Explaining Productivity Trends in Canada

Wulong Gu (Statistics Canada)

Paper prepared for the 34th IARIW General Conference

Dresden, Germany, August 21-27, 2016

Session 6C: Explaining Productivity Trends I

Time: Thursday, August 25, 2016 [Afternoon]

Explaining Productivity Growth in Canada

Wulong Gu

Economic Analysis Division

Statistics Canada

August 2016

This is a work in progress and is prepared for the conference on “Recent Developments in Productivity Measurement and Analysis” Ottawa, Canada on February 19-20, 2015. It is being circulated for comments. It has not undergone the review required before being issued as a Statistics Canada research paper. I would like to thank John Baldwin, Matt Krzepkowski, Ryan Macdonald, Jean-Pierre Maynard, Marc Tanguay, Weimin Wang and Beiling Yan, and the colleagues at the National Accounts for their contributions to the analysis and research summarized in this paper. I would also like to thank Bert Balk, Erwin Diewert and Doug May who read the first draft of the paper and provided detailed comments.

Abstract

This paper presents trends in productivity growth from the productivity accounts of Statistics Canada. It outlines a number of recent experiments and extensions to the productivity accounts In order to better understand productivity trends in Canada. First, it extends the asset coverage in capital input measure to include natural capital, intangible capital and public infrastructure capital and takes into accounts the changes in the utilization of capital. Second, it presents a measure of productivity by end products to examine the productivity effect of outsourcing and offshoring. Third, it presents an experimental measure of direct output for health and education sectors to examine productivity performance in those sectors.

1. Introduction

The productivity program of Statistics Canada publishes both labour and multifactor productivity (MFP) growth estimates. MFP growth estimates are constructed to understand the sources of labour productivity growth. MFP growth, together with investment in fixed capital and human capital are three main sources of labour productivity growth. To estimate MFP growth, the user cost and volume index of capital input need to be estimated first. While the concept of capital input has been well established since the work of Jorgenson (1963) and Jorgenson and Griliches (1967) and has been introduced to the 2008 System of National Accounts (SNA), issues arise when estimating capital input and the user cost of capital.[1]

The user cost of capital is equal to the sum of rate of return to capital, depreciation and capital gains adjusted for the effects of tax treatments. The rate of return can be either set to the endogenous rate of return or exogenous rate of return (such as the average rate of return to bonds and equity). Prior to the recent revision, the endogenous (or internal) rate of return method was used in Canada, where the rate of return is estimated from the identity that the user cost of capital across assets is equal to capital income. The approach is based on the assumption of perfect competition and constant return to scale production. It gives rise to the Domar aggregation: aggregate MFP growth is weighted sum of industry MFP growth where weights are equal to the ratio of industry nominal output to aggregate nominal output (Domar 1961).

A criticism of the endogenous approach is the volatility of internal rates of return that often occurs at the industry level (Diewert and Yu 2012, Harper et al. 2012). To address the issue, the productivity program adopted a variant of the endogenous approach in 2013

[1] Baldwin and Gu (2007) provided an detailed examination of the various issues related to the estimation of capital input.

(Baldwin et al. 2014). The external rates of return are now used to estimate the user cost of capital for industries with extremely high and low internal rates of return, and the external rates of return are set equal to average internal rates of return in the aggregate sectors. In addition, for a number of service industries where internal rates of returns are high and exhibit unusual trend, capital input is imputed by dividing gross operating surplus by the user cost of capital estimated using the external rates of return.[2]

This approach for estimating capital input provides an estimation of a surplus (which can be either positive or negative)—the difference between capital income from the National Accounts and capital costs. This difference could be the result of imperfect competition. It could also arise because the list of factors included in the MFP estimates is incomplete (for example, many intangibles are excluded). Or it could arise because of economies of scale, so that paying factors their marginal revenue product does not completely exhaust the value of output. As a result of the surplus, the Domar aggregation needs to be modified. This paper first develops a modified Domar aggregation that relates industry MFP growth to aggregate MFP growth in the presence of surplus. It then uses the aggregation to decompose MFP growth in the aggregate business sector into the contributions of individual industries.

The original Domar aggregation was developed based on the assumption of perfect competition and constant return to scale. The modified Domar aggregation in this paper is developed based on the assumption of imperfect competition and constant return to scale. Balk (2015) developed a general decomposition without making assumptions about the return to scale and competition. But that comes with a cost. The decomposition in Balk

[2] The revisions to the estimation of capital input have a small effect on the growth of capital input and MFP in the total business sector for the period after 1980. But the revisions reduced aggregate capital input growth for 1961 to 1980, and therefore increased MFP growth for that period. MFP growth is revised up from 0.7% per year to 1.1% per year for the period 1980 to 2012.

(2015) involves more components. In contrast, the decomposition in this paper is simple and more intuitive.

Busu and Fernald (2012) developed a more general and more complex aggregation formula assuming imperfect competition and increasing return to scale. Their aggregation is parametric and it requires the estimation of returns to scale. In contrast, the decomposition is this paper is non-parametric and is easy to implement.

While the revisions have produced a better set of growth accounts in terms of measurement of the components that go into the production process, there are still a number of areas in which there are data gaps as outlined in Diewert (2000). This paper outlines a number of experiments that Statistics Canada's productivity program has undertaken in order to fill gaps that still exist in the program.

The recent experiments and research have focused on the following areas. The first area of research has expanded the asset coverage to include intangible capital, natural capital and public infrastructure capital so as to develop a more comprehensive measure of capital and to better understand the role of investment in output growth and competitiveness. Intangible knowledge capital such as innovation, human capital and organization capital has been identified as important source of output growth and competitive advantage. But the growth accounting and national accounts in general do not include them as capital. Natural capital represents an important input to the mining and oil and gas extraction sector, but it is excluded in the measure of capital input to the sector. This bias in capital input measure is often hypothesized to be the reason for the negative MFP growth in the sector. Public infrastructure capital contributes to the competiveness and output growth of the business sector, but is often not included in the growth accounts.

The second area of research has focused on the role of short-run changes in utilization of capital input for the slow and volatile MFP growth in the manufacturing sector after 2000. For that purpose, MFP growth is adjusted for changes in capacity utilization in the manufacturing sector. While various procedures exist in previous studies, they are often ad hoc. To address that gap and develop a measure that is based on production theory, a new measure of capacity utilization has been developed that can be used to adjust MFP growth for changes in the utilization of capital input.

The third area of research has focused on the contribution of outsourcing and offshoring to productivity and competitiveness. The industries in Canada are highly integrated with industries in the U.S and other countries. This integration is an important source of productivity growth and competitiveness for Canadian industries which benefit from technological progress and cost improvement in foreign supplier industries. To examine the contribution of increased integration to productivity growth and competitiveness, a framework is developed to measure MFP growth in the production of final demand products. The framework provides a decomposition of MFP growth in production of end products into contributions of domestic and foreign supplier industries.

The fourth area of research has focused on development of direct output volume measure of health and education sectors in order to examine the productivity performance of those sectors. This is also done to accord with the SNA 2008 guideline that the direct output volume index should be used to measure the real output of those sectors. In the national accounts in Canada, the real output of the health and education sectors are measured by the volume index of capital and labour inputs and therefore cannot be used to measure productivity growth in those sectors.

2. Economic and Productivity Growth in Canada

This section presents the growth accounting framework that is used by the productivity program of Statistics Canada to estimate MFP growth at the industry and aggregate level. It then develops a formula that can be used to relate industry MFP growth to aggregate MFP growth when there is surplus arising from the use of external rate of return for calculating capital input. It then uses the aggregation formula to decompose aggregate MFP growth to the contributions of individual industries. The failure to adopt this aggregation when there is a surplus will produce biased estimates of industry contributions to aggregate MFP growth.

2.1 Growth Accounting Framework

Multifactor productivity measures are derived from a growth accounting framework that allows analysts to isolate the effects of increases in input intensity, skills upgrading and MFP growth on labour productivity growth. Growth in MFP is often associated with technological change, organizational change, economies of scale, or short-run variation in capacity utilization.

Jorgenson (1966), Jorgenson Gollop and Fraumeni (1987) and Jorgenson, Ho and Stiroh (2005) have developed integrated industry and total economy growth accounts for the U.S. In their accounts, industry-level productivity growth is estimated making use of detailed data on output and inputs and aggregate productivity growth is estimated making use of the industry-level data. Industry productivity accounts and aggregate productivity accounts are fully integrated and they are related to one another through the Domar aggregation (Domar, 1961).

That framework is developed under the assumption of perfect competition and constant return to scale. That assumption implies that the cost of inputs including capital, labour and intermediate inputs exhaust the value of output and there is no surplus in production. In addition, the rate of return for estimating the user cost of capital can be estimated from the identity that the sum of costs of capital across productive assets is equal to capital income. This endogenous method has been used by Statistics Canada, Australia Bureau of Statistics, and international research initiatives such as EUKLEMS for the international comparisons of productivity growth (Jorgenson 2012, Timmer and O'Mahony, 2012).

The approach has been criticised as the endogenous rates of return are often volatile and are sometimes unusually high and low. The extreme values of internal rates of return might suggest that capital income and capital stock data are not fully consistent. While those extreme values of internal rates of return are found to have relatively small effect on capital input estimate at the industry level, their effect on capital input estimates at the aggregate level could be significant (Baldwin and Gu 2007, Gu 2012).

To produce more accurate estimate of capital input and MFP, Statistics Canada has recently adopted a variant of the endogenous method (Baldwin et al. 2014). The endogenous rates are only used in the industries that show reasonable endogenous rates of return that are comparable external rates of return in bond and stock markets. But in those industries with unusually high and low rates of return, the external rates of return are now used. For Canada, the external rates of return are set equal to the average endogenous rates of return calculated at the broad sectoral levels.[3] As shown by Diewert and Fox (2016), the exogenous rate and endogenous rate methods produce similar estimates of capital input and MFP estimates at the aggregate industries sector. But there are some differences for the estimates at the detailed industry level (Baldwin et al. 2014).

[3]The BLS has adopted a similar approach. For the industries with unusually high and low rates of endogenous rates of return, the external rate of return is used which is equal to the average endogenous rate in the total business sector.

When exogenous rates of return are used to estimate the user cost of capital, the sum of input costs differs the value of output, generating a residual. As a result of the residual, the Domar aggregation needs to be modified to relate industry productivity estimates to aggregate productivity growth estimates. The rest of the section develops such aggregation.

<u>Industry Multifactor Productivity Growth</u>

Growth accounting starts with a production function that expresses gross output V_i of industry i as a function of capital K_i, labour L_i, intermediate input M_i, and technology T_i:

(1) $$V_i = F^i(K_i, L_i, M_i, T_i) \ .$$

The nominal value of gross output for industry *i* is equal to the sum of capital, labour and intermediate input costs plus a surplus:

(2) $$P_{V,i}V_i = P_{K,i}K_i + P_{L,i}L_i + P_{M,i}M_i + \Pi_i \ ,$$

where $P_V, P_K, P_L,$ and P_M are the prices of gross output, capital input, labour input, and intermediate input. Π is surplus or profits. As in the standard growth accounting, the price of gross output is valued at basic prices and the prices of inputs are valued at purchaser prices.

