Estimating Capital Input for Measuring Business Sector Multifactor Productivity Growth in Canada: Response to Diewert and Yu

Wulong Gu[1]
Statistics Canada

ABSTRACT

Diewert and Yu estimate that multifactor productivity grew at a 1.0 per cent average annual rate in the Canadian business sector from 1961 to 2011, compared to Statistics Canada's Canadian Productivity Program estimate of 0.3 per cent. The major reason for this difference is that Diewert and Yu find capital services grew at 3.0 per cent per year, compared to Statistics Canada's estimate of 4.8 per cent. This article identifies and discusses the three reasons for this discrepancy. First, while the Canadian Productivity Program aggregates capital services across industries to derive the capital input measure at the level of the business sector, Diewert and Yu use a top-down approach and directly compute capital and labour input series at the business sector level. Second, there are differences in the way the price of capital services is computed. Third, the Canadian Productivity Program bases its capital measures on a more detailed list of assets than Diewert and Yu. Statistics Canada estimates follow international guidelines and practices adopted by other statistical agencies in order to make estimates internationally comparable.

RÉSUMÉ

Diewert et Yu trouvent que la productivité multifactorielle a augmenté de 1.0% par an dans le secteur des entreprise canadien entre 1961 et 2011 par rapport à 0.3% dans le programme canadien de la productivité de Statistiques Canada. La raison majeure pour cette différence est que Diewert et Yu trouvent que les services du capital ont augmenté à un taux annuel de 3.0% par rapport à 4.8% de la Statistique Canada. Cet article identifie et discute les trois raisons pour cet écart. Premièrement, tandis que le programme de la productivité aggrége les services de capital à travers les industries pour obtenir une mesure d'intrants de capital à l'échelle du secteur des affaires, Diewert et Yu se serent d'une approache descendante dans laquelle seuls les éléments d'actif sont agrégés a l'échelle du secteur des entreprises. Deuxièmement, il y a des différences dans la manière de calculer les prix des services du capital. Troisièmement, le programme de la productivité se sert d'un ensemble plus détaille d'éléments d'actif que Diewert et Yu pour estimer les intrants de capital. Le programme de la productivité de Statistique Canada suit les lignes directrices et les pratiques internationales adoptées par d'autres bureaux de la statistique afin que les estimations soient comparables à l'échelle internationale.

1 Wulong Gu works in the Economic Analysis Division at Statistics Canada. He would like to thank Isabelle Amano, John Baldwin, Andrew Sharpe and Jianmin Tang for their comments and Weimin Wang for his assistance. E-mail: Wulong.Gu@statcan.gc.ca,

DIEWERT AND YU (2012) HAVE constructed a new estimate of multifactor productivity growth for the Canadian business sector for the period 1961-2011. Their estimate of multifactor productivity (MFP) increases at an average annual rate of 1.0 per cent per year over that period. This is higher than the estimate from the Canadian Productivity Program of Statistics Canada which has MFP increasing at 0.3 per cent per year.[2]

The growth in multifactor productivity is calculated as the difference between actual output growth and the output growth that would have been expected from the combined capital and labour input growth. Consequently, the difference in the two estimates of MFP growth can arise from differences in output growth, capital input growth and labour input growth. As Diewert and Yu point out, the difference in the two estimates of MFP growth can be almost entirely traced to the difference in capital input growth. Diewert and Yu found that capital input growth increased at 3.0 per cent per year, while the Canadian Productivity Program has capital input increasing at 4.8 per cent per year.

This article examines in more detail the sources of the difference in the estimates of the growth in capital inputs. It concludes that the discrepancy is mainly due to the difference in the approach used for estimating capital input. The approach adopted by the Canadian Productivity Program of Statistics Canada follows international guidelines and practices adopted by other statistical agencies in order to make the estimates internationally comparable. The approach used by Diewert and Yu is not commonly used by other statistical agencies. In particular, their estimate is not comparable with the MFP estimate for the United States produced by the U.S. Bureau of Labor Statistics.

Approaches for Estimating Capital Input

Baldwin and Gu (2007) discussed the various approaches for estimating capital input for measuring multifactor productivity growth. This section follows that discussion. Capital input measures the services that flow from the stock of capital. This differs from the stock of capital sometimes used in productivity measurement because not all forms of capital provide services at the same rate, just as not all hours worked of different workers provide labour services at the same rate. Short-lived assets, such as computers, provide all of their services in the few years before they completely depreciate. Office buildings provide their services over decades. So, in a year, a dollar's worth of computers provides relatively more services than a dollar's worth of a building. Because of differences in capital services between assets, capital input can increase not only because investment increases the amount of the capital stock, but also if investment shifts toward assets — such as equipment — that provide relatively more services per dollar of capital stock.

