifactor productivity program

Statistics Canada's Multifactor Productivity Program has several research goals aimed at improving MFP measures and better understanding economic growth.

First, the Program will conduct research to evaluate how alternative measurement methods affect comparisons of productivity growth between Canada and the United States. Results so far show that the relative MFP growth performance in the two countries is robust to alternative approaches. When capital and MFP are estimated by adopting the BLS procedure to adjust the extreme internal rates of return used to calculate the user cost of capital, by adopting top-down instead of the bottom-up approach, and by using alternative methods for estimating user cost of capital, the results on relative Canada–United States MFP growth are found to be similar to those based on the official estimates in the two statistical agencies.

Over the last 50 years, labour productivity in Canada and the United States grew at about the same rate. Until the early 1980s, Canadian growth exceeded that of the United States. Since then, U.S. labour productivity growth exceeded Canadian growth, a reflection of Canada's lower MFP growth (almost none, compared with about 1% annually in the United States).

Second, the Program will experiment with MFP estimates that include the natural resource capital in the mining sector. It has long been recommended that capital measures include natural resource capital.

Third, the Program will improve the consistency of the industry productivity KLEMS database, as part of the System of National Accounts historical revision. Greater consistency of output, inputs and productivity at the industry level will also improve MFP estimates for the aggregate business sector. The Productivity Accounts will also continue to examine how estimates can be produced for the non-business sector, particularly in health. Finally, the new National Accounts longitudinal micro-data file on firms will be used to better understand the determinants of MFP growth at the firm level as opposed to the industry level.

1 Introduction

Studies associated with the post-WWII effort to rebuild Europe focused on its technological differences from North America and used productivity measures to capture these disparities. In the postwar period before gross domestic product (GDP) estimates were fully developed, it was difficult to make international comparisons of industry. Rostas (1948), for example, focused on physical output per worker. But with the emergence of National Accounts estimates, international comparisons began to make use of real net output at the industry level (Paige and Bombach 1959).

The productivity program of Statistics Canada (then the Dominion Bureau of Statistics) was initiated in the late 1940s to provide background summary statistics that would enable analysts to track Canada's progress. It was a result of recommendations from an interdepartmental committee on productivity analysis (Wells 2001).

Initially, the program's only output was a labour productivity estimate, measured as GDP per worker. Growth in labour productivity was the focus because it was seen to be intrinsically dependent on the technology embedded in the capital applied to the production process, and at the time, statistical measurement of capital was not fully developed. Labour productivity is still important because of its close relationship with changes over time in real labour compensation or real wage rates.

By the mid-1970s, labour productivity growth rates had slowed in Canada and other developed countries. Research aimed at explaining the slowdown focused on technology issues and concepts that went beyond labour productivity. Statistics Canada recognized the desirability of extending its labour productivity program to include additional inputs and developments in the economic literature on productivity measurement (Solow 1957; Jorgenson and Griliches 1967; Diewert 1976). More comprehensive multifactor productivity measures were suggested that combined labour productivity with the productivity of other inputs (for instance, capital).

Following a feasibility study in the early 1980s, the Multifactor Productivity (MFP) Program was launched in 1987. The first MFP estimate published by Statistics Canada pertained to the 1961-to-1988 period.

This report documents the evolution of Statistics Canada's MFP Program. The paper traces the history of the Program, particularly improvements in MFP measurement since its launch over 25 years ago. These improvements were made to reflect developments in the economic literature, the changing nature of the economy, better data sources, and the needs of the user community.

At the outset, Statistics Canada recognized that MFP estimates, unlike labour productivity estimates, require particular assumptions about the production process. That is, MFP estimates are more of an analytical product than are most other economic statistics.

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

$$GDP_t = A(t)F(K_t, L_t). \quad (1)$$

The production model expresses GDP as a function of capital K, labour L, and a production function shift variable $A(t)$. By taking the total derivative with respect to time and assuming competitive markets, the change in GDP with respect to time can be represented:

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

where the elasticities of capital and labour growth ($\omega_{l,t}, \omega_{k,t}$) equal their respective income shares in competitive markets.

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

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

MFP, then, is the increase in GDP beyond that which would be expected from existing technology (derived from the elasticities ω_l and ω_k) based on increases in the factor inputs (labour and capital) that are applied to the production process. The strength of the theory was that it reduced a complex outcome to a simple formula; but the formula's simplicity has been criticized by those who see more complexity in the production process and believe that measuring it is essential for accuracy. The issue that the economics profession faces is whether moving away from the original simplifying assumptions improves the estimates.

Recommendations about how MFP should be calculated differ in the complexity of the methods to use and the underlying assumptions to apply. A statistical agency faces multiple, and sometimes conflicting and changing, recommendations from the research community about procedures that should be used—econometric versus non-parametric techniques, degree of aggregation (most disaggregate industry levels or economy-wide), degree of detail in factor measurement (for different types of labour and investments, whether only the business sector or the total economy should be used).

Statistics Canada has moved forward incrementally, knowing that improvements would be needed at various stages, but that continually changing the estimates would be unhelpful. A statistical agency must determine when a measure is reliable enough to be provided on a regular basis to users, who require both accurate and adequate measurement as well as certification of concept.

From the beginning, the assumptions chosen by Statistics Canada for estimating MFP have been made explicit and documented with each release of MFP measures. These assumptions involved characterizations of the production process as in the above example and of the nature of competition that allows for estimation of the elasticities present in equations 2 and 3. They also entailed increasingly finer levels of detail for the calculation—first, by using more detailed industry data on output, capital, and labour inputs. They also meant the collection of more detailed data on inputs and their prices by collecting wages across employee groups. In that way, inputs could be aggregated at more detailed industry levels to take productivity differences associated with different types of workers into account. Similarly, they involved collecting more detailed data on investments on machinery, equipment and structure assets classes and differences in the user cost of capital at the asset and industry level to allow for aggregation across heterogeneous assets, and thereby, consider productivity differences in assets as well as in labour types.

Section 2 of this report reviews major milestones in the development of the MFP Program at Statistics Canada. Section 3 summarizes research that applies alternate data and methodologies to assess the accuracy of the MFP program and to provide insight into areas that traditional international MFP programs omit. Section 4 summarizes directions that are being contemplated to improve Statistics Canada's measurement of productivity in the future. Section 5 summarizes the paper.

2 Development of the multifactor productivity program at Statistics Canada

Statistics Canada's MFP Program is based on the growth accounting framework developed by Solow (1957) and Jorgenson and Griliches (1967), among others. More recently, the OECD made detailed recommendations about MFP measurement.

Based on this framework, economic growth can be divided into that coming from increases in capital and labour inputs, and the residual coming from all other sources—referred to as MFP growth. Just as early attempts by Rostas (1948) were directed at understanding differences in the nature of the technology behind production, the measure proposed by Solow was regarded as providing a proxy for measuring technical progress. Indeed, original discussions around the MFP measure focused on the nature of the technical progress (Hicks neutral technical progress) that must exist for the first suggested measurement techniques to produce meaningful estimates. While it has been recognized that the residual includes deviations from the underlying assumptions (because economies of scale are presumed away in most variations, MFP will also include the effect of scale economies) and other progress (such as organizational change), its interpretation as mainly measuring technical progress is widespread today.

The growth accounting framework also yields a formula that relates labour productivity and MFP. Growth in labour productivity can be decomposed into MFP growth plus a term that depends on the growth in capital intensity (capital–labour ratios) as well as on changes in the composition (quality) of labour. This can be written in discrete time where all variables are measured in logarithms as:

$$\Delta\left({GDP_t}/{Hours_t} \right) = \Delta MFP_t + \beta_L \Delta\left({L_t}/{Hours_t} \right) + \beta_K \Delta\left({K_t}/{Hours_t} \right), \quad (4)$$

where ${GDP_t}/{Hours_t}$ is the labour productivity; $\beta_L \Delta\left({L_t}/{Hours_t} \right)$ is the contribution from labour composition changes; $\beta_K \Delta\left({K_t}/{Hours_t} \right)$ is the contribution from increased capital intensity (capital deepening); β_L and β_K are the income shares of labour and capital, averaged over the start and end of a period; respectively, and Δ denotes the logarithm difference over a period.