When the internal rate of return is used to estimate the user cost of capital, the costs of inputs exhaust the value of gross output and there is no surplus. But a surplus occurs when the external rate of return is used to estimate the user cost of capital and the value of gross output is not longer equal to the sum of input costs. When there is a surplus, MFP growth based on gross output ($t_{V,i}$) can be written as the difference between output growth and the cost-weighed input growth (Hall, 1990):

$$(3) \qquad t_{V,i} = \Delta \ln V_i - \left(\frac{\alpha_{K,i}}{1-\alpha_{\Pi,i}} \Delta \ln K_i + \frac{\alpha_{L,i}}{1-\alpha_{\Pi,i}} \Delta \ln L_i + \frac{\alpha_{M,i}}{1-\alpha_{\Pi,i}} \Delta \ln M_i \right),$$

where $\frac{\alpha_{K,i}}{1-\alpha_{\Pi,i}}$, $\frac{\alpha_{L,i}}{1-\alpha_{\Pi,i}}$, and $\frac{\alpha_{M,i}}{1-\alpha_{\Pi,i}}$ are the shares of capital, labour and intermediate inputs in the sum of capital, labour and intermediate input costs, $\Delta \ln$ is the log difference or log growth of a variable between two periods. $\alpha_{K,i}, \alpha_{L,i}, \alpha_{M,i}, \alpha_{\Pi,i}$ are the shares of capital costs, labour costs, intermediate input costs, surplus in the nominal value of gross output in industry i. The sum of those shares in gross output equals one.

MFP growth can also be estimated using value-added output. MFP growth based on value-added ($t_{A,i}$) can be defined as the difference between the growth of value-added and the growth of cost-weighted capital and labour inputs with weight being given by the share of capital and labour input costs in the sum of capital and labour costs:

$$(4) \qquad t_{A,i} = \Delta \ln A_i - \left(\frac{\alpha_{K,i}}{\alpha_{K,i} + \alpha_{L,i}} \Delta \ln K_i + \frac{\alpha_{L,i}}{\alpha_{K,i} + \alpha_{L,i}} \Delta \ln L_i \right).$$

It is often argued that MFP growth based on gross output is a preferred measure at the industry level. For MFP growth based on value-added to measure technical progress, an industry must have gross output production that is separable in value added, where value added is a function of capital input, labour input and technology (Jorgenson et al, 2005). Empirical evidence often rejects that assumption. However, as OECD (2001) argued, two measures are useful complements. For that reason, the productivity program of Statistics Canada publishes both gross-output and value-added MFP growth at the industry level.

Value-added in current dollars is calculated as the difference between the value of gross output and the value of intermediate inputs. Value-added in constant dollars (A) can be calculated from the equation that expresses gross output as a Tornqvist aggregation of value-added and intermediate inputs:[4]

(5) $$\Delta \ln V_i = (1-\alpha_{M,i})\Delta \ln A_i + \alpha_{M,i}\Delta \ln M_i \ .$$

This method is called double deflation as the equation can be re-written to express value-added in constant dollar as a difference between a share-weighted gross output in constant dollars and a share-weighted intermediate input in constant dollars:

(6) $$\Delta \ln A_i = \frac{1}{1-\alpha_{M,\mathrm{i}}}\Delta \ln \mathrm{V}_i - \frac{\alpha_{M,i}}{1-\alpha_{M,\mathrm{i}}}\Delta \ln \mathrm{M}_i \ .$$

It can be shown that MFP growth based on value-added is related to MFP growth based on gross output:[5]

(7) $$t_{A,i} = \frac{\alpha_{K,i}+\alpha_{L,i}+\alpha_{M,i}}{\alpha_{K,i}+\alpha_{L,i}} t_{V,i} + \frac{\alpha_{\Pi,i}\alpha_{M,i}}{\alpha_{K,i}+\alpha_{L,i}}(\Delta \ln M_i - \Delta \ln A_i) \ .$$

Value-added MFP growth is equal to gross output MFP growth times the ratio of the sum of capital, labour and intermediate input costs to the sum of capital and labour input costs plus a term that reflects the effect of changes in vertical integration on MFP growth.

[4] In the national accounts, the value-added is estimated using Fisher aggregation. For the purpose of derivation for this paper, Tornqvist aggregation will be used. Both Fisher and Tornqvist aggregation are surperlative indices introduced by Diewert (1976).

[5] A proof of the equation can be obtained from the substitution of gross-output MFP growth in equation (3) for gross-output MFP growth in equation (6).

The term is positive if the growth of intermediate inputs exceeds the growth of real value-added.

If there is no surplus, the equation simplifies to the well-known relationship between value-added MFP growth and gross-output MFP growth: value-added MFP growth is equal to gross output MFP growth times the ratio of nominal gross output to nominal value-added (Bruno, 1978, Joregsnon, Ho, Stiroh, 2005).[6]

The second term is a result of the double-deflation method used in the national accounts for calculating value-added. The double-deflation method is derived from assumption of perfect competition and constant returns to scale. With that assumption, the weights used for double deflation are based on the share of intermediate inputs in value of gross output (Bruno, 1978). With imperfect completion, appropriate weights for double deflation should be based on cost shares of intermediate inputs. It can be shown that the second term in equation (7) disappears when the cost shares are used in the double deflation method for estimating real value added.

Aggregate Multifactor Productivity Growth in the Business Sector

Aggregate MFP growth can be constructed either using the top-down approach or using the bottom-up approach. The top-down approach starts with an aggregate production function and assumes that the output prices and input prices are equalized across industries. This occurs when there is perfect competition and perfect mobility of capital and labour inputs across industries.

The bottom-up approach relaxes those assumptions, so that output prices and input prices are not required to be identical across industries. The bottom-up approach is

[6] Diewert (2015) derived an exact relationship between value-added MFP growth and gross output growth when Laspeyres and Paasche aggregation are used.

adopted in the productivity program of Statistics Canada for a number of reasons. First, the empirical evidence suggests that there are differences in input and output prices across industries (Baldwin and Gu, 2007). Second, the approach produces MFP estimates for Canada that are more comparable to the U.S. estimates from the BLS that adopts the bottom-up approach.[7]

Specifically, value-added growth in the total business sector is derived from aggregating industry value-added growth using the industry share of nominal value-added as weights. Aggregate capital input growth is derived from aggregating industry capital input growth using the industry share of capital costs as weights. However, aggregate labour input is constructed using the top-down approach and is derived from aggregating different types of hours worked dis-aggregated by education levels, experience and employment types across industries. This is done so that the methodology in the Canadian MFP program is comparable with the one adopted by the BLS for the U.S.[8]

MFP growth at the total business sector is estimated as the difference between the growth of aggregate value-added and the growth of combined capital and labour inputs using as weights the share of input costs in the sum of capital and labour input costs.

Relationship between Aggregate and Industry-level MFP Growth

When aggregate MFP growth is constructed using the bottom-up approach, it can be shown that aggregate MFP growth on value-added is equal to a weighted sum of industry value-added MFP growth using the industry shares of capital and labour costs as weights,

[7] It can be shown that aggregate MFP growth from the top-down approach is equal to aggregate MFP growth from the bottom-up approach plus the effects of reallocation of capital and labour inputs on output growth.

[8] The top-down and bottom approaches yield similar estimates of aggregate labour input once the shifts in composition of labour input in education and experience levels are taken into account.

plus a term that reflects the deviation of output price from input costs or the presence of surplus:

(8) $$t_A(bottom) = \sum_i w_i^c t_i^A + \sum_i (w_i - w_i^c)\Delta \ln A_i \ ,$$

where w_i^c is industry i's share of capital and labour costs in the total business sector, w_i is the industry share of nominal value-added in the total business sector.

The second term measures the effect of the reallocation of value added across industries. The term is positive if industries with larger surplus or high markup have faster value added growth than those industries with smaller surplus or lower markup. If there is no surplus, we have the standard aggregation: aggregate MFP growth is a weighted sum of industry MFP growth on value added using industry shares of value-added as weights.

Balk (2015) referred to the second term as the price effect. It is a result of imperfect competition and the surplus. When there is imperfect competition, aggregate value-added growth should be calculated as a weighted sum of value-added growth across industries using industry shares of total capital and labour input costs as weights. But in the national account, the aggregate valued added growth is calculated using industry shares of nominal value added as weights. This is valid with perfect competition and but will give rise to the reallocation term in equation (8) as a result of the difference between cost shares and nominal value-added shares.

Substituting equation (7) for t_i^A in Equation (8), we have an equation that expresses aggregate value-added MFP growth as an aggregation of gross-output MFP growth across industries:

(9)

$$t_A(bottom) = \sum_i w_i^c \frac{\alpha_{K,i} + \alpha_{L,i} + \alpha_{M,i}}{\alpha_{K,i} + \alpha_{L,i}} t_{V,i} + \sum_i w_i^c \frac{\alpha_{\Pi,i}\alpha_{M,i}}{\alpha_{K,i} + \alpha_{L,i}} (\Delta \ln M_i - \Delta \ln A_i) + \sum_i (w_i - w_i^c) \Delta \ln A_i$$

Aggregate MFP growth from the bottom-up approach is decomposed into three components. The first component is the weighted sum of gross output MFP growth across industries. The weight is the ratio of industry production costs (sum of capital, labour and intermediate costs) to the sum of capital and labour costs at the aggregate level. The sum of the weights exceeds one. The second and third components arise as a result of imperfect completion and surplus and they represent the effect of changes in intermediate input intensities and the effect of reallocation of value-added across industries. When there is perfect competition and no surplus, the aggregation becomes standard Domar aggregation and the second and third terms in equation are equal to zero.

The standard Domar aggregation calculates industry contributions to aggregate MFP growth based on industry shares of nominal output. This will overstate the contribution of those industries with positive surplus as their share in nominal output exceeds their share in total input costs. On the other hand, the Domar aggregation will understate the contributions of those industries with negative surplus.

The framework above is presented under the assumption of imperfect competition and constant return to scale, for which aggregate input growth should be cost-weighted. In general, cost-weighted input growth is preferred measure for calculating MFP growth when there is a surplus regardless of the sources of the surplus (Schreyer 2010, Balk 2010).

2.2 Output and Productivity Growth in the Total Business Sector

This section presents the trend in output and productivity growth in the total business sector. The first three lines in Table 1 decompose output growth into the contribution from growth in hours worked and the contribution from growth in labour productivity. The last three lines decompose labour productivity growth into contributions of capital deepening, changes in labour composition and MFP growth.

Output growth is a sum of growth in hours worked and growth in labour productivity. Before 2000, growth in labour productivity is more important contributor to output growth than the growth in hours worked. After 2000, labour productivity and hours worked made similar contributions to output growth.