To address this measurement problem, Jorgenson (1963) and Jorgenson and Griliches (1967) developed the notion of an asset-specific "user cost of capital", sometimes referred to as the rental price of capital. This price of capital can be used to aggregate the heterogeneous assets that make up capital stock to derive a measure of capital input that is used annually in the production process.

The user cost of capital measures the price of using capital in the production process during a period. It can be thought of as the price that a well functioning market would pay 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), a term

2 MFP growth estimates and related variables for the business sector can be obtained from CANSIM Table 383-0021.

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, $p_t - p_{t-1}$). Jorgenson (1963) and Jorgenson and Griliches (1967) show that the formula for the user cost of a unit of capital asset i that costs p_{it} can be estimated as:

$$c_{it} = p_{it-1}r_{it} + p_{it}\delta_i - (p_{it} - p_{it-1})$$
$$= p_{it-1}(r_{it} + (p_{it} - p_{it-1})\delta_i - \pi_{it})$$

The opportunity cost of capital (r_{it}) is often called the nominal rate of return. The difference between the nominal rate of return and the nominal capital gains term ($\pi_{it} = (p_{it} - p_{it-1})/p_{it-1}$) is called the real rate of return.[3]

Total capital input is derived from weighting heterogeneous assets using weights based on the user cost of the asset. Weighting assets by their user cost, which approximates the marginal revenue product in a competitive equilibrium, effectively incorporates differences in the productive contribution of heterogeneous investments as the composition of investment and capital changes. Changes in weighted capital input have two distinct components — changes in the quantity of capital stock, and changes in the composition of the various types of assets with different user costs. This second effect — arising from the change in the importance of different capital types in the aggregate capital stock — is referred to here as the composition effect resulting from changes in the bundle of capital assets.

The increase in the weighted bundle will be higher than in the simple aggregate when assets with higher rental prices (representing higher marginal products) are increasing at faster rates. Weighting explicitly captures substitution between heterogeneous assets in response to changing relative prices, or biased technical change. When this weighting is done for labour, the increase in the weighted aggregate is considerably above the simple sum of hours worked because the labour inputs with higher wage rates (e.g. from more experienced and more educated workers) have been increasing faster than those with lower wage rates. The same phenomenon has been occurring for capital assets with higher user costs of capital.

While Jorgenson's pioneering efforts provided the framework needed to overcome the lack of directly observable and measurable prices of capital services, providing a link between the model's theoretical structure and its application has been more difficult. In particular, there is a considerable difference between the rental price as a theoretical paradigm and its real world empirical application. Schreyer (2009), Diewert, Harrison, and Schreyer (2005), and Baldwin and Gu (2007) discussed the issues that have to be resolved in order to bridge this gap. Those issues include the rate of return, depreciation rates, capital gains, and whether the estimates are derived from direct aggregation across industries with a fully developed industry production accounts (the bottom-up approach) or whether estimates are derived from the aggregate productivity function approach (the top-down approach).

The remainder of this section will discuss those various issues, and highlight the differences between Diewert and Yu and the Canadian Productivity Program. In making various assumptions, the Canadian Productivity Program used a number of criteria. First, the choice should be based on the best available empirical evidence. Second, the choices should reflect best practices by other national statistical agencies so that the Canadian estimates are internationally

3 Alternatively, the real rate of return can be defined as the nominal rate of return minus a general inflation rate such as the CPI as in Diewert, Harrison and Schreyer (2005). A variation of the user cost of capital formula can then be expressed as the difference between the real rate of return (nominal rate of return deflated by CPI) and real capital gains (nominal capital gains deflated by CPI) plus a term for depreciation. This is not used in Diewert and Yu (2012).

comparable. Third, since Canadian productivity performance is often compared to the productivity performance in the United States, the methodology behind the estimates for Canada should be comparable to the largest extent possible to that used by the U.S. Bureau of Labor Statistics (BLS).

Exogenous versus Endogenous Rates of Return

Two main options are available for estimating the rate of return on capital: rates calculated endogenously from the System of National Accounts and rates taken exogenously from observed market rates. The statistical agencies in Canada and Australia use an endogenous rate of return in their productivity accounts, and the BLS essentially uses the endogenous method,[4] while Statistics Netherlands uses an exogenous rate of return. The advantage of using the method that employs endogenous rates is that it provides a fully integrated set of accounts. The surplus is taken directly from the National Accounts that provides the underlying data for the productivity accounts. But the method assumes a fully competitive economy with a production process subject to constant returns to scale. Choosing an exogenous rate of return allows the assumptions of constant returns to scale and competitive markets to be relaxed (Balk, 2010). And it does not require that the assets used completely exhaust capital income, thereby recognizing that some assets may be excluded in existing estimates. But it requires an exogenous rate that reflects individual risk characteristics of the assets that are not easy to obtain.

Diewert and Yu and the Canadian Productivity Program both choose the endogenous rate of return method for estimating capital input. In earlier work, Diewert (2008) used an exogenous rate of return method. The endogenous rate of return method has been chosen by the Canadian Productivity Program so as to provide a set of Productivity Accounts that are integrated into the Industry Accounts of Statistics Canada (e.g. the Input/Output Accounts).