As a result, any changes in assumptions that lead to modifications in estimates of MFP without affecting labour productivity growth (for example, those that change the rate of growth of capital devoted to the production process) must have their counterpart in an offsetting change in the growth in capital intensity. This will affect the interpretation of how the innovation system affects labour productivity and real wages—whether MFP comes from disembodied costless technology rather than increases in the capital available per worker that bring new technology directly into the production process. Both involve taking advantage of technological change in a broad sense; that is, new technologies improve labour productivity because they provide an incentive to increase the amount of capital each worker can employ, and because new technologies may enhance the ability to produce output beyond that which could be produced with these inputs in the past.

2.1 Early estimates

While the same growth accounting framework continues to be used to measure MFP growth at Statistics Canada, since the program began, improvements have been made to the measurement of capital and labour inputs. Those improvements reflect the economic literature, user needs, and better data sources.

When Statistics Canada first published MFP estimates, a simple summation of assets was used to measure capital stock, and, in turn, capital input, and an aggregation of total hours worked across all workers was used to measure labour input.[1] This was similar to the measures of capital and labour inputs used by Solow to measure MFP growth in the United States. Growth rates at the industry level were aggregated using annual wage and capital shares.

Using the decomposition of labour productivity into MFP and increases in capital intensity, Baldwin, Harchaoui and Maynard (2001) reported that MFP growth calculated with this early methodology accounted for 1.2 percentage points of the 2 percentage points of the growth in labour productivity in the Canadian business sector over the 1961-to-1999 period—or 60% of the total. Similar to the large MFP residual that Solow (1957) found for the United States, Statistics Canada's early MFP estimates also showed a large MFP residual for Canada.

Early MFP measurement at Statistics Canada closely followed Solow's framework, which modeled the role of capital and labour in the growth process (Solow 1957). Jorgenson and Griliches (1967) extended that concept to take differences in the types of capital and labour inputs into account, and introduced a constant quality index of both inputs that accounted for the heterogeneity (different productivity) of individual inputs. This shifted the contribution made to economic growth toward increases in capital and labour, and away from residual MFP growth. In the case of labour, increases in labour inputs were higher for more skilled and higher-paid workers, and thus, the growth in the constant quality index was higher than just the growth in hours worked. In the case of capital, increases were higher in assets whose capital costs were higher—primarily because of a higher depreciation component in the user cost of capital formula applied to measure the price of capital services—and the increase in the constant quality index of capital was higher than an aggregate measure that did not consider these differences.

In response, Statistics Canada made efforts to collect data to produce estimates of the growth in capital and hours at finer levels of detail and to correct for differences in the "quality" of the input. Development of a constant quality index of capital and labour input for MFP measurement required data on labour inputs for different types of workers and on investment and capital stock by different asset types. The first set of estimates of Canadian MFP had tried to account for differences in labour quality by aggregating labour growth rates across industries using labour income shares across industries (Durand 1996). With the new, more detailed data at the industry level, the capital input and labour inputs in the aggregate business sector were constructed as the weighted sum of the growth in individual capital and labour inputs across industries using their share of labour income and capital income as weights. (Harchaoui et al., 2001).

2.2 Alternative measures

MFP estimates are affected not only by the level of detail for inputs and industries used in the calculations, but also by the stage in the production chain that is used. At various times, Statistics Canada produced four measures of MFP growth for different analytical purposes, each based on a particular set of assumptions (Durand 1996; Harchaoui et al. 2001).

The first, value-added MFP, relates valued added calculated at the industry level to capital and labour inputs. It is based on a production function that relates value-added to capital and labour

1. When the MFP estimate was first produced, employment was used to measure labour input, because hours worked were not available for all industries. The hours worked measure was first used as measure of labour input in the MFP program in 1994 (Statistics Canada 1994).

input, called value-added production. The measure requires separability of value-added from gross output and the existence of a value-added production function.

The second, gross-output MFP, is based on a production function that relates gross output to capital, labour and intermediate inputs. It has the advantage of accounting for a large input into the production process, which is ignored in the value-added approach (intermediate materials), and it does not need the separability condition at the industry level.

For the third measure, intra-industry MFP, intra-industry sales are netted out from gross output. It is calculated as if all establishments were integrated into a single consolidated establishment. The Bureau of Labor Statistics (BLS) produces a similar measure of intra-industry MFP, called sectoral output MFP, at the industry level.

The fourth, inter-industry MFP, measures productivity gains in all industries involved in a particular commodity, such as automobiles. The concept was introduced by Hulten (1978) and Cas and Rymes (1991). Hulten called the measure "effective" rates of productivity growth. In the early 1990s, Statistics Canada produced inter-industry MFP measures for four final demand categories: personal expenditures, private investment, government expenditures, and domestic exports (Statistics Canada, 1992, 1994).[2] More recently, the concept of inter-industry MFP was used by Oliner et al. (2007) to measure productivity gains in the production of information and communications technologies (ICT) commodities, including semiconductors, computer hardware, software and telecommunications. Fernald (2012) used a variant of inter-industry MFP to estimate MFP growth for investment and consumption goods. Unlike Statistics Canada's inter-industry measure, these recent studies made a simplifying assumption that the production function is the same for all commodities up to a production shift factor.

The four measures yield different estimates of MFP growth (Harchaoui et al. 2001). For individual industries, value-added MFP growth was highest, followed by sector output-based MFP growth, and gross output-based MFP growth.

While Statistics Canada was explicit about the different assumptions underlying each measure, users preferred a single measure. Therefore, Statistics Canada no longer produces all four measures. The agency now produces value-added MFP for the total business sector and major sectors, and value-added and gross-output MFP at the detailed industry level (Baldwin et al. 2007).[3] Other measures are produced on request.

2.3 2002 revisions

Statistics Canada re-engineered its MFP measures in 2002. Previously, labour input at the industry level had been measured as hours worked, and capital input, by capital stock at the industry level. Statistics Canada introduced the constant quality index of capital and labour input, as proposed by Jorgenson and Griliches (1967). These changes are described in Statistics Canada (2002).

The growth in labour and capital inputs was re-estimated to recognize the heterogeneity of capital and labour inputs. This was in keeping with the spirit of the existing method of calculating MFP growth, which weights the growth in capital and labour inputs by their marginal

2. Statistics Canada (1994) reported that MFP growth in the production of private investment was highest among the four final demand categories (personal expenditures, private investment, government expenditures, and domestic exports). Gu and Whewell (2005) showed that productivity growth in the production of exports accelerated after implementation of Free Trade Agreement (FTA) between Canada and the United States compared with the production of other final demand categories and interpreted this as evidence of a positive effect of the FTA on productivity growth in Canada.
3. The sectoral output measure is made available to users when they need MFP estimates for manufacturing industries that are comparable to BLS measures.

productivities. The new method extends the existing method to develop a measure of capital and labour input that takes differences in marginal productivity across different types of capital and labour inputs into account. That is done by calculating the growth in capital and labour input as a weighted sum of the growth in each type of assets or each type of labour using as weights the share of remuneration received for each type of labour or each type of assets in total labour or capital income.

In 2002, the coverage of assets used for estimating capital was expanded to include land and inventories in addition to fixed reproducible assets (machinery and equipment and structures). The asset detail for capital services estimates in the MFP programs was expanded from just machinery and equipment and structures to include 15 types of machinery and equipment, and 13 types of structures and land and inventories, for a total of 30 types of assets.[4]

These revisions were consistent with international practice and with the recommendation of the Organisation for Economic Co-operation and Development productivity manual (OECD 2001). They also responded to users' needs for greater comparability between MFP estimates for Canada and the United States. (Coulombe 2002, Diewert 2002, Rao and Sharpe 2002).[5] For example, Coulombe (2002) recommended that Statistics Canada follow the methodology of the BLS to allow for changes in labour composition, rather than weighting industry growth rates by industry share of wages. The BLS had already introduced constant quality indices of capital and labour inputs in their MFP estimates (Dean and Harper 2001).

In addition, new estimates of depreciation made use of the rate of decline in asset prices after purchase (Gellatly et al. 2001).[6] Previous estimates were based on expected lifespans and arbitrary assumptions about depreciation functions. These changes brought the Canadian practice into line with the BLS estimates, which were based on the work of Hulten and Wykoff (1981).[7]

The 2002 revision had two major effects. First, it shifted the balance of the components of economic growth toward input growth (both labour and capital) and away from MFP growth. The revised estimate of MFP growth in the Canadian business sector for the 1981-to-1999 period was 0.2% per year (Armstrong et al. 2002), well below the earlier estimate of 0.6% per year for the 1979-to-1999 period (Baldwin, Harchaoui, Hosein and Maynard 2001).[8]

To examine the impact of the 2002 revision on the relative importance of capital deepening and MFP growth in overall labour productivity growth, Table 1 compares MFP growth after the 2002 revision based on composition-adjusted capital and labour inputs. Using capital stock and hours worked that are not adjusted for compositional changes, MFP in the Canadian business sector rose 1.4% per year over the 1961-to-2011 period. This estimate suggests that most labour productivity growth came from MFP growth rather than from investment in capital. When capital and labour inputs take the compositional changes into account, MFP growth estimates show that most labour productivity growth comes from increases in capital intensity and from increases in labour composition. When the compositional changes are taken into account, MFP in the Canadian business sector rose only 0.3% per year over the 1961-to-2011 period.