Of the three components of labour productivity growth, investment and increases in capital intensity is the most important factor. The shifts in labour composition towards more skilled workers also made a significant contribution to labour productivity growth. MFP growth is an important contributor to labour productivity growth before 2000, especially for the period before 1980. For the period 1961-1980, MFP growth accounted for 1.0 pps or about 35% of the 2.8% annual growth in labour productivity in the business sector. For the period 1980 to 2000, MFP growth accounted for 0.4 percentage points of the 1.7% annual growth in labour productivity. After 2000, MFP growth was negative. It declined by 0.3% per year over the period 2000 to 2013.

The rate of growth in output declined in the total business sector over time for the period 1961 to 2013. The growth was 4.9% per year over the period 1961 to 1980, followed by 3.2% per year over the period 1980 to 2000. The output growth was the slowest over the period 2000 to 2013 and it was 1.8% per year for that period.

The decline in output growth over time since 1961 reflects both decline in the growth of labour productivity and decline in the growth of hours worked. The decline in labour productivity growth from the 1961-1980 period to the 1980-2000 period resulted from a decline in MFP growth and a decline in the capital deepening effect. But the further decline in labour productivity growth during the post-2000 period is mainly due to a decline in MFP growth. The capital deepening effect showed little change for the period 1980-2000 and 2000-2013 periods. The changes in labour composition contributed slightly to the slower labour productivity growth after 2000.

2.3 Industry Contributions

Aggregate multifactor productivity growth in the business sector can be traced to its origins at the industry level. This section quantifies the contributions of industries to MFP growth in the total business sector, with a focus on the slow aggregate MFP growth after 2000. Industry contributions are derived using a variant of the Domar aggregation technique shown in section 2.1.

Table 2 presents MFP growth by industry. Table 3 presents the industry contributions to aggregate MFP growth in the total business sector where industry MFP growth is based on value added. The contribution of an industry to aggregate MFP growth is equal to industry MFP growth on value added multiplied by the ratio of capital and labour input costs of the industry to total capital and labour input costs in the total business sector..

For the period before 2000, agriculture, manufacturing, distributive trade and transportation industries experience high MFP growth. The high MFP growth in those industries is a result of innovation and technical progress in those industries. For example, the rapid MFP growth in the manufacturing sector was a result of trend towards trade liberalization in manufacturing that led to innovation and adoption of advanced manufacturing technologies. Those industries accounted for almost all MFP growth in the total business sector for that period.

For the period after 2000, MFP growth slowed and even became negative in goods-producing industries, especially in the mining and manufacturing industries. The service industries that invested heavily in information and communication technologies maintained positive MFP growth and in general did show a decline in MFP growth. Those industries include wholesale and retail trade, information and cultural industries, and finance, insurance and real estate industries.

MFP increased at 0.4% per year in the business sector over the period 1980 t0 2000. It then declined by 0.3% per year over the period 2000 to 2013, which represents a 0.7 percentage-point decline in MFP growth between the two periods. The decline in MFP growth in the manufacturing and mining was largely responsible for the decline in aggregate MFP growth between the two periods. The decline in MFP growth in the manufacturing sector accounted for 0.5 percentage point of the post-2000 decline in aggregate business sector MFP growth. The decline in MFP growth in the mining, oil and gas extraction industry accounted for another 0.5 percentage points of the post-2000 decline in MFP growth in the total business sector.

The sum of industry contributions is almost equal to aggregate MFP growth in the total business sector. The small difference between them reflects the effect of reallocation in value-added on aggregate MFP growth. The effect of reallocation is negative for all periods. This is a result of negative correlation between surplus and output growth: those industries with smaller or negative surplus tend to grow faster, as shown in Table 4. Transportation and information and cultural sectors had large negative surplus and but experienced rapid growth in output over the period 1961 to 2013. Accommodation & food services and other private services sectors had large positive surplus, but experienced relatively slower growth. But there are exceptions to this negative correlation between surplus and output growth. Professional services and administrative support, and waste management and remediation services had large positive surplus, but at the same time experienced faster growth in output.

When there is surplus, the correct weights for estimating industry contributions to aggregate MFP growth are based on input costs. If the weights are based on the value of output, the estimated contributions will be biased. But the bias is found to be small in Canada as industry contributions estimated using output shares are similar to the contributions based on input cost shares.

3. Extensions of the Productivity Accounts

This section summarizes the recent research that extends the core productivity accounts in order to improve productivity measurement and to better understand productivity growth in Canada. First, the coverage of assets is expanded to include natural capital, intangible capital and infrastructure capital so as to provide more comprehensive measure of capital input and to examine the contribution of those capital assets to output and labour productivity growth. Second, MFP growth is adjusted for short-term changes in capital utilization so that MFP growth better measures technological progress. Third, a measure of multifactor productivity growth in the production of final products has been estimated to examine the contribution of offshoring and outsourcing to multifactor productivity growth in the production of those end products. Finally, a direct volume measure of output has been developed for the output of the health and education sectors in order to measure productivity growth in those sectors..

3.1 Intangible Capital and MFP Growth in the Business Sector

The accuracy of MFP estimates is dependent on the comprehensiveness and the measurement taking place in the National Accounts that feeds the productivity program. Recent attention has been paid to the incomplete coverage of assets used for estimating capital input. In particular, it has been argued that a number of intangible assets exist that have not been appropriately taken into account in measuring the growth in capital.

Intangible assets can be classified into computerized information (software and computerized database), innovative property (scientific R&D and non-scientific R&D), and economic competencies (brand equity, training and organizational capital) (Corrado, Hulten and Sichel, 2009). The MFP measure published at Statistics Canada and elsewhere only includes a small portion of intangible assets--those related to R&D, exploration and software. Whether the inadequate coverage of intangibles has a deleterious effect on the MFP measure is difficult to judge without an empirical study—since reclassifying an intermediate expense to an investment both affects measured output and measured capital.

Baldwin et al (2009, 2012) developed a more extensive measure of intangible capital than is used at present in the National Accounts and extended the growth accounting to include intangible capital. They found that investment in intangibles totalled $151 billion in the Canadian business sector in 2008, which represented 13.2% of gross domestic product in that year. Investment in intangibles increased much faster than investment in tangibles over time and the ratio of intangible investment to tangible investment increased from 0.23 in 1976 to 0.66 in 2008. The results from the extended growth accounting show that intangibles made a significant contribution to labour productivity growth and the contribution of intangibles to labour productivity growth was almost as high as that of tangibles in the Canadian business sector (Table 5).

The relative contribution of investment in capital (both tangible and intangible) to labour productivity and economic growth increased while the relative contribution of residual MFP growth decreased when investment in intangibles is taken into account. This is consistent with the findings on the nature of U.S. economic growth reported by Corrado, Hulten and Sichel (2009). They examined the contribution of intangibles to U.S. economic growth and concluded that "the innovation process 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 design, and organizational capability."

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

3.2 Natural Capital and MFP Growth in the Oil and Gas Extraction and Mining

Multifactor productivity has been declining in the oil and gas extraction sector since the early 1990s and it has been declining in the other mining sector (coal, metal ores and non-metallic mineral mining) since the early 2000s (Figure 2).[9] The decline in MFP in those two sectors accounted for a 0.5-percentage-point decline or more than the overall 0.3 percentage-point decline in the total business sector after 2000 (Table 3).

The decline in MFP in the oil and gas extraction and the other mining sectors does not necessarily suggest there is a decline in technical efficiency. The research in Australia and Netherland shows that a substantial part of the decline in MFP in the mining sector can be attributed to unmeasured natural capital inputs (Topps and Kuluys, 2014; Veldhuizen

[9] The MFP is figure 2 is calculated on value-added, The MFP on gross output shows a similar trend. The decline in MFP in the mining sector based on the standard growth accounting framework is also found in other countries including Australia, the United States and Netherland.

and de Haan,2012; ABS,2014).[10] When natural capital is not included in capita input, MFP measure is biased as the output includes the rent while the input does not include natural capital input used to generate that output. MFP growth is found to be downward biased as a result of upward bias in growth in capital input that excludes natural capital input in those countries. This is the case as the mining industries typically involve more and more capital being applied for the extraction of natural resources. The growth in combined natural capital and other capital tends to be slower than the growth in the other capital.

Schreyer (2012) presented an extended growth accounting framework for incorporating natural capital input in MFP measure for the oil and gas extraction and the other mining industries. In the extended framework, the volume index of natural capital input is equal to the volume index of resource extraction, while the user cost of natural capital input is the resource rent. The resource rent can be estimated residually and is equal to the difference between the value of resource extracted and the costs of capital excluding natural capital, labour and intermediate inputs. The cost of capital is estimated assuming that the rate of return is equal to the average rate of return in the business sector excluding the oil and gas and other mining sectors. The resource rent is set equal to zero when negative. This occurs during the late1980s and the 1990s in Canada when the price of natural resource was low and showed a large decline.

The procedure for estimating the volume index of natural capital input differs from the one for estimating the volume index of the other capital. The volume index of capital input other than natural capital is not observed and is assumed to be proportional to capital stock. In contract, the volume index of natural capital input is observed and is equal to the volume of resource extraction.

[10] ABS (2014) finds that the decline in the mining MFP is reduced significantly when natural capital input is included in the MFP measure, from -5.8% per year to -2.2% for the period from 2003-04 to 2012-13.

An industry often uses various natural capital inputs in its production. To measure MFP growth, different types of natural capital inputs need to be aggregated to derive an aggregate measure of natural capital input. Similar to the procedure for the aggregation of produced capital across asset types, the weights for the aggregation should be based on the user costs of natural capital inputs. Adam and Wang (2015) implemented such approach using resource rent estimates for various types of natural capital inputs with an industry.

The resource rents by assets are often difficult to estimates as revenues and input costs must be allocated between multiple resources for those firms that engage in the extraction of multiple natural resource assets. For this paper, the value of natural resource assets will be used for aggregation. This assumes that resource rent per dollar value of resource extracted is equalized across different types of resource assets. This is the procedure used by Statistics Netherland in their measure of natural capital input and MFP for the mining sector (Veldhuizen and de Haan, 2012). For Canada, the choice of weights for aggregation is found to have a little effect on growth in estimated natural capital input.

Table 6 presents the extended growth accounts for the oil and gas extraction and the other mining sectors. The data on gross output, capital, labour and intermediate inputs are taken from the productivity accounts of Statistics Canada (CANSIM table 383-0032). The volume index of natural capital input is derived from the make tables of input-output accounts and it is available for the period up to the most recent input/output table reference year 2011.

The growth in produced capital, inventory capital, labour and intermediate inputs was faster than the growth in natural capital input in the Canadian oil and gas extraction over the period 1961 to 2011. This difference becomes larger during the period after 2000. This reflects the substitution of traditional inputs for natural capital input in the oil and gas extraction sector as oil and gas become increasingly more expensive to extract.

Multifactor productivity from the traditional growth accounts without natural capital input declined by 1.8% per year in the oil and gas extraction sector over the period 1961 to 2011. When natural capital is included, the decline in MFP in the oil and gas extraction is much smaller. It declined by 0.9% per year for the period 1961 to 2011. This suggests that about half of the decline in the current MFP measure in the oil and gas extraction is due to unmeasured natural capital input.