Expected Capital Gains and Real versus Nominal Rates of Return

The capital gains component of the rental price formula has been and continues to be controversial. There is little disagreement that, on theoretical grounds, capital gains should be included in the rental price of capital. A lessor of capital will charge a lower price if a capital gain is expected by the end of the holding period or a higher price if a capital loss is expected. Nevertheless, there is some disquiet among practitioners when it comes to including a term for capital gains and losses. First, there is a concern about whether capital gains should be included in empirical studies, as the volatility in capital gains is not likely to be matched in the short run by changes in the marginal product of capital because of long gestation periods for capital projects.

Second, there is some uncertainty as to whether capital gains should be asset-specific and differ across assets. The answer to the question depends on whether there are ways that holding-period gains arising from differential rates of asset price increases can be harvested, especially for investment goods. This concern revolves around the level of transaction costs that must be incurred in selling investment goods. Because many assets are firm specific, they lose a considerable portion of their value when transferred — especially if they are transferred to alternate uses. If there is no inexpensive way to realize capital gains, the change in asset prices may not provide a

4 It replaces the endogenous rate of return with an external rate in about 40 per cent of its industries when it deems the endogenous rate implausible. Source: BLS website.

very precise estimate of the amount of capital gains that should be included in the user cost of capital.

Diewert and Yu and the Canadian Productivity Program make different choices about the asset-specific capital gains. Diewert and Yu assume that there are no asset-specific capital gains in the user-cost of capital while the Canadian Productivity Program assumes that there are asset-specific capital gains. The choice made by Diewert and Yu comes from their assumption that the real rate of return (defined as nominal rate of return minus nominal capital gains) is equalized across assets for applying the endogenous rate of return method for estimating capital input. The choice made by the Canadian Productivity Program stems from the assumption that the nominal rate of return is equalized across assets when applying the endogenous rate of return method.

The Canadian Productivity Program of Statistics Canada includes asset-specific capital gains and assumes that the nominal rate of return is equalized across assets. This is a common practice adopted by other statistical agencies including the U.S. Bureau of Labor Statistics and the Australia Bureau of Statistics. The practice has been adopted by a major international initiative EU-KLEMS that attempts to harmonize capital input and multifactor productivity estimates across European Union countries, Canada, the United States and a number of other non-EU countries (Timmer *et al.*, 2007 and 2011). The choice has also been adopted by the pioneering work of Jorgenson and his co-authors in developing the growth accounts for the United States and other major developed countries including Canada (Jorgenson and Fraumeni, 1987; Jorgensen, Ho and Stiroh, 2005).

Bottom-up versus Top-down Approach

Aggregate capital input for the total business sector can be estimated using bottom-up or top-down approaches. The bottom-up approach or the direct aggregation across industries involves the aggregation of various asset types within each industry to estimate industry capital services, and the aggregation of capital services across industries to derive aggregate capital input in the total business sector. The top-down approach or the aggregation production approach involves the aggregation of various asset types at the total business sector to derive aggregate capital input.

Jorgenson *et al.* (2005) presented those two alternative methods for estimating capital input and multifactor productivity at the aggregate level and discussed various assumptions underlying those two approaches. They conclude that the most restrictive approach is the aggregate production function or the top-down approach, which imposes highly restrictive and implausible assumptions about the relative prices and mobility of the primary factors of production, capital and labour. Jorgenson, Gollop, and Fraumeni (1987) show the aggregation of heterogeneous types of capital and labour must be the same across industries, and each type of capital and labour must command the same price in each industry. Under these assumptions, the aggregate production function yields a valid representation of the underlying industry-level production structure.

The alternative approach is a direct aggregation across industries or bottom-up approach, which relaxes all of the restrictions on inputs across industries. Measures of industry output, input, and productivity growth are weighted by the relative size of the industry and summed across all industries.[5] This approach makes no

5 For capital inputs the weights are the share of nominal capital income. For labour, the weights are the share of labour income. For output, the weights are for share of nominal value-added. For discussion of this issue, see Jorgenson (2012).

assumption about common prices of outputs or inputs across industries and treats the aggregate economy as a weighted average of the component industries.

More specifically, the bottom-up approach allows for differences in the user cost of capital of an asset and the rate of return across industries. In contrast, the top-down approach assumes the user cost of capital of an asset and the rate of return is the same across industries.

Baldwin and Gu (2007) found that there is a large variation in the rate of return and the user cost of capital across industries. Those large variations are also found in EU-KLEMS. Baldwin and Gu (2007) found that differences in the rate of return across industries can be significant and that capital tends to move towards those industries that earn relatively higher rates of return. These differences in the rate of return to capital may reflect barriers to mobility of capital across industries and indicate that adjustments that bring rates of return together do not happen quickly. In this case, a bottom-up approach should be used for estimating aggregate capital input using different rates of return across industries.