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4. Underlying this were detailed data on investment in some 50 different assets aggregated to this level (Statistics Canada 2007).
5. Those papers are published in an Industry Canada research monograph, "Productivity Issues in Canada," edited by Rao and Sharpe (2002).
6. These estimates were subsequently refined by Statistics Canada (2007).
7. For a comparison of the Canadian and U.S. rates, see Baldwin et al. (2008).
8. The most recent estimate from the MFP program shows that MFP growth was 0.2% per year for the 1981-to-1999 period (the same as reported in Armstrong et al. 2002) and 0.1% for the 1979-to-1999 period that Baldwin, Harchaoui, Hosein and Maynard (2001) examined.

Table 1

Effects of the 2002 revision on sources of labour productivity growth, Canadian business sector, 1961 to 2011

	1961 to 2011	1961 to 1980	1980 to 2011
		percent	
Labour productivity growth	2.0	2.9	1.4
Contribution of capital deepening	1.3	1.7	1.0
Capital stock	0.6	1.0	0.3
Capital compositon	0.7	0.7	0.6
Contribution of labour composition	0.4	0.5	0.4
MFP with adjustment for capital and labour compostion	0.3	0.7	0.0
MFP without adjustment for capital and labour composition	1.4	1.9	1.0

Notes: MFP stands for multifactor productivity. Authors' recalculation from Statistics Canada CANSIM table 383-0021. The contribution of capital input deepening is equal to the contribution of increases in capital stock per hour worked and the contribution of capital compositional changes, which is calculated as changes in capital composition times the share of capital income in nominal value-added. MFP without adjustment for capital and labour composition is equal to MFP with adjustment plus the contribution of capital and labour composition to labour productivity growth.

Source: Statistics Canada, authors' calculations.

The revision yielded more methodologically sound comparisons of MFP growth in Canada and the United States. Previous comparisons, which included the effect of changes in labour and capital quality in the Canadian estimate, found few differences between Canadian and U.S. MFP performance between 1961 and 1997. The revised estimates, which took account of growth that resulted from shifting toward higher-quality inputs, showed lower MFP growth in the Canadian business sector compared with that in the United States: 0.2% versus 0.9% per year for the 1981-to-1999 period (Armstrong et al. 2002). Baldwin and Gu (2009) extended the estimates to the period after 2000 and found that Canada's relatively lower labour productivity growth was due to lower MFP growth.

2.4 Alternative methods of estimating capital services and their effect on estimates

MFP measures are affected by the assumptions made about the production process and the method chosen to estimate capital services. The method that Statistics Canada chose for estimating MFP growth in the 2002 revision was consistent with international practices and OECD recommendations. Nonetheless, the agency also documented the extent to which the official MFP growth estimates are affected by alternative assumptions. Baldwin and Gu (2007a) presented a range of MFP estimates for the Canadian business sector based on alternative estimation methods. In particular, they examined alternate methods of estimating the user cost of capital—with regard to the expected rate of return, depreciation rates, expected capital gains, expectations of price changes and capital gains, and finally, the impact of including tax parameters in the user-cost formulae. They also examined the effect of the top-down and bottom-up approaches for estimating capital input and MFP growth. Some of those issues were re-examined more recently by Diewert and Yu (2012) and Gu (2012).

One of the main topics in recent discussions about MFP measurement for Canada is the top-down versus bottom-up approach for estimating MFP growth in the total business sector. The approaches were developed by Jorgenson (1966) and Jorgenson et al. (2005) to construct aggregate estimates of MFP growth. They are more commonly known as the approaches using the production possibility frontier and direct aggregation across industries.

The approach using the production-possibility frontier assumes that capital and labour receive the same price in all industries, but industries have different production functions that relate value added to capital and labour input. Direct aggregation across industries (Jorgenson et al.

2005) relaxes this assumption, and instead, assumes that the prices of capital, labour, and intermediate inputs differ across industries.

Since inception of the MFP Program, Statistics Canada has used the bottom-up approach to estimate capital input and MFP for the total business sector. A KLEMS database constructed by the BLS and the Bureau of Economic Analysis (BEA) employed the same approach (Fleck et al. 2012). The BLS adopted a similar approach in their estimate of MFP for the U.S. business sector (BLS 2006).

The difference between the estimates produced by the top-down and bottom-up approaches stems from the impact of the reallocation of labour and capital on MFP growth—the bottom-up approach removes the impact of reallocation of inputs across industries from MFP growth, while the top-down approach leaves it in the estimate. Baldwin and Gu (2007a) show that the reallocation effect was large in Canada, which will result in lower MFP growth from the bottom-up estimates compared with the top-down estimates.

3 Understanding productivity growth

The MFP Program has been assessed by examining the sensitivity of the estimates to the use of alternate parameters in the formulae, and by using alternate data and methodologies. First, micro-data have been used to gain a better understating of the dynamics of productivity growth. Second, the neoclassical assumptions underlying the standard growth accounting approach have been relaxed to examine the roles of scale economies and short-run fluctuations in capacity utilization on estimates of productivity growth. Third, asset coverage has been expanded to include assets the regular programs of statistical agencies typically exclude from estimates of investment (for example, intangibles and infrastructure).

3.1 Micro–macro linkages and dynamics of productivity growth

To understand the extent to which the dynamics of reallocation affect aggregate productivity growth, Statistics Canada has conducted empirical studies using data from individual firms. These studies quantify the contribution the reallocation of outputs and inputs across individual producers to measures of overall industry productivity growth. They also compare productivity estimates derived from micro-data with aggregate statistics at the industry level, and thereby, evaluate the quality of the aggregate statistics.

Early studies (Baldwin and Gorecki 1991, Baldwin 1995) and more recent studies (Baldwin and Gu 2006 and 2011, Baldwin and Lafrance 2011) found firm turnover (often due to entry and exit) to be important because new firms provide competition to incumbents. New firms are a source of new products and technologies and make significant contributions to aggregate productivity growth. The reallocation of output and inputs among incumbents from less to more productive producers also contributes to aggregate productivity growth in some industries. As well, these studies found differences in the importance of the competitive process associated with entry and reallocation to overall productivity growth across industries and over time. For example, in the 1990s, the retail sector was characterized by more entry and exit, which made a much larger contribution to aggregate productivity growth, compared with the manufacturing sector. After 2000, the entry and exit process made a smaller contribution to aggregate productivity growth, but the shift from less productive to more productive incumbents became more important. Together, these studies show that reallocation is an important contributor to aggregate industry productivity growth, and that asking how much overall productivity growth comes from reallocation of resources is justified.

These studies often found that organic growth within firms and plants was an important source of productivity growth. But growth accounting and MFP estimation are generally deficient on the causes and the direct relationship to technological change. Therefore, Statistics Canada conducted surveys of technology and innovation and linked the results to administrative data to examine the relationship between technology adoption and productivity growth. These technology and innovation surveys provided a richer picture of growth within individual producers and how it is related to the adoption of advanced technologies. Firm growth is linked to the use of advanced manufacturing technology and ICT, and to investment in innovation and intangible capital (Baldwin and Sabourin 2004, Baldwin and Gu 2004).

3.2 Scale economies and cyclical fluctuation in productivity growth

The MFP measures published by Statistics Canada are based on a growth accounting framework that assumes perfect competition in markets and constant returns to scale in the production function. As well, these MFP measures are not corrected for short-run fluctuations in capacity utilization. Consequently, MFP estimates include a component attributed to technological change that may more correctly be attributed to improvements in efficiency due to exploitation of economies of scale. Similarly, slowdowns in productivity growth may really be due to the development of excess capacity, which reduces efficiency. A number of studies have evaluated and relaxed those assumptions to derive alternative estimates of productivity growth.

