Has Trend Productivity Growth Increased in Canada? *

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ABSTRACT

It is still often argued that, in contrast to the United States where labour productivity growth accelerated markedly in the second half of the 1990s, there is no strong evidence of such acceleration in Canada. This paper argues that a significant acceleration in labour productivity growth also occurred in Canada but somewhat later than in the U.S. This view is further examined by estimating Canada's trend labour productivity growth within a neo-classical growth accounting framework. Our results suggest that trend labour productivity growth has indeed increased steadily since the early 1990s, reaching about 2 per cent in recent years, in line with recent estimates for the United States. This productivity improvement reflects both increased machinery and equipment capital deepening and TFP growth.

JEL classification code: O3, O4, O5

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* We thank Richard Landry from Investment and Capital Stock Division, Statistics Canada for kindly providing data on ICT capital stocks and Andrew Sharpe for comments. To some extent, this paper provides an update to Muir and Robidoux (2001). However, the methodology is different and information technology is defined more broadly. The views expressed in this paper are our own and should not be attributed to the Department of Finance.

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1. Introduction

It is well known that labour productivity growth has increased significantly in the U.S. since 1995. What is less widely recognized, however, is that a similar acceleration has occurred in Canada since 1996 (Table 1).[1] The acceleration in labour productivity growth amounted to about 1 percentage point in the business sector and ¾ of a percentage point for the total economy in both countries. In recent years, although labour productivity growth remains somewhat higher in the United States than in Canada for the business sector, this is not the case for the total economy where it averages 1.8 per cent in both countries.

As noted earlier, the much improved productivity performance of Canada since 1996 is largely overlooked in the productivity literature. For example, Sharpe (2002) in a review of recent productivity developments in the United States and Canada notes first that

> *"The second half of the 1990s saw a marked acceleration in labour productivity growth in the United States, but not in Canada"(p. 3)*

and concludes:

> *"While aggregate productivity growth in Canada in 2001 did somewhat better than might have been expected given the phase of the business cycle, there is certainly no strong evidence of an acceleration in productivity growth such as the United States experienced after 1995." (p. 10).*

To some extent this reflects the fact that the productivity performance of Canada and other countries is generally compared to that in the United States using the breakpoint specific to that latter country, which is 1995.[2] We argue that it is not appropriate to use the dating of the U.S. productivity revival as an universal benchmark for all countries. For example, labour productivity growth has improved earlier in Australia than in the United States. Concentrating on the pick up in labour productivity growth in the second half of the 1990s tend to hide the remarkable pick-up in Australian productivity growth.[3] We advocate that each country should be examined according to its own breakpoint. This is why in this paper we look at the change in labour productivity growth starting in 1995 in the United States, but in 1996 in Canada.

[1] Unless otherwise noted, labour productivity refers to output per hour, average rate of growth over sub-periods are simple average not compound, and when referring to average labour productivity growth over a given period, the first year refers to the base -year productivity level not growth.

[2] The difference of views does not reflect differences in period examined since Sharpe (2002) sample ends in 2001 as ours, but may reflect data revisions. And to be fair, we need to acknowledge that Sharpe and Gharani (2000) concluded that "Canada will see a significant pick-up in productivity growth (to at least the 2-2.5 per cent range for business sector output per hour) over the next decade if not for two decades." (p.5)

[3] See Parham (2002) for an analysis of the Australian productivity performance.

In the United States, there is a consensus emerging from aggregate growth accounting analyses that development in information and communication technologies (ICT) was a key factor in their much improved productivity performance.[4] According to these analyses, it appears indisputable that a significant proportion of the acceleration in U.S. labour productivity growth since 1996 can be explained by an increase in total factor productivity (TFP) growth in the ICT sector, together with the associated ICT capital boom in the rest of the U.S. economy. However, there is not much evidence that TFP growth outside of the ICT sector has also contributed to the U.S. productivity resurgence, particularly when the more recent 1996-2001 period is examined (Oliner and Sichel (2002)).