The top-down approach for estimating aggregate capital input would be justified if markets operated quickly and capital earned approximately the same rate of return across industries. In this case, the observed difference in earned rates of return across industries would reflect random measurement errors in investment, capital stock and capital income. The use of a common rate of return and common user cost of capital would reduce measurement errors in capital services estimates that would otherwise be present in the underlying data.

The difference between the estimates from the bottom-up and top-down approaches reflects the effect of the reallocation of capital services across industries. This effect is often found to be positive as capital tends to shift towards those industries with relatively higher rates of return, higher user cost of capital, and implicitly higher marginal products of capital.

Diewert and Yu used the top-down approach for estimating aggregate capital input in the total business sector. The Canadian Productivity Program uses the bottom-up approach for estimating aggregate capital input and is consistent with the empirical evidence that there are considerable differences in the rate of returns across Canadian industries.

Asset Classification

Aggregate capital input is derived from weighting heterogeneous assets using the user cost of capital as weights to reflect differences in the productive contribution of different assets. Ideally, the assets with a similar user cost of capital (e.g. similar depreciation rates and similar capital gains) should be grouped together. In practice, the asset classification used for estimating capital input is mainly determined by data availability. Diewert and Yu (2012) estimate capital input from 14 types of reproducible assets (machinery and equipment, and structures) plus land and inventory. The Canadian Productivity Program estimates capital input using 28 types of reproducible assets (15 types of machinery and equipment, and 13 types of structures) plus land and inventories.

The choice of different asset classifications may yield different estimates of capital input if individual assets within a broad asset group have different growth rates and different user costs of capital arising from the difference in depreciation rates and capital gains. The capital input estimate from a more detailed asset classification will grow faster if assets in a broad asset grouping with higher user costs increase faster than those with lower user costs.

An Overview of Differences

To sum up, Diewert and Yu and the Canadian Productivity Program used different approaches for estimating aggregate capital input in the Canadian business sector. The approach chosen by the Canadian Productivity Program is to use as detailed an asset and industry classification as possible to reflect differences across industries and assets and methods that reflects international guideline and practices adopted by other statistical agencies.

There are thus three main differences when it comes to estimating aggregate capital input between Diewert and Yu and the Canadian Productivity Program.

- the Canadian Productivity Program uses the bottom-up approach for estimating aggregate capital input, while Diewert and Yu uses the top-down approach.
- the Canadian Productivity Program assumes that the nominal rate of return is equalized across assets and the user cost of capital includes asset-specific capital gains when using the endogenous rate of return method for estimating capital input. In contrast, Diewert and Yu assume that the real rate of return is equalized across assets and the user cost of capital does not include asset-specific capital gains.
- the Canadian Productivity Program estimates capital input from a more detailed list of assets than Diewert and Yu.

In addition to those three main differences, there are a number of other differences. As shown in the next section, those differences are found to have little effect on aggregate capital input estimates. First, the estimate of land in constant dollars differs. Diewert and Yu assume that the volume of land is constant. The Canadian Productivity Program set the real value of land equal to an estimate of total area of the dependable agriculture land for cultivation and total area of urban land.

Second, there are some differences in depreciation rates. Diewert and Yu and the Canadian Productivity Program both use depreciation rates that are estimated in recent studies employing used asset prices that provide new empirical evidence on the depreciation rate for various types of assets in Canada (Statistics Canada, 2008). Those new depreciation rates differ from those used in early capital stock estimates. But there are some differences between Diewert and Yu and the Canadian Productivity Program. The Canadian Productivity Program has applied those depreciation rates to estimate capital stock over time.[6] In contrast, Diewert and Yu allowed depreciation rates to vary over time and introduced the new depreciation rates that are from Statistics Canada (2008) gradually into their capital stock estimates.[7]

In addition, the Canadian Productivity Program provides a more comprehensive treatment of tax provisions in estimating the user cost of capital. It takes into account the effect of corporate income tax rates and capital consumption allowance on the estimated user cost of capital. The coverage of the business sector differs between the Canadian Productivity Program and Diewert and Yu. The Canadian Productivity Program defines the business sector to include the rental housing sector, while Diewert and Yu do not.

6 The U.S. Bureau of Labor Statistics adopts a similar approach and assumes the depreciation rates do not change over time for almost all assets.

7 The Productivity Accounts make use of depreciation rates that can be estimated from used asset prices that are available after 1987 and assumes these depreciation rates for earlier periods. There are no estimates of depreciation rates from used asset prices for earlier periods. There are arbitrary estimates derived from a set of tax related sources for previous periods. The Productivity Program considered them sufficiently unreliable as not to use them for the historical period. These are the estimates that Diewert and Yu employ for the earlier period.