Baldwin, Gaudreault and Harchaoui (2001) used econometric techniques to simultaneously estimate MFP and scale economies. They reported that MFP measures based on the assumptions of constant returns to scale and full capacity tend to overestimate technical progress in the Canadian manufacturing sector over time. Baldwin et al. (2012) found that most of the decline in MFP growth in Canadian manufacturing after 2000 was associated with the decline in capacity utilization as a result of slow growth in exports and output in the exporters. Gu and Lafrance (2012) found that both technical progress and scale economies contributed to the post-2000 slowdown in aggregate productivity growth in the Canadian broadcasting and telecommunications industry.

Gu and Wang (2012) developed new ways to correct MFP growth for capacity utilization. Previous empirical studies had relied on imperfect proxies for excess capacity, but little consensus exists on which adjustment procedure is best. Solow (1957) used unemployment rates to adjust both capital and labour to modify the measures of inputs in place to better reflect inputs in use. Jorgenson and Griliches (1967) used an index of electric motor utilization in U.S. manufacturing to adjust capital utilization in the U.S. private economy. Other measures include growth of materials, hours worked per worker, the ratio of energy costs to capital stock, and profit shares.

Gu and Wang (2012) built upon a concept suggested by Berndt and Fuss (1986) that the variation in ex post returns to capital reflects the variation in capacity utilization. Gu and Wang, however, argued that the ex post return to capital should be used to adjust the quantity of capital input rather than the price of capital input, as in Berndt and Fuss (1986). They showed that when the ratio of ex post to ex ante return to capital is used to adjust the quantity of capital input, estimated MFP growth takes the rate of capital utilization into account. Moreover, it loses most of its apparent procyclicality. Future work will consider applying these techniques to provide a capacity-corrected measure of MFP growth.

3.3 Intangible capital and infrastructure capital

The accuracy of MFP estimates depends on the comprehensiveness and the measurement in place in the National Accounts that feed the Productivity Accounts. Two measurement issues have been addressed by background studies at Statistics Canada. The first is the impact of not appropriately classifying some expenditures as investment. The second is omission of public infrastructure capital from capital stock estimates for the business sector.

Recent attention has been paid to the possibility that measurements of investments are inadequate. Specifically, it has been argued that a number of intangible assets have not been appropriately taken into account in measuring the growth of capital. Intangible assets consist of computerized information (software and databases), innovative property (scientific and non-scientific research and development [R&D]), and economic competencies (brand equity, training and organizational capital). The MFP measure published at Statistics Canada and elsewhere includes only a portion of intangible assets—those related to R&D, exploration, and software. Without an empirical study, it is difficult to judge whether inadequate coverage of intangibles has a deleterious effect on the MFP measure, because reclassifying an intermediate expense to an investment affects both measured output and measured capital.

Baldwin et al. (2009, 2012) developed a more extensive measure of intangible capital than is currently used in the National Accounts, and examined the contribution of intangibles to labour productivity growth. They found that investment in intangibles totaled $151 billion in the Canadian business sector in 2008, which represented 13.2% of gross domestic product that year. Investment in intangibles rose much faster than did investment in tangibles, with the ratio of intangible-to-tangible investment increasing from 0.23 in 1976 to 0.66 in 2008. The contribution of intangibles to labour productivity growth in the Canadian business sector was only slightly lower than that of tangibles (Table 2).

Table 2
Intangible capital and labour productivity growth, Canadian business sector, 1976 to 2008

	1976 to 2000	2000 to 2008	2000 to 2008 less 1976 to 2000
		percent	
Including SNA intangibles			
Labour productivity growth	1.5	0.7	-0.8
Contributions			
Capital deepening	1.0	1.1	0.1
Labour composition	0.4	0.3	-0.1
Multifactor productivity growth	0.1	-0.6	-0.8
Including all intangibles			
Labour productivity growth	1.7	0.8	-1.0
Contributions			
Capital deepening	1.3	1.4	0.1
Tangible assets	0.8	0.8	0.0
ICT excluding software	0.3	0.3	-0.1
Non-ICT excluding mineral exploration	0.4	0.5	0.1
Intangible assets	0.5	0.6	0.0
Computerized information	0.1	0.1	0.0
Innovative property	0.2	0.2	0.0
Economic competencies	0.3	0.2	0.0
Labour composition	0.4	0.3	-0.1
Multifactor productivity growth	0.1	-0.8	-0.9

Notes: ICT stands for information and communications technologies. SNA stands for System of National Accounts.
Source: Table 3 in J.R. Baldwin, W. Gu and R. Macdonald, 2012, *Intangible Capital and Productivity Growth in Canada,* Statistics Canada Catalogue no. 15-206-X, no. 29.

Baldwin et al. (2012) found that when investments in intangibles are taken into account, the relative contribution of investment in capital (tangible and intangible) to labour productivity and economic growth increased, while the relative contribution of residual MFP growth decreased

(Table 2). This is consistent with the findings on U.S. economic growth reported by Corrado and Hulten (2012, p. 103) who concluded that "the innovation that has shaped recent economic growth is not an autonomous event that falls like manna from heaven…. Instead, a surge of new ideas (technological or otherwise) is linked to output growth through a complex process of investments in technological expertise, product design, market development, and organizational capability."

The estimates of GDP and labour productivity growth over the 1976-to-2008 period would be about 0.2 percentage points higher if intangibles not currently included as investment in the National Accounts were counted as investment (intangibles other than R&D, software and mineral exploration expense, which currently are capitalized). But inclusion of intangible capital and recalculation of GDP would not increase MFP growth. Rather, for the 2000-to-2008 period, MFP growth would decline an estimated 0.8% per year, compared with the 0.6% per year previously estimated.

The MFP measure published by Statistics Canada considers only the inputs of the business sector and does not take the role of public infrastructure in private sector MFP growth into account. Yet, part of the growth in business sector output may have come from increases in public infrastructure, and therefore, business sector MFP would be overestimated. Using estimates of the impact of infrastructure on business sector output, Gu and Macdonald (2009) examined the importance of public capital in private sector productivity growth. They found that part of the rapid MFP growth in the 1960s and 1970s was due to investment in public infrastructure, thereby explaining part of the productivity slowdown, which has attracted so much attention.

4 Future directions for the Multifactor Productivity Program

The MFP Program of Statistics Canada has several research goals aimed at further improving MFP measures and better understanding economic growth. First, in partnership with major data users, the effect of alternative measurement methods on comparisons of productivity growth between Canada and the United States will be evaluated. Second, the Program will experiment with MFP estimates that include the natural resource capital in the mining sector. Third, as part of the System of National Accounts historical revision, the consistency of the industry productivity KLEMS database will be improved. Greater consistency of output, inputs and productivity at the industry level will also improve MFP estimates for the aggregate business sector. The Productivity Accounts will continue to examine how estimates can be made for the non-business sector, notably, health. Finally, the Productivity Accounts will use the newly developed National Accounts longitudinal micro-data file on firms to investigate determinants of MFP growth at the firm rather than the industry level.

4.1 Relative Canada–United States productivity growth

The 2002 changes to the MFP measures improved the comparability of MFP growth estimates published by Statistics Canada and the BLS in the United States. Using BLS estimates and Canadian estimates derived for purposes of comparability, Baldwin and Gu (2007b) examined growth in labour and multifactor productivity in Canada and the United States from 1961 to 2006. Over the entire period, labour productivity in both countries grew at about the same rate. Canadian growth exceeded that of the United States up to the early 1980s. Thereafter, U.S. labour productivity growth was faster, and the gap widened, particularly after 2000. Baldwin and Gu decomposed labour productivity growth into three components—that arising from increases in capital intensity, that arising from increases in the skill level of the labour force (due to changes in labour composition) and a residual (multifactor productivity growth). The first two (both attributable to investment, one in machinery and structures, the other in training) were more important in Canada. The third (often referred to as technological progress) was more important in the United States.

Table 3 updates these findings with more recent data.[9] Over the 1980-to-2011 period, as a result of lower MFP growth, Canada had lower labour productivity growth in the business sector than did the United States.[10] After 1980, there was no MFP growth in Canada, compared with 0.9% annually in the United States.