This first objective of this paper is to examine within a standard growth accounting framework the source of the acceleration in labour productivity growth in Canada since 1997 and determine if ICT played a role as prominent as in the United States. The second objective is to assess whether the recent improvement in Canada's productivity performance is structural or cyclical by developing an estimate of trend labour productivity growth. Building on the growth accounting framework, we examine the sources of trend labour productivity growth, paying particular attention to information and communication technology (ICT) capital.

The rest of this paper is organized as follows. Section 2 outlines the growth accounting framework and how we used it to estimate trend labour productivity growth. Section 3 discusses our empirical results. Finally, section 4 presents the conclusion.

2. The Analytical Framework

In this paper, we use the standard neo-classical growth accounting framework pioneered by Solow (1957) and used extensively in many studies to assess the source of the U.S. productivity revival since 1995. The growth accounting framework decomposes the growth in output into the contributions from increases in labour, capital and total factor productivity (TFP). Alternatively, it decomposes the growth in labour productivity into contributions from increases in the amount of capital per unit of labour—capital deepening—and TFP. More specifically, the growth accounting stipulates that:

(1) $$\dot{Y}_t - \dot{N}_t = \dot{TFP}_t + \left[1 - \frac{(\alpha_t + \alpha_{t-1})}{2}\right]\sum_i \left(\frac{\beta_{i,t} + \beta_{i,t-1}}{2}\right)(\dot{K}_{i,t} - \dot{N}_t)$$

where a dot over a variable represents the rate of growth of that variable, Y denotes total-economy output, N denotes hours worked, K_i denotes the capital stock of asset i, α denotes the elasticity of output with respect to hours worked and $(1-\alpha)\beta_i$ denotes the elasticity of output with respect to asset capital stock i. The neo-classical growth

[4] See Oliner and Sichel (2002), Jorgenson, Ho and Stiroh (2002, 2003) for recent assessments.

framework assumes that product and labour markets are competitive and that the underlying production process exhibits constant returns to scale with respect to labour and capital. As a result, the output elasticity with respect to each of the production factors equals the factors' income shares in total nominal output and sum to one.

Five distinct types of capital are identified in the analysis: the stocks of computers and office equipment (C), software (S), telecommunication equipment (T), other machinery and equipment (ME) and of non-residential construction (NRS). Thus capital deepening in equation (1) is the sum of the contributions from five types of capital that can be aggregated in two large components: non-residential construction and machinery and equipment. Machinery and equipment in turn is the sum of information and communication technology (ICT)—computers, software and telecommunication—and other machinery and equipment.

In the growth accounting framework, total factor productivity growth is obtained residually by subtracting income-share weighted input growth from output growth. In that framework, TFP growth is assumed to be exogenous to aggregate demand shocks. However, it is well known that estimated TFP growth tends to be pro-cyclical. In order to estimate trend labour productivity growth it is necessary to obtain a measure of TFP growth that respects the theoretical prior of being exogenous to aggregate demand shocks. To that end, the capital stocks, *K*, used in this paper are adjusted for variable capacity utilization rates.[5] As shown by Paquet and Robidoux (2001), estimated TFP growth is exogenous to variables that are known to be the sources of aggregate demand fluctuation, such as monetary, fiscal and foreign conditions, when capacity-adjusted capital stocks are used.

The next step consists of estimating trend labour productivity growth. Using lower-case letters to denote trend values, we get an equation that parallel the equation 1:[6]

(2) $$\dot{y}_t - \dot{n}_t = \dot{tfp}_t + \left[1 - \frac{(\alpha_t + \alpha_{t-1})}{2}\right] \sum_i \left(\frac{\beta_{i,t} + \beta_{i,t-1}}{2}\right)(\dot{k}_{i,t} - \dot{n}_t)$$

The trend level of hours worked, *n*, corresponds to the level of hours worked that is consistent with estimated trend hours worked per worker, the trend labour force participation rate and the natural rate of unemployment. The trend level of the capital stocks, k_i, corresponds to the capital stock unadjusted for capacity utilization (i.e. a capacity utilization rate of one). Trend TFP, *tfp*, is obtained by filtering the raw TFP series with an HP filter.[7]

[5] In the Canadian context, Wilkins et al (1992) have pioneered this approach.