The extended growth accounts for oil and gas extraction in Table 6 also provide an assessment of contribution of natural capital input to economic growth. Over the period 1961 to 2011, the largest contributors to output growth in the oil and gas extraction sector are the other capital and intermediate inputs, followed by natural capital input and labour input. Natural capital input contributed 0.4 pps of 4.0% annual growth in gross output in the oil and gas extraction, while labour input contributed 0.3 pps.

Table 7 presents the growth accounts for the other mining sector. MFP also declined in the other mining sector over the period 1961 to 2011. But the decline is much smaller compared with that in the oil and gas extraction sector. The trend in MFP in the other mining sector shows three distinct periods. MFP declined in the period 1961 to 1980, and then increased at a rapid pace in the period 1980 to 2000. After 2000, it experienced a large decline in MFP.

Over the period 1961 to 2011, MFP in the other mining sector declined by 0.6% per year from the traditional growth accounting. The extended growth accounts shows that MFP declined by 0.2% per year. That is, more than half of the decline in MFP in the sector is due to unmeasured natural capital input.

While incorporating natural capital input improves the measure of capital input and MFP in the oil and gas and the other mining sectors, there is still a long-term decline in MFP after the incorporation. A question remains. What are the sources of long-term decline in MFP in those sectors? To shed light on the issue, annual changes in MFP are regressed on annual changes in price of natural resources. It is found that MFP growth is negatively correlated with changes in the price of natural resources. MFP growth tends to be slow during a period of rapid increase in resource price. The less efficient or lower grade mines become operational when the resource prices are high.

3.3 Infrastructure Capital and MFP Growth in the Business Sector

Public infrastructure capital (the nation's roads, bridges, sewer systems and water treatment systems) constitutes a vital input for business sector production. It contributes to productivity in the private business sector as it enables concentrations of economic resources, provides wider and deeper markets for output and employment and reduces the transportation and production costs.

The contribution of public infrastructure capital to productivity growth can be examined using an extended growth accounting framework (Mas, 2006; Gu and Macdonald, 2009). The growth accounting framework currently employed for productivity analysis by Statistics Canada and other statistical agencies focuses on private sector inputs and outputs. MFP is calculated as the difference between the rate of growth of business sector output and the rate of growth in private labour and capital inputs that are applied by the business sector in the production process. The impact of public capital at present is subsumed in MFP.

To explicitly analyse public capital’s influence, changes in MFP from the traditional growth accounting for the business sector are decomposed into the contribution from public capital and MFP net of the effect of public capital. This approach adopts the usual assumptions about constant returns to scale across private inputs and private factors being paid their marginal revenue product. Public capital is assumed to affect output growth, but not the substation between private capital and labour inputs.

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

(10) $t_A = t_A^* + \beta_G \Delta \ln G$,

where t_A denotes multifactor productivity in the business sector from the growth accounting that includes private capital and private labour inputs for the business sector, t_A^* denotes MFP growth net of public capital's contribution, G denotes public capital stock in constant dollars. β_G is the elasticity of public capital with respect to the output of the business sector. It indicates the percentage change in business sector output for a given percentage change in public capital stock. The term $\beta_G \Delta \ln G$ in the equation measures the effect of public capital on business sector output and productivity growth.

The output elasticity β_G can written as: $\beta_G = \frac{G}{A}\frac{\Delta A}{\Delta G}$, where A denotes value-added in constant dollars, and $\Delta A / \Delta G$ is the marginal product of public capital. If there is a competitive market for the provision of public capital, the value of marginal product of public capital is equal to the user cost of public capital, and the output elasticity of public capital is equal to the share of the cost of public capital in the value of the business sector output:

(11) $\beta_G = \frac{c_G G}{P_A A}, c_G = P_G(\gamma + \delta - \pi)$

where c_G is the user cost of public capital, γ is the nominal rate of return, δ is the depreciation of public capital, π is capital gains for public capital or percentage changes in the investment price for public capital. P_G is the investment price for public capital while P_A is the price of the business sector output.

In general, the rate of return in the equation can be interpreted as the return to investment in public capital. A large number of studies have estimated the output elasticity and the implied rate of return to public capital. Macdonald (2008) reports an estimate of the elasticity of output with respect to public infrastructure capital of around 0.1 for the Canadian business sector. The implied rate of return from the elasticity is similar to the nominal after-tax return to capital in the business sector.

Gu and Macdonald (2009) examined the contribution of public infrastructure capital to productivity growth in the business sector for the period 1961 to 2006. The results from Gu and Macdonald (2009) are extended to more recent years in Table 7. The stock of public capital includes public capital stock of governments and public health and education sectors. It consists of roads, bridges, sewer systems, water treatment systems, schools and hospitals. The output elasticity of public capital in equations (10) and (11) is estimated assuming that the rate of return to public capital is equal to the after-tax return on capital in the business sector.

Figure 3 presents the growth of public capital stock and business sector capital stock for the period 1961 to 2013.The growth in public capital stock exceeded the growth in business sector capital stock in the 1960s as a result of large infrastructure project such Trans-Canada highway. During the 1970s, 1980s and 1990s, the growth in public capital was slower than the growth in capital stock in the business sector as decades of cross-country highway expansion came to an end. In the 2000s, the growth of public capital exceeded the growth in business sector capital, as a result of large investments in infrastructure from the government economic stimulus program during that period.

Table 8 presents the contribution of public capital to business sector. Over the period 1961 to 2013, the conventional estimate of MFP growth averages 0.4% per year. About half of this growth is attributable to public capital. The results are consistent with those reported in Gu and Macdonald (2009).

The largest contributions of public capital to productivity growth occurred during the 1960s and 1970s, when it contributed up to 0.2 percentage points to average multifactor productivity growth. During the 1980s and 1990s, its contribution to productivity averaged only 0.1 percentage points a year as a result of slower growth in public capital stock in that period.

During the period after 2000, the contribution of public capital to the business sector MFP growth picked up as a result of increased investment in public infrastructure during that period. It contributed 0.2 percentage points to MFP growth in the business sector for the period 2000-2013.

3.4 Capacity Utilization and MFP Growth in the Manufacturing Sector

Productivity statistics published by Statistics Canada and most other statistical agencies do not correct for short run variations in capacity utilization. As such, the changes in MFP growth will reflect the changes in capacity utilization in the short run.

Correction for the effect of variations in capacity utilization is important when rates of capacity utilization change. Canada has recently experienced a resource boom and an upward appreciation of the Canada–United States exchange rate. Based on micro-data on plant adjustments to pressures arising from changes in export markets and resulting declines in capacity utilization, Baldwin, Gu and Yan (2011) show that that the decline in standard measures of MFP during the early part of the 2000s was primarily, if not completely, due to the decline in capacity utilization.

Numerous studies have tried to adjust the MFP measure for capacity utilization. But as Berndt and Fuss (1986) noted, the adjustment is mostly ad hoc, because it lacks a theoretical framework. Gu and Wang (2013) developed a non-parametric procedure for such an adjustment. The adjustment procedure is based on the economic theory of production. Capacity utilization is measured based on the comparison of the *ex-post* return with the *ex-ante* expected return on capital. This is intuitively appealing, because changes in the *ex-post* return on capital should mainly reflect the variation in capacity utilization. A higher level of unused capital and the resulting lower level of capacity utilization should be associated with a lower *ex-post* rate of return, which is calculated on the actual level of capital. Similarly, a higher level of capacity utilization should be associated with a higher *ex-post* rate of return on the actual level of capital.

More specifically, the ratio of the user cost of capital based on the *ex-post* return on capital to the user cost of capital based on the *ex-ante* return is used to measure capacity utilization. MFP growth is adjusted for changes in capacity utilization using the following equation:

(12) $$t_A = t_A^{cu} + \alpha_K^{\cos t} \Delta \ln(P_K^{ex\ ante} / P_K^{ex\ ante}) ,$$

where t_A^{cu} is utilization–adjusted MFP growth base on value-added, $\alpha_K^{\cos t}$ is the share of capital costs in the sum of capital and labour costs.

Gu and Wang (2013) shows that, in order to take into account the rate of capital utilization when measuring MFP, the ratio of *ex-post* to *ex-ante* user cost of capital should be used to adjust the *quantity* of capital input rather than the *price* of capital input. This is in contrast to Berndt and Fuss (1986) who argued that the *ex-post* user cost of capital should used to value the *price* of capital input to take into account the rate of capacity utilization in measuring MFP. But as observed by Basu and Fernald (2001) and Hulten (2009), the Berndt and Fuss procedure does not provide a solution for the issue of capacity utilization in the measurement of MFP.

Figure 4 presents the two measures of capacity utilization for the total manufacturing sector. The first measure is the ratio of the *ex-post* user cost of capital to the *ex-ante* user cost of capital that is used to adjust MFP growth for changes in capacity utilization. The *ex-post* user cost of capital is estimated using the five year moving average of real internal rate of returns.[11] The second measure is the industrial capacity utilization rate. It measures the intensity with which industries use their production capacity and represents the percentage of actual to potential output. The measure is obtained from the Capital and Repair Expenditures survey (CAPEX). Both measures show similar trend: a decline in capacity utilization from 2000 to 2009 that is accompanied by a decline in output and employment, and an increase after 2009 that is accompanied by an increase in output and employment.

Table 9 presents MFP growth for the manufacturing sector. Changes in capacity utilization have little effect on MFP growth over the long run. But the changes in capacity utilization have a significant effect on MFP growth in the short run. For example, over the period 2000 to 2009, MFP without utilization adjustment declined by 0.9% per year over the period. In contrast, MFP adjusted for capacity utilization increased by 0.4% per year.

During the period after 2009, output and employment showed positive growth and capacity utilization increased. MFP increased by 2.0% per year for the period 2009 to 2013.

[11] Gu and Wang (2015) used the 9-year moving average and found a similar the results on the effect of utilization adjustment on MFP growth

The positive MFP growth was largely due to an increase in capacity utilization. MFP adjusted for capacity utilization increased by 0.9% per year.[12]

Table 10 and Figure 5 present the effect on MFP growth in the business sector of incorporating public capital, natural capital and changes in capacity utilization. Without those adjustments, MFP increased at 0.4% per year in the business sector over the period 1961 to 2013. About half or 0.2 percentage point of that growth is due to the contribution of public capital. MFP net of the effect of public capital increased at 0.2% per year during that period. When natural capital is included, annual MFP growth rose by 0.1 percentage point in the business sector. The adjustment for changes in capacity utilization affects MFP growth in the short run, but has no effect on long-term growth in MFP.

For the period 2000-2013, multifactor productivity declined by 0.3% per year in the business sector. MFP became virtually unchanged in the business sector when natural capital input and changes in capacity utilization were taken into account.