Table 3
Sources of labour productivity growth, Canada and United States, 1961 to 2011

	1961 to 2011	1961 to 1980	1980 to 2011
		percent	
Canada			
Labour productivity growth	2.0	2.9	1.4
Contributions			
Capital deepening	1.3	1.7	1.0
ICT capital	0.4	0.2	0.5
Non-ICT capital	0.9	1.5	0.5
Labour composition	0.4	0.5	0.4
Multifactor productivity	0.3	0.7	0.0
United States			
Labour productivity growth	2.3	2.5	2.2
Contributions			
Capital deepening	0.9	0.9	0.9
ICT capital	0.4	0.2	0.6
Non-ICT capital	0.5	0.7	0.3
Labour composition	0.2	0.1	0.3
Multifactor productivity	1.2	1.5	0.9

Notes: ICT stands for information and communications technologies. The U.S. estimates are for the private business sector, which excludes government enterprises; the Canadian estimates are for the business sector. The separate contributions of ICT and non-ICT capital for 2011 are imputed, because the Bureau of Labor Statistics has estimates for ICT and non-ICT capital only up to 2010.
Sources: Statistics Canada; and Bureau of Labor Statistics.

While the Canadian estimates were calculated so as to be broadly similar to those of the BLS, not all aspects of the underlying processes were completely harmonized. Statistics Canada has been careful to provide guidance to users on the magnitude of the changes that would occur if parameters embedded in the Canadian estimates were changed. For instance, Baldwin and Gu (2007a) examined the effect of alternative methods of estimating capital services on MFP growth in the Canadian business sector. Baldwin and Harchaoui (2001) examined the sensitivity of alternative estimation techniques (parametric versus non-parametric approaches), alternative measures of capital input, and revision and imprecision in the data on MFP growth estimates. The MFP research program will continue to examine the impact of alternative approaches on relative Canada–United States MFP growth performance. The rest of this section reports some preliminary results from that exercise.

9. The U.S. result is for the private business sector, which excludes government enterprises that provide goods and services in markets. The BLS provides only estimates of the separate ICT and non-ICT contribution to aggregate labour productivity growth up to 2010. The ICT and non-ICT contribution for 2011 is imputed based on the contribution of overall capital deepening in that year and the relative importance of ICT and non-ICT in the overall capital deepening effect.
10. The BLS estimate is for the private business sector, which excludes government enterprises.

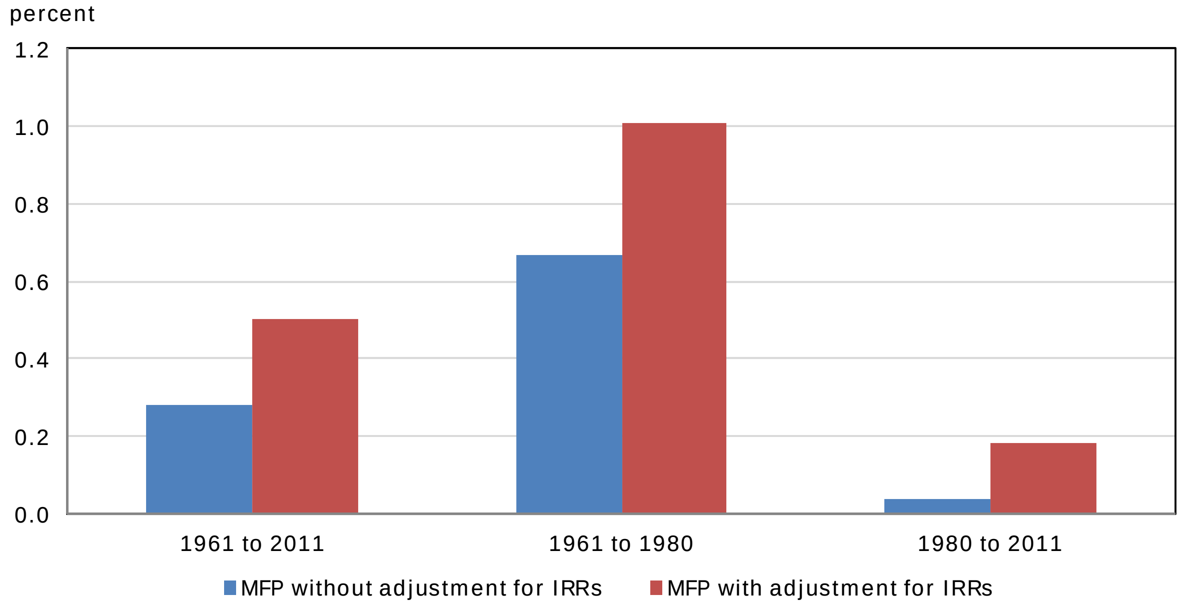
Both Statistics Canada and the BLS used the bottom-up approach to estimate capital input in the aggregate sector. In particular, capital inputs for aggregate sectors were estimated using a three-step procedure (BLS 2006; Baldwin et al. 2007). First, a detailed array of capital stocks was developed for different asset types in various industries. Second, asset-type capital stocks were aggregated for each industry to measure capital input for the industry. Third, industry capital inputs were aggregated to measure sectoral level capital input.

While both Statistics Canada and the BLS used the bottom-up approach to estimate capital input in the total business sector, as noted by Harper et al. (2012), there was one possibly important difference in its implementation. Both countries employed the endogenous rate approach. That is, the rate of return used to estimate the cost of capital was derived endogenously from estimates of surplus derived from the industry accounts and of the capital stock used in estimating the flow of capital services applied to production. But the BLS adopted a modified endogenous rate of return or internal rate of return (IRR) specification for calculating capital input, and replaced unusually high and low endogenous rates of return with an external rate of return in about 45% of the industries. By contrast, Statistics Canada adopted the pure endogenous rate of return specification derived from the above estimation procedure for calculating capital input for all industries.

To examine what the effect would be, the BLS procedure for adjusting IRRs was implemented for the Canadian MFP estimates. The unusually high and low endogenous rates of return were replaced in 53% of the industries by average IRRs in the aggregate services, manufacturing and non-manufacturing goods sector. This slightly altered the allocation of labour productivity growth between the contribution of capital deepening and MFP growth. It lowered capital input growth and increased MFP growth by 0.2% per year in the Canadian business sector over the 1961-to-2011 period (Chart 1). The MFP growth estimates rose from 0.3% per year to 0.5% per year over the period. However, this does not change the overall conclusions about trends in MFP growth in the Canadian business sector over time, or about relative Canada–United States MFP growth.

Chart 1

Annual multifactor productivity growth, Canadian business sector, adjusted for IRRs at industry level, 1961 to 2011



Notes: MFP stands for multifactor productivity. IRR stands for internal rate of return.
Source: Statistics Canada, authors' calculations.

The above comparison is based on the bottom-up approach, but the same comparison can be made using the top-down approach to estimate capital input and MFP growth. For this exercise, GDP data and labour input data for the United States are from the BLS productivity program. The U.S. data on investment in non-residential fixed reproducible assets are from the BEA. To be consistent with the output estimates for the private business sector used by the BLS, the data on investment in rental buildings obtained from the BEA are added to investment. Land and inventory estimates are obtained from the BLS. According to the BEA, total investment is about 5% higher than the investment data for the private business sector that the BLS used to construct capital input. The difference arises partly because the BLS removes non-profit institutions from its estimates, whereas BEA data include them (BLS 2006).

Table 4
Sources of labour productivity growth, Canada and United States, 1961 to 2011 (top-down approach)

	1961 to 2011	1961 to 1980	1980 to 2011
		percent	
Canada			
Labour productivity growth	2.0	2.9	1.4
Contributions			
Capital deepening	1.1	1.2	1.0
ICT capital	0.3	0.2	0.4
Non-ICT capital	0.7	1.1	0.5
Labour composition	0.4	0.5	0.4
Multifactor productivity	0.5	1.1	0.1
United States			
Labour productivity growth	2.3	2.5	2.2
Contributions			
Capital deepening	0.8	0.8	0.8
ICT capital	0.5	0.3	0.6
Non-ICT capital	0.3	0.6	0.2
Labour composition	0.2	0.1	0.3
Multifactor productivity	1.2	1.6	1.0

Note: ICT stands for information and communications technologies.
Sources: Authors' calculations based on data from Statistics Canada; Bureau of Economic Analysis; and Bureau of Labor Statistics.

There are a total of 84 types of assets for the U.S. business sector (42 types of equipment, 32 types of structures, 8 types of rental residential capital, plus land and inventory). Those assets were aggregated to the 30 assets used in the Canadian MFP estimates. To improve comparability, BEA depreciation rates were used to estimate capital stock for Canada. To estimate capital input for both Canada and the United States, tax parameters were excluded because those that the BLS used in their MFP estimates are not available. Table 4 presents the Canada–United States results, based on this set of comparable data.