Table 1
Reconciling Aggregate Capital Input Growth between Diewert and Yu and the Canadian Productivity Program
(average annual rate of change)

	1961-2011	1961-1980	1980-2011
Canadian Productivity Program (bottom-up, variable land, equal nominal rates, 28 reproducible assets)	4.8	6.6	3.7
Canadian Productivity Program modified to adopt			
top-down approach	4.0	5.4	3.2
plus constant land	4.0	5.5	3.1
plus equal real rates of return across assets	3.6	4.8	2.8
plus 14 reproducible assets	3.2	4.0	2.7
Diewert and Yu (2012)	3.0	4.2	2.3

Sources of Difference in Capital Input Estimates between Diewert and Yu and the Canadian Productivity Program

In this section, the variation between aggregate capital input estimates from the Canadian Productivity Program and Diewert and Yu is traced to various differences in the approaches used to estimate capital input. The features of the method used by the Canadian Productivity Program for estimating aggregate capital input include: bottom-up approach; variable land; equalized nominal rates of returns across assets; and aggregation over 28 reproducible assets plus land and inventory stock. The method used by Diewert and Yu includes: top-down approach; constant land; equalized real rates of returns across assets; and aggregation over 14 reproducible assets plus land and inventory stock.

To examine the effect of the differences across these areas on the estimate of capital input, the data on investment and capital stock for 28 reproducible assets plus land and inventory at a detail level of industry aggregation for estimating capital input in Statistics Canada's productivity program are used.[8] The section starts with the approach used in the Canadian Productivity Program and estimates aggregate capital input from the bottom-up approach, variable land, equalized nominal rates of returns across assets, and aggregation over 28 reproducible assets. It then re-estimates aggregate capital input in the Canadian Productivity Program to reflect the assumptions used by Diewert and Yu. A comparison of the two capital input estimates between those estimates captures the effect of the choice in each of those areas on the estimate of growth in capital inputs.

Table 1 presents the average annual growth of capital input for the Canadian business sector over the period 1961 to 2011 under alternative assumptions.

The estimate from the Canadian Productivity Program has found capital input increasing at 4.8 per cent per year in the Canadian business sector over the period 1961 to 2011. When the top-down approach as in Diewert and Yu is used, aggregate capital input increased at 4.0 per cent per year over the same period. The difference in the two estimates reflects the effect of reallocation of capital across industries. This result suggests that the effect of reallocation on capital input growth across industries is large. An earlier study (Baldwin and Gu, 2007) found a similar large effect of reallocation across industries.

When the volume of land is assumed constant as in Diewert and Yu, aggregate capital input growth changes little. Next the real rate of return is assumed to be equalized across assets and capital gains are excluded as in Diewert and Yu. This lowers the annual capital input growth estimates. The difference in capital input growth from equalizing nominal rate of return versus real rate of return across assets is due to the rapid growth of high-tech capital assets such as computers and commu-

8 The data at a more aggregate level of assets and industries are published in CANSIM Table 383-0025.

nication equipment. Those assets have slow rates of price increase or even declines in prices, which results in little or negative capital gains. Assuming equal nominal rate of return and including capital gains give rise to relatively higher user costs for those assets than assuming equal real rates of return and excluding capital gains. As a result, growth in capital input from equalizing nominal rates in the Canadian Productivity Accounts is higher than the estimate from equalizing real rates in Diewert and Yu.

Finally, we aggregate investment and capital stock from 28 to 14 reproducible assets, and re-estimate aggregate capital input from 14 reproducible assets plus land and inventory stock as in Diewert and Yu. This is also found to lower capital input growth as shown in Table 1.

Table 1 also presents the estimate of capital input growth from Diewert and Yu. When we adopt the approach used by Diewert and Yu, we essentially replicate their estimates. The remaining small differences come from additional differences between the Canadian Productivity Program and Diewert and Yu, which include differences in depreciation rates, the coverage of the business sector, and treatment of tax parameters.

Table 2 uses the estimates from Table 1 and traces the difference in capital input growth between the Canadian Productivity Program and Diewert and Yu to the differences in the approaches. The capital input growth from the Canadian Productivity Program was higher than that in Diewert and Yu by 1.8 percentage points over the 1961-2011 period. The difference is almost entirely accounted for by three main differences in the two approaches: bottom-up versus top-down approaches (0.8 percentage points); equalizing nominal versus equalizing real rates of returns across assets (0.5 points), and 28 versus 14 types of reproducible assets (0.4 points).

Table 2
Sources of Differences in Capital Input Growth between Diewert and Yu and the Canadian Productivity Program
(percentage points per year)

	1961-2011	1961-1980	1980-2011
CPA minus Diewert and Yu (2012)	1.8	2.4	1.5
Accounted for by:			
Bottom-up vs. top-down approach	0.8	1.2	0.6
Variable land vs. constant land	0.0	-0.1	0.1
Equal nominal vs. equal real rates of return across assets	0.5	0.7	0.3
28 vs. 14 reproducible assets	0.4	0.8	0.1
Unexplained	0.2	-0.2	0.4

There is a residual 0.2 percentage points difference between the two estimates. Our preliminary analysis suggests that the remaining difference is mainly due to difference in the depreciation rates used. The Canadian Productivity Program sets depreciation rates to be constant over time as is done by the U.S. Bureau of Labor Statistics so as to provide comparable multifactor productivity estimate to the United States. In contrast, the estimate used by Diewert and Yu assumes that depreciation rates vary over time.