3.5 MFP Growth by Final Demand Products

Statistics Canada and most other statistical agencies publish the estimates of MFP growth by industry. MFP by industry measures the efficiency with which domestic industries use inputs in their production. Denison (1989) recommends that statistical agencies introduce an alternative way of dividing the total economy and measure the productivity by final demand products. MFP by find demand products has a number of advantages. MFP growth for the production of final demand products captures the impact that productivity gains in the production of intermediate inputs have on the productivity gains of downstream industries. It provides an assessment of production integration on

[12] The utilization adjustment based on a comparison of the ex post with the ex ante user cost can be done for the period up to 2011 for which nominal value-added and capital income are available. The capacity utilization in the recent years are extended using the industrial capacity rates from the CAPEX survey.

productivity and competitiveness in domestic production and provides a proper measure of the price competitiveness in domestic production.

The measure of MFP growth for the production of final demand products was proposed by Domar (1961), Rymes (1971), and Hulten (1978), and has been estimated in a number of studies (Durand 1996; Aulin-Ahmavaara 1999). However, in those studies, the measure was developed in a closed economy. Gu and Yan (2015) extended that framework to develop an MFP growth measure in an open economy, thus providing a framework for examining the effect of global production and offshoring on MFP growth.

MFP growth in producing final demand products can be calculated as the difference between growth in the output of final product and growth in the combined capital and labour inputs used directly and indirectly in the production of final products, where the weights are shares of direct and indirect capital and labour costs. The data for estimating such measure requires the world input/output tables and the world productivity database.

A number of previous papers have also estimated the MFP growth for the production of end products. Oliner, Sichel, and Stiroh (2007) constructed a measure of MFP growth for the production of final demand goods and services in the United States, with a focus on the role of production of ICT investment goods. However, those papers assume that combined input growth is the same for the production of different types of final demand products.

Basu and Fernald (2010) estimated MFP growth in the production of investment and consumption goods for the United States when intermediate inputs are partly imported. They captured the impact of productivity gains from imports on domestic production through the terms of trade. By contrast, Gu and Yan (2015) followed the traditional growth accounting framework to capture the impact of productivity gains from imports; productivity gains in intermediate imports are calculated as the difference between import growth and the combined input growth used in foreign countries to produce the imports.

Gu and Yan (2015) found that a substantial portion of MFP growth for the production of final demand products, especially for small, open economies like Canada's, originates from gains in the production of intermediate inputs in foreign countries. Because Canada imported a larger share of intermediate inputs from foreign countries than did the other countries and productivity growth in its supplier industries (notably, in the United States) was higher, Canada is found to benefit more from productivity gains in foreign countries than did the other countries. The foreign contribution to Canada's MFP growth increased from 24% in the 1995-to-2000 period, to 65% in the 2000-to-2007 period.

Table 11 presents MFP growth for the production of investment, consumption and export products. Productivity growth tends to be higher in the production of investment and export products than in the production of consumption products. For instance, in the United States, MFP growth in the production of investment, export and consumption products was 1.6%, 3.2% and 0.8%, respectively, in the pre-2000 period, and 0.04%, 2.1% and 0.4% after 2000. This can be attributed to relatively high productivity growth in industries that produce investment and export products (such as electrical and optical equipment, transport equipment), and slower growth in consumption-producing industries (such as real estate activities, public administration and health/social work)

Productivity growth in foreign countries made a larger contribution to MFP growth in the production of investment and export products, compared with the production of consumption products. This is because domestic industries producing investment and exports are more integrated with industries in foreign countries and those industries tend to have higher productivity growth than do consumption-product producing industries.

3.6 Output and Productivity Growth in the Education and Health Care Sectors

In Canada, output in the education and health care sectors is essentially measured with inputs and deflated with input costs. This means that productivity estimates are zero. In light of the large size of those sectors, current measures provide less-than-complete coverage of economic activity.

The recent research has focused on the output measure of the health and education sectors. Experimental measures of output and productivity have been developed for the education sector, hospitals, residential care facilities and physicians paid under fee-for-service model (Gu and Wong, 2012, Gu and Morin 2013, and Gu and Li, 2014).

The direct output measures are constructed for those sectors. For the education sector, the direct output measure is based on the number of student enrolments weighted using the costs of education across different education levels. For the hospital sector, the direct output measure is based on the number of "activities" in hospitals, with activities defined as episodes of treatment of diseases and conditions. Once again, weights based on costs of treatments are applied to construct the direct output measure. For residential care facilities, the direct output is based on the number of resident days by the level of care properly weighted by the costs of providing such care. For the physicians, the direct output measure is based on the number of patient visits and consultations, again cost-weighted across different types of services.

The major challenge for developing a direct output measure of the health and education sectors is to take into account the quality changes in the health and education service output. In the work for the measurement of output of the education sector, the quality indicators are measured by test scores, and implicit prices associated with the test scores are estimated from a hedonic regression that relates the price of education output to test scores. The changes in the price of education output associated with changes in test scores is counted as the change in the quality-adjusted volume of education output. In the work on the output of the hospital sector output, the quality adjustment captures the substitution of treatments towards outpatient treatments that are less expensive and provide similar or improved health effects to the patients. The adjustment of quality changes resulting from such substitution requires the classification of outpatient and inpatient treatments into the same group and the use of similar weights to aggregate the various types of treatments to derive an output measure for the hospital sector. To take into account quality changes in the output of residential care facilities, the share of personnel that provide direct care to residents is used as an indicator for the quality of the care to residents.

The education sector is found to have low productivity growth. Labour productivity of the Canadian education sector increased at 0.4% per year over the period 1990 to 2005. The increase is much slower than the growth in labour productivity in the business sector.

Productivity growth of health care varies across sectors. Labour productivity in the hospital sector increased 2.6% per year over the 2002-to-2010 period. The growth is much faster than the average labour productivity growth in the business sector. But there were little productivity growth in residential care facilities and physicians paid under fee-for-service model.

4. Conclusions

The recent revision to the productivity program of Statistics Canada adopted a variant of the internal rate of return method for estimating capital input. The internal rates of return are only used for those industries with reasonable rates of return compared with exogenous rates of returns in bond and stock markets. For those industries with extremely high and low internal rates of return, the external rates of return are now used and they are set equal to the average internal rates of return in the major sectors. This approach for estimating capital input provides an estimation of a surplus (which can either positive or negative). The paper developed a modified Domar aggregation and showed that the proper weights for examining industry contributions to aggregate MFP growth should be based on industry shares of input costs when there is a surplus.

Much of the recent work has focused on expanding the asset coverage of capital inputs in the traditional growth accounting to include intangible capital, infrastructure capital, natural capital, and changes in the utilization of capital in order to better understand the growth process. When the concept of capital and investment is expanded to include intangible capital, it is found that intangibles made a significant contribution to labour productivity growth and the contribution of intangibles to labour productivity growth was almost as high as that of tangibles in the Canadian business sector.

The current MFP measure for the oil and gas extraction and the other mining sector does not include natural capital as inputs. This MFP measure showed a large decline in that sector over time. When natural capital is included, it is found that a substantial portion of the decline in MFP is due to unmeasured natural capital input.

The growth account for the business sector can be extended to include public infrastructure capital. When this done, it is found that about half of the growth in the conventional estimate of MFP growth is attributable to public capital. The largest contributions of public capital to productivity growth occurred during the 1960s and 1970 and in the period after 2000 as a result of large infrastructure projects in the 1960s and 1970s and an increased investment in public infrastructure during that period after 2000.

Changes in capacity utilization are found to have little effect on MFP growth over the long run. But the changes in capacity utilization have a significant effect on MFP growth in the short run. For the period 2000-2013, multifactor productivity declined by 0.3% per year in the business sector. MFP became virtually unchanged in the business sector when natural capital input and changes in capacity utilization were taken into account.

For the period 2000-2013, multifactor productivity declined by 0.3% per year in the business sector. MFP became virtually unchanged in the business sector when natural capital input and changes in capacity utilization were taken into account.

Statistical agencies mostly publish MFP growth by industry. But MFP growth measure by end products can be also estimated using similar data sources, and the measure contributes to the understanding of the growth process. The MFP estimates by end products show productivity growth tends to be higher in the production of investment and export products than in the production of consumption products. Productivity growth in foreign countries made a larger contribution to MFP growth in the production of investment and export products, compared with the production of consumption products. This is because domestic industries producing investment and exports are more integrated with industries in foreign countries and those industries tend to have higher productivity growth than do consumption-product producing industries.

The experimental measures of direct output and productivity for the health and education sectors show that the education sector has lower productivity growth compared with the business sector. Productivity growth of health care varies across sectors. Labour productivity in the hospital sector increased 2.6% per year over the 2002-to-2010 period. The growth is much faster than the average labour productivity growth in the business sector. But there were little productivity growth in residential care facilities and physicians paid under fee-for-service model.

References

Adams, P. and W. Wang, 2015, “Accounting for Natural Capital in Productivity in the Mining and Oil and Gas Sector,” Statistics Canada.

Australia Bureau of Statistics (ABS), 2014, “Introduction of Mining Natural Resources into Australia Productivity Measures,” ABS, Australia.

Baldwin, J. R. and W. Gu. 2007, “Multifactor Productivity in Canada: An Evalution of Alternative Methods of Estimating Capital Services,” Canadian Productivity Review, 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, R. Macdonald, W. Wang, and B. Yan (2014) “Revisions to Multifactor Productivity Accounts,” Catalogue No. 15-206-X *The Canadian Productivity Review,* No. 35. Ottawa: Statistics Canada.

Baldwin, J.R., W. Gu, and B. Yan. (2013) “Export Growth, Capacity Utilization and Productivity Growth: Evidence for Canadian Manufacturing Plants,” *Review of Income and Wealth.*

Balk, B.M. 2010, “An Assumption-free Framework for Measuring Productivity Change,” *The Review of Income and Wealth*, vol. 56l

Balk, B.M. 2015,” Measuring and relating aggregate and subaggregate total factor productivity change without neoclassical assumptions,” Statistica Neerlandica, vol. 69 (1): 21-48

Basu, S. and J. Fernald (2002), “Aggregate Productivity and Aggregate Technology,” *European Economic Review*, 56(6): 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*, 33, pp. 7-29.

Brandt N.. P. Schreyer, and V. Zipper, 2013, “Productivity Measurement with Natural Capita,”OECD.

Bruno, M. 1978, “Duality, Intermediate Inputs and Value-added, “ in M. Fuss and D. McFadden (eds.), *Production Economics: A Dual Approach to Theory and Applications*, vol. 2. North Holland.

Corrado, Carol, Charles Hulten, and Daniel Sichel, “Intangible Capital and U.S. Economic Growth,” *Review of Income and Wealth*, 55, 3, September 2009, 661-685.

Denison, E.F. 1989*, Estimates of Productivity Changes by Industry: An Evaluation of an Alternative.*The Brookings Institution, Washington D.C.

Diewert, W.E. 1976, “Exact and Superlative Index Numbers,” *Journal of Econometrics. 4.* 115-145

Diewert. W.E. (2000), “The Challenges of Total Factor Productivity Measurement,” *International Productivity Monitor*

Diewert, W.E. (2015), “A Note on Reconciling Gross Output TFP Growth with Value Added TFP Growth,” Department of Economics, UBC.