The top-down approach raised MFP growth estimates in the two countries by 0.1 to 0.2 percentage points over the entire period. It had little effect on the trend in MFP growth or in relative productivity growth, although it had a larger impact in the 1960s and 1970s for Canada, mainly because of the large reallocation effect in the Canadian business sector for that period, previously documented in Baldwin and Gu (2007a) and Gu (2012).[11]

When using an alternative method to estimate the user cost of capital by excluding asset-specific capital gains (Diewert and Yu 2012), alternative depreciation rates, alternative asset details, and alternative asset coverage by excluding land and inventories, the results for relative Canada–United States MFP growth are similar. Excluding asset-specific capital gains in the user cost estimation reduces the contribution to growth of investment in ICT by about 0.1 percentage points in Canada and the United States for the 1961-to-2011 period, and thus, increases the MFP growth estimate by 0.1 percentage points in both countries.

Future research on relative productivity growth in the two countries requires the construction of an industry productivity database for both countries using comparable methods. That can be done in collaboration with partners such as Industry Canada. While the EUKLEMS has made

11. This is consistent with the fact that the early period had much more structural change—based on changes in a dissimilarity index using the KLEMS database. The difference between the top-down and bottom-up approaches in Tables 3 and 4 is partly a result of the reallocation of capital across industries, and partly, the effect of ignoring tax parameters in the top-down estimate.

such comparisons for Canada and the United States, it did not explore whether the relative Canada–United States MFP growth difference is affected by alternative approaches (O'Mahony and Timmer 2009).

4.2 Natural resource capital and productivity growth in the mining sector

Diewert (1980), among others, has recommended that capital measures include machinery and equipment, structures, land, inventories and natural resource capital. All these assets, except natural resource capital, are currently included in the capital input component of Statistics Canada's MFP measure. Recently, Schreyer (2012a) proposed a framework for including natural capital in an extended growth accounting framework.

To improve MFP measurement in the mining, oil and gas sector, three major measurement issues must be addressed. First, in the National Accounts, the rent generated from natural resource capital is included in output, but it is not included as input for measuring productivity in the mining sector. This introduces a bias in the productivity measures for that sector, which can be removed by expanding inputs to include natural resource capital.

Second, in the System of National Accounts, the output of *exploration* is measured by costs of inputs in exploration (European Commission et al. 2009, p. 207). An independent estimate of the output of exploration activities in terms of reserves discovered should be developed to measure the productivity performance of these activities. Preliminary work suggests that this would dramatically increase productivity of the sector.

Third, the quality of natural resource reserves must be accounted for in the productivity measurement in the oil and gas extraction sector. This would make it possible to examine the extent to which the decline in productivity of the mining sector is due to the extraction of low-grade reserves (Baldwin and Gu 2009) and to better profile productivity in this sector.

4.3 Improved consistency in industry productivity database

Some industries have unusually high or low IRRs (Baldwin and Gu 2007a). Diewert (2012) suggests that extreme IRRs affect overall MFP growth in Canada. While results generally show that those IRRs have a minor impact on long-run aggregate MFP growth estimate, it is, nonetheless, desirable to improve the industry productivity accounts to have better productivity estimates at this level.

The research program in the productivity accounts will examine the consistency of inputs, output and productivity estimates at the industry level. Some inconsistencies may result from changes in industry and commodity classifications over time, in data sources, and in what is included in output and inputs. Inconsistency may also arise because capital is allocated to an industry based on purchase and ownership, not on the use of assets, which is more appropriate for productivity measurement using the Solow framework. Work is underway to revise the productivity accounts to generate MFP estimates based on capital applied to production rather than capital owned. Capital investment in Canada is collected from the firm that does the purchasing, and therefore, may differ from the industry in which it is used if it is leased by a firm in one industry (for example, finance) to a firm in another industry (for example, transportation).

The MFP program will also develop a measure of productivity growth for the non-business sector. In Canada, output in the non-business sector is basically measured with inputs and deflated with input costs. This means that productivity estimates are essentially zero. In light of the large size of the non-business sector, current measures provide less-than-complete coverage of economic activity. The research will focus health and education. Preliminary work for the education sector shows relatively low productivity growth (Gu and Wong 2012). Work is underway on the health sector.

4.4 Development and use of firm-level databases

MFP estimates are macro statistics. The top-down MFP estimates focus above the industry level. The bottom-up MFP estimates focus on entire industries and ignore the individual entities, which are referred to as establishments or firms. If the bottom-up estimates yield MFP growth rates that are generally lower than those from the top-down estimates, a relevant question is "will moving to firm-level data further reduce the amount of MFP growth that is measured?"

Therefore, the research program will focus on the development and use of micro-databases at the firm level. The database construction phase of this project is well underway. Several papers have experimented with decompositions used at the industry level and applied them at the firm level within industries (Baldwin et al. 2011, Gu and Lafrance 2012).

These databases open the way to answering a wide range of other questions. They make it possible to tackle the effects of off-shoring and factor substitution. They can be linked to surveys to study how technology adaptation and innovation are associated with firm growth and industry productivity. What was once possible only by indirect inference can now be directly observed.

5 Conclusions

Since its launch in the mid-1980s, Statistics Canada's Multifactor Productivity Program has evolved to reflect developments reported in the economic literature and to meet the needs of data users. The changes increased understanding of the process of economic growth in Canada and the country's productivity performance compared with its major trading partner—the United States. The Program has been complemented by studies that directly examined technological change and its impact on firm growth, and studies of the dynamics of the competitive process, notably, the reallocation of resources, which, in turn, contributes to productivity growth.

The conclusion to be drawn from the MFP statistics is that economic growth in Canada has come mostly from tangible and intangible investments. As the measurement system improved, the residual or unexplained component of economic growth has diminished. Evidence is similar in the United States and other developed countries (Jorgenson 2011, Jorgenson 2009). As Jorgenson (2011, p. 294) noted in his T.W. Schultz lecture, "Replication of established technologies through growth of capital and labour inputs, recently through massive investments in IT hardware and software, explains by far the largest proportion of U.S. economic growth. International productivity comparisons reveal similar patterns for the world economy."

Lower MFP growth in Canada and other countries has raised the issue of how estimated MFP growth is interpreted. When Jorgenson and Griliches (1967) introduced the constant quality index of capital and labour input, which is used by Statistics Canada, the BLS and other statistical agencies, they interpreted their estimated MFP as consistent with Abramovitz's (1962, p. 764) definition of total factor productivity: "… the effect of 'costless advances' in applied technology, managerial efficiency, and industrial organization." Advances in those areas, such as the application of information technologies that require employment of scarce resources, are included in capital and labour inputs. The decline in measured MFP growth that emerged as better measures have been deployed (measures that more fully took the heterogeneous nature of inputs used in the production process into account) means that the "costly" factors captured in the System of National Accounts are responsible for most output growth. Free technical progress may be largely embedded in investments made in human capital and investment in goods and other assets. What remains may be small compared with the former, and is difficult to measure precisely.

As demonstrated in Tables 3 and 4, asking whether it is better to use the top-down or the bottom-up estimates is akin to inquiring about the practical utility of knowing that Canada was 0.9 percentage points versus 0.7 percentage points behind the United States during the 1961-to-2011 period. The differences are within the margin of error in the underlying data. According to the bottom-up approach, 1.7 percentage points of the 2.0 percentage points of the growth in labour productivity over the period (85%) came from placing more capital in workers' hands by increasing capital intensity; the corresponding figure yielded by the top-down approach is 75%.

Questions remain about why the MFP growth estimate from the top-down approach is typically higher than the estimate from the bottom-up approach, and which measure should be used to interpret the impact of technological progress. As Schreyer (2012b) pointed out, the difference between the two estimates partially reflects the effect of reallocation of capital and labour toward industries and firms with higher marginal products of both capital and labour (Jorgenson, et al., 2005). Basu and Fernald (2002) and Fernald (2012) have interpreted the estimate of MFP growth from the top-down approach as reflecting changes in total welfare, and the MFP growth estimates from the bottom-up approach as purified technological progress net of the relocation effect that occurs across industries. The question for practitioners is which approach should be used. If the definition of Basu and Fernald (2002) is accepted, notably, that some reallocation effects, especially from entry and exit, represent the introduction of new technologies, it might be desirable to include the impact of reallocation in measures of aggregate MFP growth and adopt the top-down approach. On the other hand, if the definition of Abramovitz (1962) is adopted, since these reallocations involve the employment of scarce resources used for organizing a firm, these resources should be included in the measurement of capital and labour input, and the fact that they enhance productivity estimates may be a measurement error caused by a failure to capitalize organizational expenses.