A major international initiative EU-KLEMS has developed comparable estimates of capital input, labour input and multifactor productivity growth at both the aggregate level and detailed industry level for EU countries, Canada, United States, and a number of other non-EU countries. Similar to the Canadian Productivity Program, the EU-KLEMS has also used the bottom-up approach and included asset-specific capital gains for estimating aggregate capital input (Timmer *et al.*, 2007 and Jorgenson, 2012). EUKLEMS shows lower multifactor productivity growth performance in Canada relative to the United States as does the official data from the two statistical agencies in the two countries (Gu, 2008).

Statistics Canada's productivity program has also investigated the nature of aberrant observations in the underlying KLEMS industry database that produce the rates of return (Macdonald, 2007). Such observations can occur for several reasons. First, changes in classification and methodology can lead to discontinuities over time. Second, disaggregation into finer industry classifications produces data where coherency may be of lower quality. Using these methods, the rates of return in the underlying industry data were smoothed and a number of industries where average levels were unreasonably high or low were replaced with more aggregate sectoral averages. This reduces the difference between the top-down and bottom-up approaches by about half of the 0.8 percentage points reported in column 1 of Table 2.[9]

Multifactor productivity growth estimates are designed to measure the increase in output that is produced beyond that expected from the increase in inputs that were applied to production. Accurate estimates of the latter require estimates of the differences in the productivity contribution (the marginal productivity) of inputs. When inputs are heterogeneous, failure to reflect differences in the productive contribution of different assets will tend to overestimate MFP when inputs with higher marinal productivity such as educated workers and information and communication technology assets have been growing fastest. Failure to capture differences across industries will do the same when the growing industries also have higher marginal productivity. When these differences are not taken into account, MFP estimates will tend to be higher because the MFP estimate will include the effect of these differences.

The differences in the estimates of Statistics Canada's Productivity Program and those of Diewert and Yu arise because the former allow for more differences in the marginal productivity of assets across industries. This partially comes from considering a finer level of asset detail, which when combined with the differences in the user cost of capital increases capital input growth and reduces MFP growth relative to estimates that use less asset detail.

The differences between the two estimates shed light on one of the causes of economic growth that we have previously discussed (Baldwin and Gu, 2007). Output growth does not just come from disembodied technical progress. It also comes from applying more of the types of inputs — skilled labour and rapidly depreciating high tech equipment that are more productive than other inputs. Estimates of MFP that do not take these heterogeneous differences into account are higher because they allocate the impact of this shift in the composition of inputs to MFP growth. The Statistics Canada Productivity Accounts on both the labour and capital side are built from detailed micro data. As such, they enable a large amount of industry and asset detail to be considered in the estimation process. And they show that if this were not used, the estimates of the amount of disembodied technical change, that is MFP growth, would be higher (Baldwin and Gu, 2007).

The question is: what is the correct level of asset and industry detail that should be used? Statistics Canada has chosen to work at a particular level — one that is believed to be supported by the quality of the data and follows international guidelines and practices adopted by other statistical agencies. And in doing so, it is recognized that the data at this level will contain measurement errors. But detailed studies of the differences in the results of working at different levels have been provided to the user community (Baldwin and Gu, 2007). There will, of course, be legitimate differences of opinion on the

9 This is also consistent with the difference that Jorgenson, Ho and Samuels (2012) report for the United States.

appropriateness of the levels at which the analysis should be carried out. The Diewert and Yu results provide readers with additional information that can be used to evaluate the sensitivity of the estimates to alternate assumptions. Having a good idea as to what differences are made by alternate assumptions of how the world operates is one way in which such information can be provided to the user community.[10]

Conclusion

All multifactor productivity programs are analytical in nature. As with other National Accounts summary statistics, they aggregate a large amount of data from different sources to provide summary statistics that attempt to shed light on a particular phenomenon. MFP estimates also require an underlying model of the production process and assumptions about how certain concepts can be measured.