Diewert, Erwin and Kevin Fox “Alternative User Costs, Rates of Return and TFP Growth Rates for the US Nonfinancial Corporate and Noncorporate Business Sectors: 1960-2014”, paper presented at the North American Productivity Workshop, Quebec City. 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.

Domar, E. 1961. “On the measurement of technical change.” *Economic Journal* 71: 710-729.

Durand, Rene. (1996), “Canadian Input-Output-Based Multi-factor Productivity Accounts,” *Economic Systems Research*, v. 8, 367-389.

Fernald J. (2012), “A Quarterly, Utilization-Adjusted Series on Total Factor Productivity,” Federal Reserve Bank of San Francisco Working Paper 2012-19.

Gu, W. and J. Li. 2014, “Output and Productivity of Residential Care Facilities in Canada,” Economic Analysis Division, Statistics Canada, paper presented at the 2014 IARIW Conference, Rotterdam, Netherlands.

Gu, W. and R. MacDonald (2009), “The Impact of Public Infrastructure on Canadian Multifactor Productivity Estimates,” *The Canadian Productivity Review*, Statistics Canada.

Gu, W. and S. Morin. 2014. “Experimental Measures of Output and Productivity in the Canadian Hospital Sector, 2002 to 2010,” Economic Analysis Research Paper Series, Statistics Canada (also in *Measuring Economic Sustainability and Progress*, edited by D. Jorgenson, S. Landerfield, and P. Schreyer, NBER.

Gu, W. and W. Wang, 2013, “Correction for Variations in Capacity Utilization in the Measurement of Productivity Growth: a Non-parametric Approach,” *Journal of Economic and Social Measurement.*

Gu, W. and A. Wong, 2014, “Productivity and Economic Output of the Education Sector” *Journal of Productivity Analysis.*

Gu, W. And B. Yan, 2015. “Productivity Growth and International Competitiveness,” Revised and resubmitted to *the Review of Income and Wealth.*

Hall, R. 1990 “Invariance Properties of Solow’s Productivity Residual,” in *Growth/Productivity/Employment* edited by P. Diamond.

Harper, M.J., A. O. Nakamura, and L. Zhang (2013), “Difficulties in Assessing Multifactor Productivity Growth in Canada’, *International Productivity Monitor.*

Hulten, C. R. 1978, “Growth accounting with intermediate inputs”, *Review of Economic Studies*, 45, pp. 511-518.

Hulten C.R. 2009, “Growth Accounting”, NBER working paper.

Jorgenson D.W. 1963, “Capital Theory and Investment Behaviour,” *American Economic Review*, vol. 53. 247-259.

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

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

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.

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.

Mas, Matilda, 2006, “Infrastructures and New Technologies as Sources of Spanish Economic Growth,” MPRA paper.

Oliner S.D., D.E. Sichel, and K.J. Stiroh (2007), “Explaining a Productivity Decade,” Brookings Papers on Economic Activity, 2007(1): 81-152.

O.Mahony, M. and M. Timmer (2009), “Output, Input and Productivity Measures at the Industry Level: the EU KLEMS Database,” *The Economic Journal*, F374-F403.

Rymes, T.K. 1971. *On the Concepts of Capital and Technical Change*. Cambridge, United Kingdom: Cambridge University Press.

Schreyer, P. (2001). *Measuring Productivity – OECD Manual*, Paris: OECD.

Schreyer, P. (2012), “Productivity Measurement and Natural Assets – An Extended Growth Accounting Approach,” Draft, OECD.

Schreyer, P. 2010, "Measuring Multi-factor Productivity when Rates of Return are Exogenous," in W..E. Diewert et al. (eds.), *Price and Productivity Measurement*, Trafford Press.

Solow, R. (1957), "Technical Change and the Aggregate Production Function," *Review of Economics and Statistics*, 39(3):312-320.

Topps V., and T. Kuluys, 2014, "On Productivity: The Influence of Natural Resource Inputs," *International Productivity Monitor*, Fall 2014.

Veldhuiszen E. and M de Haan, 2012, "The Dutch Growth Accounts: Measuring Productivity with non-Zero Profits," paper presented to the IARIW meeting, Boston.

Table 1

Sources of output and labour productivity growth in the business sector

	1961-1980	1980-2000	2000-2013
Growth in real value-added	4.9	3.2	1.8
Growth in hours worked	2.0	1.5	0.9
Labour productivity growth	2.8	1.7	0.9
Contributions to labour productivity growth			
Capital deepening	1.3	0.9	0.9
Labour composition	0.5	0.4	0.3
MFP growth	1.0	0.4	-0.3

Table 2

Multifactor productivity growth by industry

Industry	1961-1980	1980-2000	2000-2013
Agriculture, forestry, fishing and hunting	0.8	2.6	2.6
Mining and Oil and Gas Extraction	-2.5	-0.3	-5.1
Utilities	2.1	0.1	-1.0
Construction	1.5	-0.2	0.0
Manufacturing	2.1	2.0	0.0
Wholesale Trade	1.5	2.0	1.1
Retail Trade	2.0	1.1	0.9
Transportation and Warehousing	3.0	1.1	-0.2
Information and Cultural Industries	3.7	0.2	1.0
Finance, Insurance, Real Estate and Renting and Leasing	-1.8	-0.7	0.6
Professional, Scientific and Technical Services	0.6	-1.2	-0.2
Administrative and Support, Waste Management and Remediation Services	-1.6	-1.5	-0.8
Arts, Entertainment and Recreation	-0.3	-3.2	-1.2
Accommodation and Food Services	-1.2	-1.5	0.5
Other Private Services	1.0	-0.9	0.3

Table 3

Industry contributions to MFP growth in the total business sector

Industry	1961-1980	1980-2000	2000-2013
Agriculture, forestry, fishing and hunting	0.05	0.10	0.07
Mining and Oil and Gas Extraction	-0.20	-0.03	-0.49
Utilities	0.06	0.00	-0.04
Construction	0.13	-0.02	0.00
Manufacturing	0.55	0.46	0.01
Wholesale Trade	0.09	0.13	0.08
Retail Trade	0.15	0.08	0.06
Transportation and Warehousing	0.26	0.08	-0.02
Information and Cultural Industries	0.18	0.01	0.04
Finance, Insurance, Real Estate and Renting and Leasing	-0.21	-0.09	0.09
Professional, Scientific and Technical Services	0.01	-0.05	-0.01
Administrative and Support, Waste Management and Remediation Services	-0.01	-0.03	-0.03
Arts, Entertainment and Recreation	0.00	-0.02	-0.01
Accommodation and Food Services	-0.03	-0.04	0.01
Other Private Services	0.04	-0.04	0.01
Sum of industry contributions	1.07	0.54	-0.22
Reallocation of output	-0.04	-0.17	-0.07
Total business sector	1.03	0.37	-0.29

Table 4

Average share of surplus and average annual growth in value-added growth by industry, 1961 to 2013

	Share of surplus (%)	Growth in value-added (%)
Agriculture, forestry, fishing and hunting	-0.6	1.7
Mining and Oil and Gas Extraction	-0.8	2.5
Utilities	-0.2	3.8
Construction	10.8	2.8
Manufacturing	3.8	2.8
Wholesale Trade	0.0	4.8
Retail Trade	0.0	4.1
Transportation and Warehousing	-25.9	3.7
Information and Cultural Industries	-14.4	5.5
Finance, Insurance, Real Estate and Renting and Leasing	0.0	3.8
Professional, Scientific and Technical Services	16.4	5.3
Administrative and Support, Waste Management and Remediation Services	19.3	5.6
Arts, Entertainment and Recreation	-0.1	4.3
Accommodation and Food Services	14.2	2.2
Other Private Services	12.8	3.0
Total business sector	1.7	2.7

Note. The average share of surplus in nominal value-added is for the period 1961 to 2011.

Table 5

Intangible capital and labour productivity growth in the Canadian business sector

	1976-2000	**2000-2008**	**2000-20008 less 1976-2000**
Including SNA intangibles			
Labour productivity growth	1.5	0.7	-0.8
Contributions of:			
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 of:			
Capital deepening	1.3	1.4	0.1
Tangible	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	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

Source: Table 3 in Baldwin, Gu and MacDonald (2012).

Table 6

Multifactor productivity growth in the oil and gas extraction sector

	1961-2011	1961-1980	1980-2000	2000-2011
Real gross output	4.0	5.7	3.7	1.4
Contributions:				
Labour input	0.3	0.5	0.1	0.4
Capital input	2.7	3.7	1.6	3.0
Natural capital input	0.4	0.5	0.4	0.1
Intermediate input	1.5	1.5	1.8	0.9
MFP growth	-0.9	-0.5	-0.2	-3.0
Addendum				
Real output growth	4.0	5.7	3.7	1.4
Labour input growth	6.0	9.5	2.2	6.8
Capital input growth	5.9	7.5	3.9	6.9
Natural capital input growth	3.7	5.3	3.4	1.6
Intermediate input growth	5.4	7.6	4.8	2.6
MFP growth without natural capital	-1.8	-1.9	-0.7	-4.0

Table 7

Multifactor productivity growth in the mining sector (except oil and gas extraction)

	1961-2011	1961-1980	1980-2000	2000-2011
Real gross output	2.0	3.8	1.0	0.8
Contributions:				
Labour input	0.0	0.3	-0.4	0.3
Capital input	1.0	1.9	-0.2	1.8
Natural capital input	0.2	0.4	0.0	0.0
Intermediate input	1.0	2.1	0.0	1.0
MFP growth	-0.2	-0.9	1.6	-2.3
Addendum				
Real output growth	2.0	3.8	1.0	0.8
Labour input growth	0.3	1.1	-1.2	1.8
Capital input growth	3.4	6.0	-0.5	6.0
Natural capital input growth	1.7	3.2	1.1	0.4
Intermediate input growth	3.2	6.9	-0.1	3.0
MFP growth without natural capital	-0.6	-1.2	1.5	-3.4

Table 8

Contributions of public capital to MFP growth in the business sector

	1961-2013	1961-1980	1980-2000	2000-2013
MFP growth	0.4	1.0	0.4	-0.3
Public capital contribution	0.2	0.2	0.1	0.2
MFP growth net of public capital	0.3	0.8	0.3	-0.5

Table 9

MFP growth adjusted for capacity utilization in the manufacturing sector

	1961-2013	1961-1980	1980-2000	2000-2009	2009-2013
MFP growth	1.5	2.1	2.0	-0.8	2.0
MFP growth adj. for capacity	1.5	1.6	2.0	0.4	0.9
Addendum					
Value-added	2.8	5.0	3.3	-2.6	2.3
Labour input	0.7	2.3	0.8	-2.6	0.9
Capital input	2.6	4.5	2.6	-0.1	-0.7
Labour productivity	2.7	3.4	3.1	0.7	1.8

Table 10

Multifactor productivity in the business sector with various adjustments

	1961-2013	1961-1980	1980-2000	2000-2013
Official MFP	0.4	1.0	0.4	-0.3
MFP adjusted for natural capital and utilization	0.5	1.0	0.4	0.0
MFP with all adjustments	0.4	0.7	0.4	-0.2
Total adjustment	-0.1	-0.3	0.0	0.1
Contributions to overall adjustment:				
public capital	-0.2	-0.2	-0.1	-0.2
natural capital	0.1	0.1	0.0	0.1
capacity utilization	0.0	-0.1	0.0	0.1

Note: Total adjustment is the sum of the adjustments due to public capital, natural capital and capacity utilization.