This question is similar to that posed when deciding whether to remove the impact of scale effects on estimated MFP growth. It is sometimes argued that this is necessary to obtain a "pure" productivity effect. But many forms of scale (e.g., steel blast furnace) have been exploited only after major technological breakthroughs, and separating out those that are costless contributions from those that relied on technological breakthroughs is difficult. MFP studies can aspire to do no more than separate efficiency gains into various components in preparation for further examination of the reasons (technological or otherwise) behind these components. Pursuit of answers to the latter questions requires further investigation of the innovation process. Statistics Canada has pursued these options making use of technology and innovation surveys, which can offer much richer pictures of the nature of changes occurring in the Canadian economy.

References

Abramovitz, M. 1962. "Economic growth in the United States." *American Economic Review*. Vol. 46. No. 2. p. 5–23.

Armstrong, P., T.M. Harchaoui, C. Jackson, and F. Tarkhani. 2002. "A comparison of economic growth in Canada and the United States in the Information Age, 1981-2000: The importance of investment in information and communications technologies." *Productivity Growth in Canada – 2002*. J.R. Baldwin and T.M. Harchaoui (eds.). Statistics Canada Catalogue no. 15-204-X. Ottawa, Ontario. p. 9–24.

Baldwin, J.R. 1995. *The Dynamics of Industrial Competition*. New York. Cambridge University Press.

Baldwin, J.R., A. Fisher, W.Gu, F.C. Lee, and B. Robidoux. 2008. *Capital Intensity in Canada and the United States, 1987 to 2003.* Statistics Canada Catalogue No. 15-206-X. Ottawa, Ontario. The Canadian Productivity Review. No.18.

Baldwin, J.R., V. Gaudreault, and T.M. Harchaoui. 2001. "Productivity growth in the Canadian manufacturing sector – A departure from the standard framework." *Productivity Growth in Canada.* J.R. Baldwin, D. Beckstead, N. Dhaliwal, R. Durand, V. Gaudreault, T.M. Harchaoui, J. Hosein, M. Kaci, and J.-P. Maynard (eds.). Statistics Canada Catalogue no. 15-204-X. Ottawa, Ontario. p. 107–142

Baldwin, J.R., and P.K. Gorecki.1991. "Entry, exit and productivity growth." *Entry and Market Contestability: An International Comparison*. P.K. Geroski and J. Schwalbach (eds.). Oxford, United Kingdom. Basil Blackwell. p. 244–256.

Baldwin, J.R., and W. Gu. 2004. *Innovation, Survival and Performance of Canadian Manufacturing Plants*. Statistics Canada Catalogue no. 11F0027M. Economic Analysis (EA) Research Paper Series. No. 22.

Baldwin, J.R., and W. Gu. 2006. "Plant turnover and productivity growth in Canadian manufacturing." *Industrial and Corporate Change*. Vol. 5. No. 3. p. 417–465.

Baldwin, J.R., and W. Gu. 2007a. *Multifactor Productivity in Canada: An Evaluation of Alternative Methods of Estimating Capital Services*. Statistics Canada Catalogue no. 15-206-X. Ottawa, Ontario. The Canadian Productivity Review. No. 9.

Baldwin, J.R., and W. Gu. 2007b. *Long-term Productivity Growth in Canada and the United States, 1961-2006.* Statistics Canada Catalogue no. 15-206-X. Ottawa, Ontario. The Canadian Productivity Review. No. 13.

Baldwin, J.R., and W. Gu. 2009. *Productivity Performance in Canada, 1961 to 2008: An Update of Long-term Trends.* Statistics Canada Catalogue no. 15-206-X. Ottawa, Ontario. The Canadian Productivity Review. No. 25.

Baldwin, J.R., and W. Gu. 2011. "Firm dynamics and productivity growth: A comparison of the retail trade and manufacturing sectors." *Industrial and Corporate Change*. Vol. 20. No. 2. p. 367–395.

Baldwin, J.R., W. Gu, A. Lafrance, and R. Macdonald. 2009. *Investment in Intangible Assets in Canada: R&D, Innovation, Brand, and Mining, Oil and Gas Exploration Expenditures*. Statistics Canada Catalogue no. 15-206-X. Ottawa, Ontario. The Canadian Productivity Review. No. 26.

Baldwin, J.R., W. Gu, and R. Macdonald. 2012. *Intangible Capital and Productivity Growth in Canada.* Statistics Canada Catalogue no. 15-206-X. Ottawa, Ontario. The Canadian Productivity Review. No. 29.

Baldwin, J.R., W. Gu, and B. Yan. 2007. *User Guide for Statistics Canada's Annual Multifactor Productivity Program.* Statistics Canada Catalogue No. 15-206–X. Ottawa, Ontario. The Canadian Productivity Review. No. 14.

Baldwin, J.R., W. Gu, and B. Yan. 2011. *Export growth, capacity utilization and productivity growth: Evidence for Canadian manufacturing plants.* Statistics Canada Catalogue No. 11F0027M. Ottawa, Ontario. Economic Analysis (EA) Research Paper Series. No. 75. Forthcoming in the *Review of Income and Wealth*.

Baldwin, J.R., and T.M. Harchaoui. 2001. "The precision of productivity measures." *Productivity Growth in Canada*. J.R. Baldwin, D. Beckstead, N. Dhaliwal, R. Durand, V. Gaudreault, T.M. Harchaoui, J. Hosein, M. Kaci, and J.-P. Maynard (eds.). Statistics Canada Catalogue no. 15-204-X. Ottawa, Ontario. p. 39–50.

Baldwin, J.R., T.M. Harchaoui, J. Hosein, and J.-P. Maynard. 2001. "Productivity, concepts and trends." *Productivity Growth in Canada*. J.R. Baldwin, D. Beckstead, N. Dhaliwal, R. Durand, V. Gaudreault, T.M. Harchaoui, J. Hosein, M. Kaci, and J.-P. Maynard (eds.). Statistics Canada Catalogue no. 15-204-X. Ottawa, Ontario. p. 13–37.

Baldwin, J.R., T.M. Harchaoui, and J.-P. Maynard. 2001. "Productivity growth in Canada and the United States." *Productivity Growth in Canada*. J.R. Baldwin, D. Beckstead, N. Dhaliwal, R. Durand, V. Gaudreault, T.M. Harchaoui, J. Hosein, M. Kaci, and J.-P. Maynard (eds.). Statistics Canada Catalogue no. 15-204-X. Ottawa, Ontario. p. 51–60.

Baldwin, J., and A. Lafrance. 2011. *Firm Turnover and Productivity Growth in Selected Canadian Services Industries, 2000 to 2007*. Statistics Canada Catalogue no. 11F0027M. Ottawa, Ontario. Economic Analysis (EA) Research Paper Series. No. 72.

Baldwin, J., and D. Sabourin. 2004. *The Effect of Changing Technology Use on Plant Performance in the Canadian Manufacturing Sector*. Statistics Canada Catalogue no. 11F0027M. Ottawa, Ontario. Economic Analysis (EA) Research Paper Series. No. 20.

Basu, S., and J. Fernald. 2002. "Aggregate productivity and aggregate technology." *European Economic Review*. Vol. 56. No. 6. p. 963–991.

Berndt, E.R., and M.A. Fuss. 1986. "Productivity measurement with adjustments for variations in capacity utilization and other forms of temporary equilibrium." *Journal of Econometrics*. Vol. 33. No. 1-2. p. 7–29.

Bureau of Labor Statistics (BLS). 2006. *Overview of Capital Inputs for the BLS Multifactor Productivity Measures.* Washington, D.C. Bureau of Labor Statistics.

Cas, A., and T.K. Rymes. 1991. *On Concepts and Measures of Multifactor Productivity in Canada, 1961-1980.* New York. Cambridge University Press.

Coulombe, S. 2002. "The Canada-U.S. productivity growth paradox." *Productivity Issues in Canada*. S. Rao and A. Sharpe (eds.). Calgary, Alberta. University of Calgary Press. Industry Canada Research Paper Series.

Corrado, C.A., and C.R. Hulten. 2012. "How do you measure a 'technological revolution'?" *American Economic Review, Papers and Proceedings*. Vol.100. No. 2. p. 99–104.