Professional analysts will often recommend different ways to approach the measurement of MFP. Statisticians who are tasked with producing MFP estimates must choose amongst alternate proposed solutions. Statistics Canada has examined the alternatives proposed for the estimation of MFP and chosen a particular set. It has been transparent in doing so. It provides detailed documentation on the methodology used (Baldwin, Gu and Yan 2007). It has discussed the impact of using alternate assumptions. For example, Statistics Canada (2007) discusses the sensitivity of the use of different methods for estimating depreciation from used asset prices on the growth rates of capital and on the estimates of MFP. Baldwin and Gu (2007b) discuss the effects on MFP of estimating the impact of capital gains and using different ways to calculate the growth in capital services— the topic that is raised in the paper of Diewert and Yu. This study also investigated the differences between the top-down approach for the entire business sector and the bottom-up approach using an aggregate set of industries (36 industries at the M level of the Input/Output tables) and reported the differences in the rate of capital growth as 0.6 percentage points for the period 1961-2001. It was pointed out that endogenous rates of return at this level were more variable than the exogenous rate. However, the endogenous rate does not lead to an increase in the volatility of the estimated MFP rate relative to the exogenous rate.

Studies such as those noted above are provided to give guidance to users of the aggregate statistics as to the range within which the aggregate MFP estimates fall when alternate assumptions are used (see also Baldwin and Harchaoui (2002)). And testing the reasonableness of the alternate assumptions has occurred both by examining these assumptions, subjecting them to the scrutiny of Statistics Canada's Advisory Committee, and examining other evidence that corroborates differences in the outcomes produced by the alternative assumptions. For example, the difference between the bottom-up and top-down approaches comes partly from the effect of reallocation. Papers that have examined the impact of reallocation on aggregate industry productivity growth (e.g. Baldwin and Lafrance 2011) using micro level firm data have found that it is large. Work is constantly ongoing looking for ways of improving the program to shed light on the factors behind economic growth.

For example, the accuracy of traditional MFP estimates also depends upon the comprehensive of assets that are considered. Traditionally, official estimates do not take into account the effect of government infrastructure. Macdonald (2008) investigates the impact of public infrastructure on business-

10 For more information on the effect of alternate assumptions on MFP estimates, see Baldwin and Gu (2007).

sector production and Baldwin, Gu and Macdonald (2012) show that the incorporation of this effect would cause traditional estimates of MFP to change by a significant amount. Similar issues arise from the emerging importance of investments in intangible assets (intellectual capital) as a complement to machinery and equipment and structures. Baldwin, Gu, Lafrance and Macdonald (2009) provide estimates of the magnitude of expenditures on intangibles and Baldwin, Gu and Macdonald (2012) investigate how their inclusion would affect the traditional measures of MFP. Baldwin, Gu and Yan (2011) explore how traditional approaches to MFP estimation can be modified to take into account periods of over capacity and how this affects estimates of business sector MFP.

Statistics Canada has chosen to design its estimates around what it sees as best practice elsewhere so that there is broad comparability with other countries-so that cross country comparisons can be made by the research community. But there remain differences that are sometimes important for specific studies. The productivity program has therefore provided studies that adjust remaining differences to facilitate cross country comparisons (Baldwin, Maynard et al., 2005, Baldwin, Gu and Yan, 2008).

Statistics Canada has worked with users from other departments (Finance, Industry, Bank of Canada) who have accessed the underlying confidential data bases to investigate specific issues that have been or relevance to them (e. g. Baldwin, Fisher, Gu, Lee and Robidoux 2008). More recently, Statistics Canada has made all of the data on CANSIM free and the productivity accounts has added to its holdings thereby-providing a KLEMS data base at the industry level covering indices of outputs, labour inputs, capital service growth and materials inputs. We have been adding additional data at the request of users and will continue to do so where it is possible to so without violating the confidentiality provisions of the Statistics Act.

Statistics Canada is constrained by the Statistics Act on the level of detail that can be made public. In a small economy such as Canada, this places greater constraints than for other statistical agencies like the BLS where there are far more firms within an industry than is the case for Canada. As is the custom with the National Accounts, data in the Productivity Accounts is constructed at detailed industry levels that are sometimes confidential under the Statistics Act and then aggregated upwards to levels that can be published.

In keeping with the agency's commitment to providing maximum use of data that has been collected with public funds, while respecting the law on confidentiality, Statistics Canada has established the Canadian Centre for Data Development and Economic Research (CDER) where accredited researchers can access confidential business data under controlled conditions that maintain confidentiality and respect the sensitivity of the data. CDER has already provided access to the federal research community that has allowed them to investigate important issues related to productivity. It is now possible for an extended research community to use these data to answer the type of questions posed in the articles within this issue of the *International Productivity Monitor*.

References

Baldwin, J.R., and J. Dixon. (2008) "Infrastructure Capital: What Is It? Where Is It? How Much of It Is There?" Catalogue No. 15-206-XIE, T*he Canadian Productivity Review*, No. 16 (Ottawa: Statistics Canada).

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

Baldwin, J.R and W. Gu (2007) "Multifactor Productivity in Canada: An Evaluation of Alternative Methods of Estimating Capital Service," Catalogue No. 15-206–XIE–No. 009, *The Canadian Productivity Review* (Ottawa: Statistics Canada).