Table 11
Country origins of effective multifactor productivity (EMFP) growth, by type of product, 1995 to 2000 and 2000 to 2007

Type of product and country	1995 to 2000					2000 to 2007				
	Canada	United States	Australia	Japan	European Union	Canada	United States	Australia	Japan	European Union
	percentage points									
EMFP growth in the production of										
Final demand product										
Canada	0.65	0.02	0.00	0.00	0.00	0.08	-0.01	0.00	0.00	0.00
United States	0.19	0.90	0.04	0.02	0.04	0.12	0.36	0.03	0.02	0.03
Australia	0.00	0.00	0.81	0.00	0.00	0.00	0.00	-0.26	-0.01	0.00
Japan	0.01	0.01	0.01	0.24	0.01	0.02	0.01	0.02	1.16	0.01
European Union	0.02	0.00	0.02	0.00	0.31	0.02	0.01	0.02	0.01	0.22
Total	0.86	0.92	0.89	0.27	0.35	0.23	0.37	-0.20	1.18	0.26
Consumption products										
Canada	0.39	0.01	0.00	0.00	0.00	0.09	-0.01	0.00	0.00	0.00
United States	0.12	0.73	0.04	0.01	0.03	0.09	0.43	0.03	0.01	0.03
Australia	0.00	0.00	0.84	0.00	0.00	0.00	0.00	-0.47	-0.01	0.00
Japan	0.01	0.01	0.01	0.10	0.01	0.01	0.01	0.01	1.09	0.01
European Union	0.01	0.00	0.02	0.00	0.33	0.01	0.01	0.01	0.00	0.19
Total	0.53	0.75	0.90	0.13	0.37	0.20	0.43	-0.41	1.09	0.22
Investment products										
Canada	1.47	0.03	0.00	0.00	0.00	0.05	0.00	-0.01	0.00	-0.01
United States	0.41	1.49	0.06	0.04	0.06	0.22	0.01	0.03	0.03	0.04
Australia	0.00	0.00	0.71	0.00	0.00	0.00	0.00	0.34	-0.01	0.00
Japan	0.03	0.02	0.02	0.57	0.01	0.04	0.02	0.02	1.38	0.02
European Union	0.03	0.01	0.03	0.01	0.19	0.03	0.01	0.02	0.01	0.32
Total	1.94	1.55	0.82	0.63	0.27	0.33	0.04	0.41	1.41	0.37
Export products										
Canada	1.31	0.03	0.00	0.00	0.00	-0.42	-0.01	-0.01	0.00	0.00
United States	0.33	3.10	0.04	0.07	0.07	0.20	2.05	0.03	0.05	0.05
Australia	0.00	0.00	0.94	0.00	0.00	-0.01	0.00	-1.30	-0.02	0.00
Japan	0.02	0.02	0.01	1.17	0.01	0.03	0.03	0.02	2.43	0.02
European Union	0.02	0.01	0.02	0.01	0.64	0.03	0.02	0.02	0.01	0.72
Total	1.68	3.17	1.02	1.26	0.73	-0.16	2.09	-1.25	2.48	0.78

Sources: Statistics Canada; authors' tabulations from world input-output tables and European Union-KLEMS (Capital, Labour, Energy, Materials and Services).

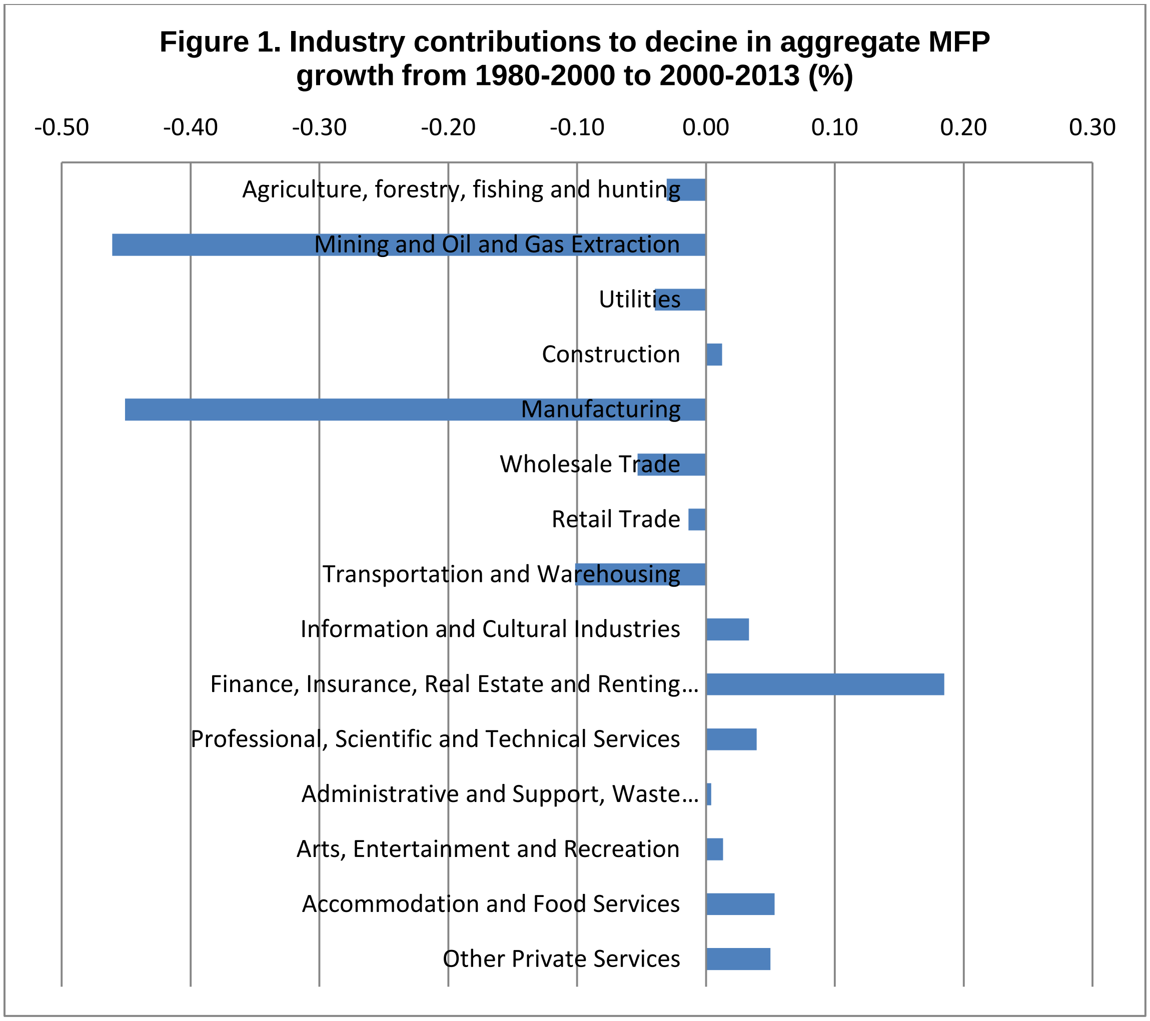
Figure 1. Industry contributions to decine in aggregate MFP growth from 1980-2000 to 2000-2013 (%)
-0.50
-0.40
-0.30
-0.20
-0.10
0.00
0.10
0.20
0.30
Agriculture, forestry, fishing and hunting
Mining and Oil and Gas Extraction
Utilities
Construction
Manufacturing
Wholesale Trade
Retail Trade
Transportation and Warehousing
Information and Cultural Industries
Finance, Insurance, Real Estate and Renting…
Professional, Scientific and Technical Services
Administrative and Support, Waste…
Arts, Entertainment and Recreation
Accommodation and Food Services
Other Private Services

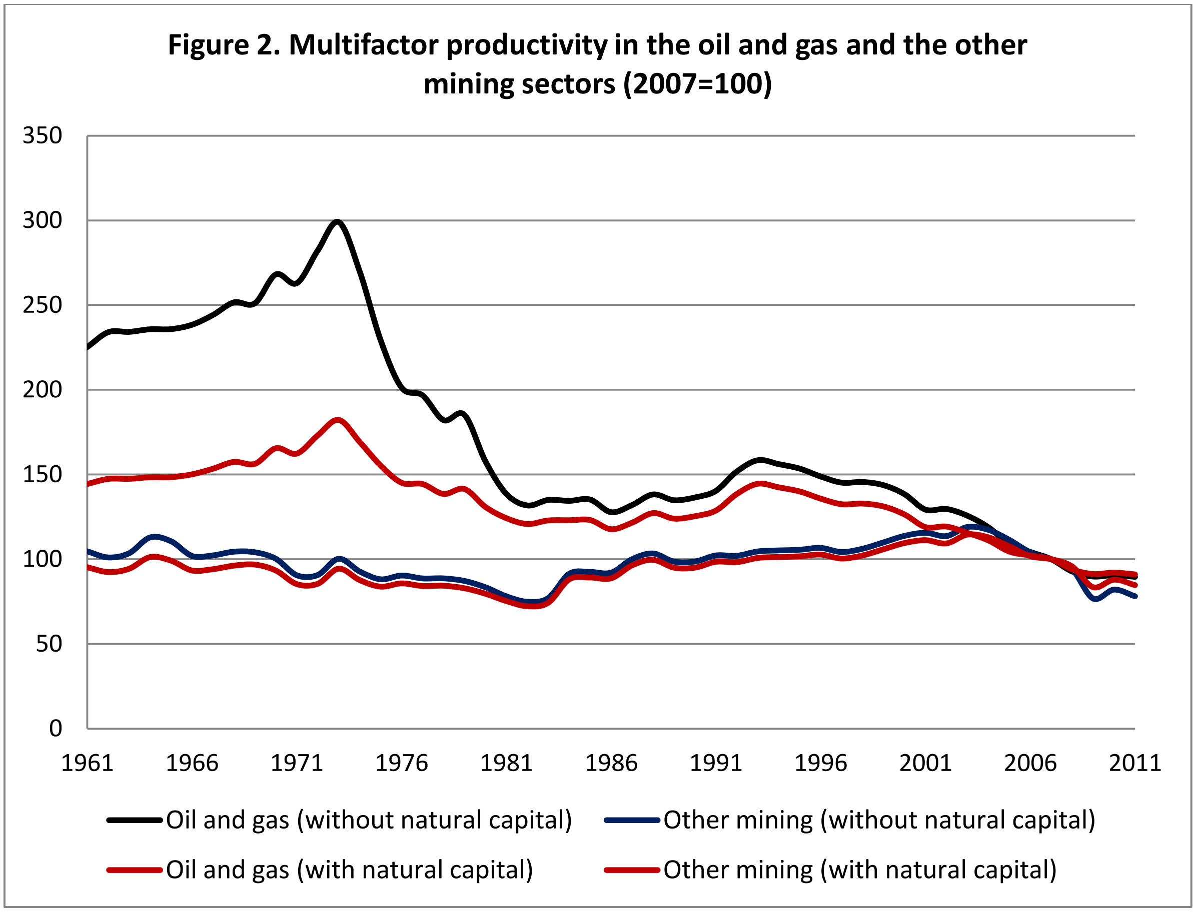
Figure 2. Multifactor productivity in the oil and gas and the other mining sectors (2007=100)
350
300
250
200
150
100
50
0
1961
1966
1971
1976
1981
1986
1991
1996
2001
2006
2011
Oil and gas (without natural capital)
Other mining (without natural capital)
Oil and gas (with natural capital)
Other mining (with natural capital)