Dean, E.R., and M.H. Harper. 2001. "The BLS measurement program." *New Developments in Productivity Analysis, Studies in Income and Wealth.* Vol. 63. C.R. Hulten, E.R. Dean, and M.J. Harper (eds.). Chicago. The University of Chicago Press.

Diewert, W.E. 1976. "Exact and superlative index numbers." *Journal of Econometrics*. Vol. 4. No. 2. p.115–145.

Diewert, W.E. 1980. "Aggregation problem in the measurement of capital." *The Measurement of Capital*. D. Usher (ed.). Chicago. University of Chicago Press.

Diewert, W.E. 2002. "Productivity trends and determinants in Canada." *Productivity Issues in Canada*. S. Rao and A. Sharpe (eds.). Calgary, Alberta. University of Calgary Press. Industry Canada Research Paper Series.

Diewert, E. 2012. "Rejoinder to Gu on 'Estimating Capital Input for Measuring Business Sector Multifactor Productivity Growth in Canada." *International Productivity Monitor.* Vol. 24. Fall.

Diewert, W.E., and E. Yu. 2012. "New estimates of real income and multifactor productivity growth for the Canadian business sector, 1961-2011." *International Productivity Monitor*. Vol. 24 Fall. p. 27–48.

Durand, R. 1996. "Canadian input-output-based multi-factor productivity accounts." *Economic Systems Research*. Vol. 8. No. 4. p. 367–389.

European Commission, International Monetary Fund, Organisation for Economic Co-operation and Development, United Nations, and World Bank. 2009. *System of National Accounts 2008.* New York. United Nations.

Fernald, J. 2012. *A Quarterly, Utilization-Adjusted Series on Total Factor Productivity*. Federal Reserve Bank of San Francisco Working Paper. No. 2012-19.

Fleck S., S. Rosenthal, M. Russell, E.H. Strassner, and L. Usher. 2012. "A prototype BEA/BLS industry-level production account for the United States." *The 2nd World KLEMS Conference*. Harvard University, Cambridge, Massachusetts. August.

Gellatly, G., M. Tanguay, and B. Yan. 2001. "An alternative methodology for estimating economic depreciation: New results using a survival model." *Productivity Growth in Canada – 2002.* J.R. Baldwin and T.M. Harchaoui (eds.). Statistics Canada Catalogue no. 15-204-X. Ottawa, Ontario. p. 25–56.

Gu, W. 2012. "Estimating capital input for measuring business sector multifactor productivity growth in Canada." *International Productivity Monitor.* Vol. 24. Fall.

Gu, W., and A. Lafrance. 2012. "Productivity growth in the Canadian broadcasting and telecommunication sector." *The 32nd International Association of Research on Income and Wealth (IARIW) General Conference*. Boston. August 5–11.

Gu, W., and R. Macdonald. 2009. *The Impact of Public Infrastructure on Canadian Multifactor Productivity Estimates.* Statistics Canada Catalogue no. 15-206-X. Ottawa, Ontario. The Canadian Productivity Review. No. 21.

Gu, W., and W. Wang. 2012. *Productivity Growth and Capacity Utilization.* Statistics Canada catalogue no. 11F0027M. Ottawa, Ontario. Economic Analysis (EA) Research Paper Series. Forthcoming.

Gu, W., and L. Whewell. 2005. "The effect of trade on productivity growth and the demand for skilled workers in Canada." *Economic Systems Research*. Vol. 17. No. 3. p. 279–296.

Gu, W., and A. Wong. 2012. *Measuring the Economic Output of the Education Sector in the National Accounts.* Statistics Canada Catalogue no. 11F0027M. Ottawa, Ontario. Economic Analysis (EA) Research Paper Series. No. 80.

Harchaoui, T.M., M. Kaci, and J.-P. Maynard. 2001. "The Statistics Canada Productivity Program: Concepts and Methods." *Productivity Growth in Canada.* J.R. Baldwin, D. Beckstead, N. Dhaliwal, R. Durand, V. Gaudreault, T.M. Harchaoui, J. Hosein, M. Kaci, and J.-P. Maynard (eds.). Statistics Canada Catalogue no. 15-204-X. Ottawa, Ontario. p. 143–176.

Harper, M.J., A.O. Nakamura, and L. Zhang. 2012. "Difficulties in assessing multifactor productivity for Canada." *International Productivity Monitor*. Vol. 24. Fall.

Hulten, C.R. 1978. "Growth accounting with intermediate inputs." *Review of Economic Studies*. Vol. 45. p. 511–518.

Hulten, C.R., and F.C. Wykoff. 1981. "The Measurement of Economic Depreciation." *Depreciation, Inflation, and the Taxation of Income from Capital.* C.R. Hulten (ed.). Washington, D.C. The Urban Institute Press. p. 81–125.

Jorgenson, D.W. 1966. "Embodiment Hypothesis." *Journal of Political Economy.* Vol. 74. No.1. p. 1–17.

Jorgenson, D.W. (ed.). 2009. *The Economics of Productivity*. Cheltenham, United Kingdom. Edward Elgar Publishing.

Jorgenson, D.W. 2011. "Innovation and productivity growth." *American Journal of Agricultural Economics.* Vol. 92. No. 2. p. 276–296.

Jorgenson, D.W., and Z. Griliches. 1967. "The explanation of productivity change." *Review of Economic Studies*. Vol. 34. No. 3. p. 249–283.

Jorgenson, D.W., M. Ho, and K. Stiroh. 2005. *Information Technology and the American Growth Resurgence*. Cambridge, Massachusetts. The MIT Press.

Oliner, S.D., D.E. Sichel, and K.J. Stiroh. 2007. "Explaining a productive decade." *Brookings Papers on Economic Activity.* Vol. 38, No. 1. p. 81–152.

O'Mahony, M., and M.P. Timmer. 2009. "Output, input and productivity measures at the industry level: the EU KLEMS database." *The Economic Journal*. Vol. 119, No. 538. p. F374–F403.

Organisation for Economic Co-operation and Development (OECD). 2001. *Measuring Productivity: Measurement of Aggregate and Industry-level Productivity Growth.* Paris. OECD.

Paige, D., and G. Bombach. 1959. *A Comparison of National Output and Productivity of the United Kingdom and the United States*. Paris. Organisation for European Economic Co-operation.

Rao S., and A. Sharpe (eds.). 2002. *Productivity Issues in Canada*. Industry Canada Research Paper Series. Calgary, Alberta. University of Calgary Press.

Rostas, L. 1948.*Comparative Productivity in British and American Industry*. Cambridge, England. Cambridge University Press.

Schreyer, P. 2012a. *Productivity Measurement and Natural Assets – An Extended Growth Accounting Approach*. Paris. Organisation for Economic Co-operation and Development. Draft.

Schreyer, P. 2012b. "Comment on 'Estimating Capital Input for Measuring Business Sector Multifactor Productivity Growth in Canada'." *International Productivity Monitor.* Forthcoming.

Solow, R. 1957. "Technical change and the aggregate production function." *Review of Economics and Statistics*. Vol. 39. No. 3. p. 312–320.

Statistics Canada. 1992. *Aggregate Productivity Measures 1990 – 1991*. Statistics Canada Catalogue no. 15-204E. Ottawa, Ontario. Input-Output Division.

Statistics Canada. 1994. *Aggregate Productivity Measures 1994.* Statistics Canada Catalogue no.15-204E. Ottawa, Ontario. Input-Output Division.

Statistics Canada. 2001. *Productivity Growth in Canada.* J.R. Baldwin, D. Beckstead, N. Dhaliwal, R. Durand, V. Gaudreault, T.M. Harchaoui, J. Hosein, M. Kaci, and J.-P. Maynard (eds.). Statistics Canada Catalogue no. 15-204-X. Ottawa, Ontario.

Statistics Canada. 2002. *Productivity Growth in Canada – 2002.* J.R. Baldwin and T.M. Harchaoui (eds.). Statistics Canada Catalogue no. 15-204-X. Ottawa, Ontario.

Statistics Canada. 2007. *Depreciation Rates for the Productivity Accounts*. Statistics Canada Catalogue no. 15-206-X. Ottawa, Ontario. The Canadian Productivity Review. No. 5.

Wells, S. 2001. "Preface." *Productivity Growth in Canada*. J.R. Baldwin, D. Beckstead, N. Dhaliwal, R. Durand, V. Gaudreault, T.M. Harchaoui, J. Hosein, M. Kaci, and J.-P. Maynard (eds.). Statistics Canada Catalogue no. 15-204-X. Ottawa, Ontario. p. 7.