Baldwin, J.R., and W. Gu. (2007b) "Investment and Long-term Productivity Growth in the Canadian Business Sector, 1961 to 2002," Catalogue No. 15-206-XIE, T*he Canadian Productivity Review*, No. 6 (Ottawa: Statistics Canada).

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," Catalogue No. 15-206-X, *The Canadian Productivity Review*, No. 26 (Ottawa: Statistics Canada).

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

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

Baldwin, J.R., W. Gu, and B. Yan. (2008) "Relative Multifactor Productivity Levels in Canada and the United States: A Sectoral Analysis," Catalogue No. 15-206-X, *The Canadian Productivity Review.* No. 19 (Ottawa: Statistics Canada).

Baldwin, J.R., W. Gu, and B. Yan. (2011) "Export Growth, Capacity Utilization and Productivity Growth: Evidence for Canadian Manufacturing Plants," Catalogue No. 11F0027MIE, *Economic Analysis (EA) Research Paper Series.* No. 75.

Baldwin, J.R. and T. Harchaoui (2002) "The precision of productivity measures," in J.R. Baldwin and T. Harchaoui (eds.) *Productivity Growth in Canada*, Catalogue no. 15-204XPE (Ottawa: Statistics Canada).

Baldwin, J.R., J.P. Maynard, Marc Tanguay, Fanny Wong and Beiling Yan (2005) "A comparison of Canadian and U.S. productivity levels: an exploration of measurement issues," Economic Analysis (EA) Research Paper Series, Catalogue no. 11F0027MIE2005028 (Ottawa: Statistics Canada).

Balk, B.M. (2010) "An Assumption-free Framework for Measuring Productivity Change," *Review of Income and Wealth*, Vol. 56, Special Issue 1, pp. S224-S256.

Diewert, W.E. (2008) "Changes in the Terms of Trade and Canada's Productivity Performance," Discussion Paper 08-05, Department of Economics, University of British Columbia.

Diewert W.E., A. Harrison, and P. Schreyer (2005) "Cost of Capital Services in the Production Accounts," paper presented to the fourth Ottawa Productivity Workshop, Ottawa, Canada.

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*, No. 24, Fall, pp. 27-48.

Gu, W. (2008) "An Update on KLEMS Data at Statistics Canada," Presentation to the 2008 World Congress on National Accounts and Economic Performance Measures for Nations, Washington.

Jorgenson, D.W. (1963) "Capital Theory and Investment Behaviour," *American Economic Review*. Vol. 53, No. 2, pp. 247–259.

Jorgenson, D.W. (1996) "The Embodiment Hypothesis," in Dale Jorgenson (ed.) *Postwar U.S. Economic Growth* (Cambridge: MIT Press).

Jorgenson, D. W. (2012) "The World KLEMS Initiative," *International Productivity Monitor*, No. 24, Fall, pp. 5-19.

Jorgenson, D.W., F.M. Gollop and B.M. Fraumeni (1987) *Productivity and U.S. Economic Growth* (Cambridge: Harvard University Press).

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

Jorgenson, Dale W., Mun S. Ho, and Jon D. Samuels (2012) "A Prototype Industry-Level Production Account for the United States, 1947-2010," presentation to the Final World Input-Output Database Conference, Groningen, The Netherlands, April 25.

Jorgenson, D.W. and Z. Griliches (1967) "The Explanation of Productivity Change," *Review of Economic Studies*, Vol. 34, No. 3, pp. 249–283.

Macdonald, Ryan (2007) "Estimating TFP in the Presence of Outliers and Leverage Points: An Examination of the KLEMS Dataset," Economic Analysis (EA) Research Paper Series, Statistics Canada, Analytical Studies Branch.

Macdonald, Ryan (2008) "An Examination of Public Capital's Role in Production," Economic Analysis (EA) Research Paper Series, Statistics Canada, Analytical Studies Branch.

Organisation for Economic Co-Operation and Development (2001) *Measuring Productivity, OECD Manual* (Paris: OECD).

Schreyer, Paul (2009) *Measuring Capital, OECD Manual* (Paris: OECD).

Statistics Canada (2007) "Depreciation Rates for the Productivity Accounts," *The Canadian Productivity Review*. Catalogue no. 15-206-XIE (Ottawa: Statistics Canada).

Statistics Canada (2008) "Depreciation Rates for the Productivity Accounts," Catalogue No. 15-206–XIE–No. 005, Research Paper, *The Canadian Productivity Review* (Ottawa: Statistics Canada).

Timmer, M. P., M. O'Mahony, and B. van Ark (2007) "EU-KLEMS Growth and Productivity Accounts: An Overview," *International Productivity Monitor*, No. 14, Spring, pp. 71-85.

Timmer, M. P., R. Inklaar, R., M. O'Mahony, and B. van Ark (2011) "Productivity and Economic Growth in Europe: A Comparative Industry Perspective," *International Productivity Monitor*, No. 21, Spring, pp. 3-23.