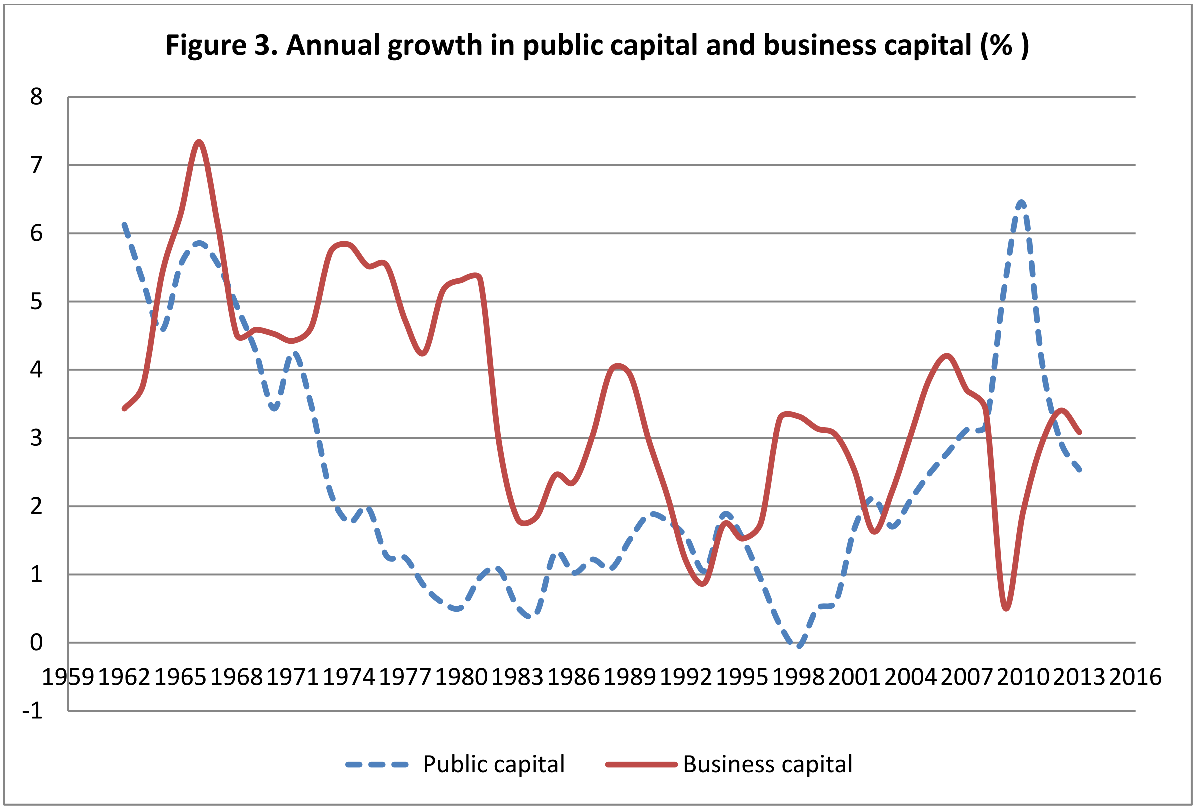
Figure 3. Annual growth in public capital and business capital (%)
8
7
6
5
4
3
2
1
0
-1
1959 1962 1965 1968 1971 1974 1977 1980 1983 1986 1989 1992 1995 1998 2001 2004 2007 2010 2013 2016
Public capital
Business capital

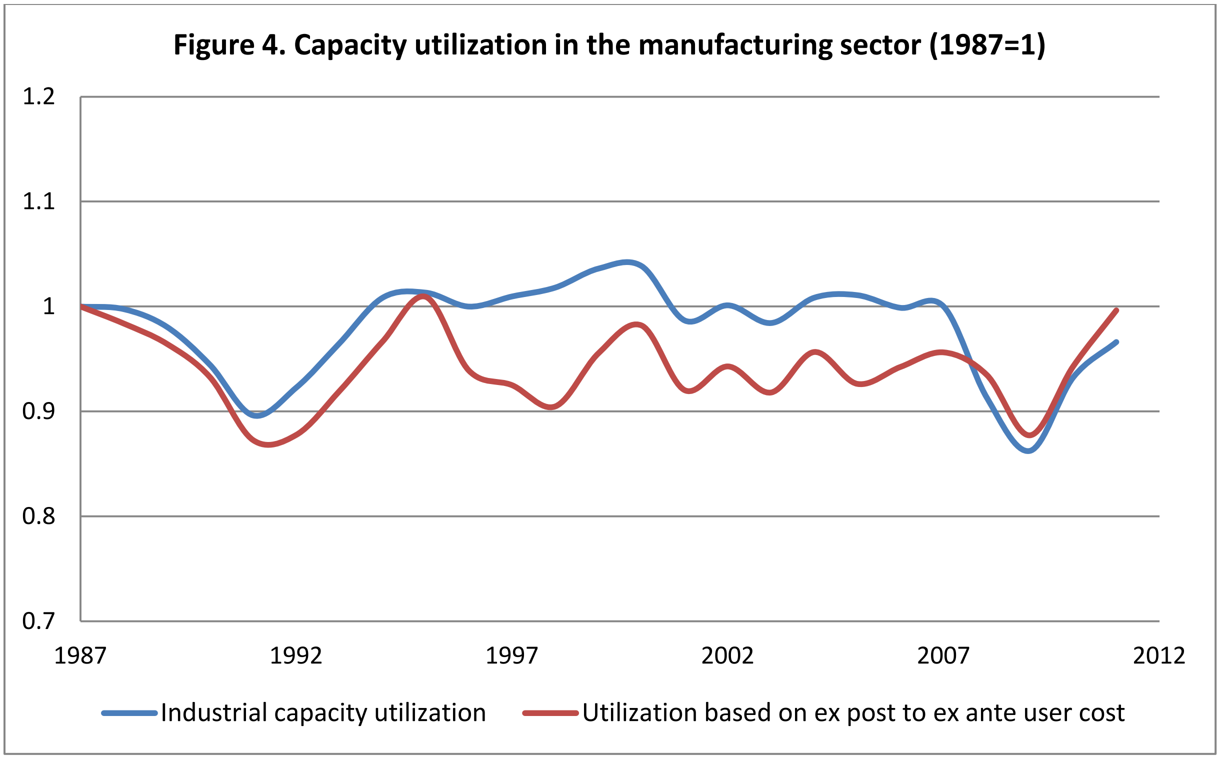
Figure 4. Capacity utilization in the manufacturing sector (1987=1)
1.2
1.1
1
0.9
0.8
0.7
1987
1992
1997
2002
2007
2012
Industrial capacity utilization
Utilization based on ex post to ex ante user cost

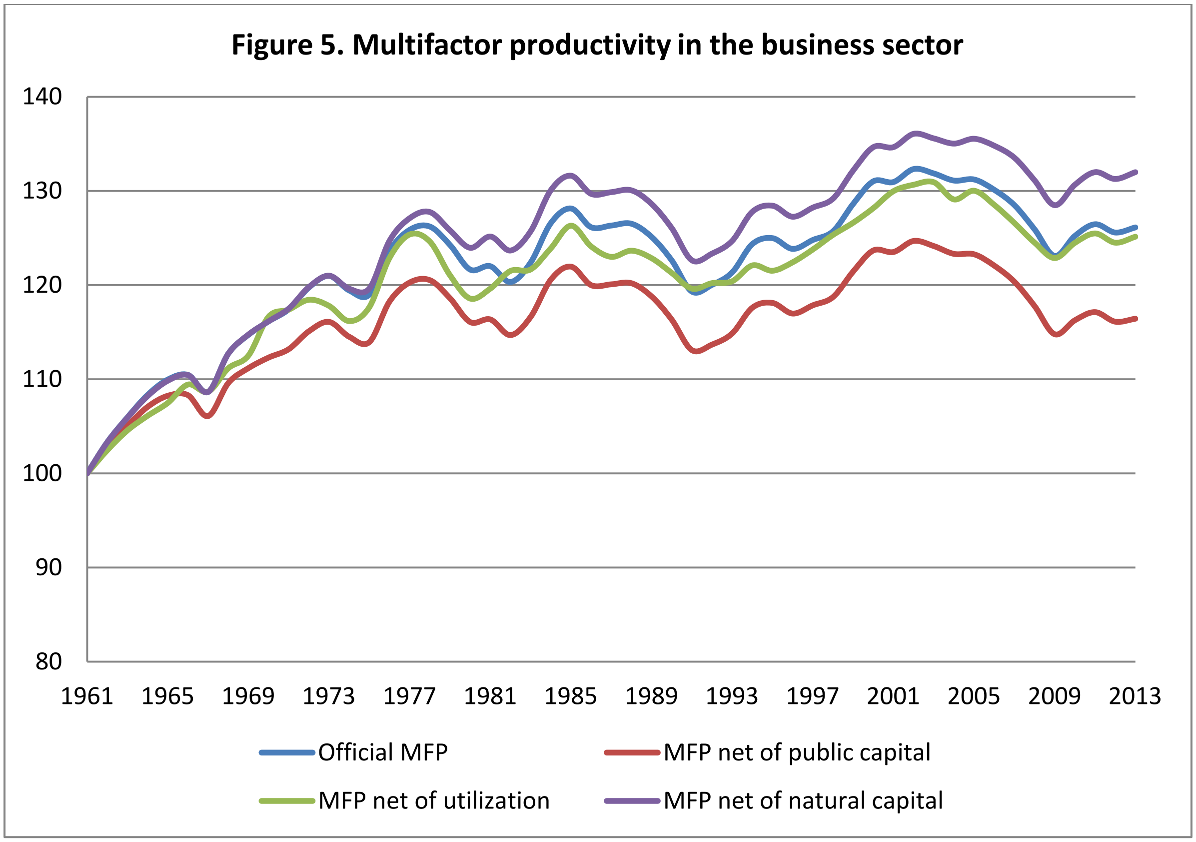
Figure 5. Multifactor productivity in the business sector
140
130
120
110
100
90
80
1961
1965
1969
1973
1977
1981
1985
1989
1993
1997
2001
2005
2009
2013
Official MFP
MFP net of public capital
MFP net of utilization
MFP net of natural capital