[6] This measurement of trend labour productivity growth is inspired by the standard structural approach to the measurement of potential output growth.

[7] The Hodrick-Prescott (HP) filter is a two-sided linear filter that allows users to set the degree of smoothness for the trend series.

3. Empirical Results

In this section we present the empirical results obtained for Canada with the growth accounting framework presented above. Labour productivity growth corresponds to the rate of change in total-economy output per hours worked over the 1971-2001 period at annual frequency.[8] Although the main goal of our analysis is to estimate trend labour productivity growth, it is instructive to first use this framework to examine actual labour productivity growth. Moreover, since most studies do not correct for variations in capacity utilization, the growth accounting decomposition of labour productivity growth is first performed without capacity utilization rate adjustments for comparison purposes.

3.1 Growth Accounting Without Capacity Utilization Rate Adjustments

As noted above, from 1996 to 2001, total-economy labour productivity grew at an average annual rate of 1.8 per cent compared with an average increase of only 1.1 from 1988 to 1996. This improvement of 0.7 percentage point in labour productivity growth is decomposed between capital deepening and total factor productivity growth in Table 2 assuming that capital is always fully used—i.e. capital stocks are not adjusted for variations in capacity utilization rates.

Increased M&E capital deepening explains a bit less than half of the increase in labour productivity growth. Computer capital deepening accounts for two-third of the M&E capital deepening, while software and telecommunication do not contribute significantly. However, increased M&E capital deepening is offset by reduced structure capital deepening, leaving no role to capital in aggregate in explaining the improvement in labour productivity growth since 1996. As a result, all of the improvement is explained by an increase in total factor productivity growth. Armstrong et al. (2002) find similar results for the Canadian business sector by comparing 1995-2000 and 1988-1995 periods.[9] Although we do not decompose TFP growth between ICT and non-ICT sectors in this paper, Muir and Robidoux (2001) show that the ICT-producing sector has not contributed significantly to the improvement in TFP growth observed in Canada in the late 1990s. Overall, this suggests that most of the improvement in TFP growth experienced in Canada in the late 1990s originated outside of the ICT sector.

[8] More details on data definition and construction as well as on annual results are included in Annex 1.

[9] The exact comparison is provided in Annex 2. Aside from considering the business sector instead of the total economy, one important difference between our analysis and the study by Armstrong *et al.* (2002) is the definition of the capital input. While they use capital services, where each capital asset received a weight proportional to its marginal product—its user cost—we use instead capital wealth stocks. It is well know that capital services is conceptually better than capital stocks as measure of capital input in productivity analysis (see Steindel and Stiroh (2001) for a non-technical discussion). Nevertheless, our findings for capital deepening during the 1990s are almost identical to those obtained by Armstrong *et al.* (2002) using capital services.

These results for Canada contrast with those obtained by most studies for the United States. Table 3 compares our results with those obtained by Oliner and Sichel (2002) for the U.S. non-farm business sector.[10] In the United States, higher ICT capital deepening and higher TFP growth in the ICT sector essentially explain all the improvement since 1995. U.S. TFP growth in other sectors taken together hardly shows any improvement. To the contrary, as noted above, higher TFP growth outside of the ICT sector appears to be the source of the improvement in Canada since 1996.[11,12]

3.2 Growth Accounting With Capacity Utilization Rate Adjustments

Adjusting capital stocks for variations in their utilization does not affect much the results for the 1996-2001 period but decreases the contribution from capital deepening and increases the contribution from TFP growth for the 1988-1996 period (Table 4). Excess supply and hence under-utilization of capital on average over the 1988-1996 period leads to lower capital deepening effect. As a result, about forty per cent of the improvement is now explained by capital deepening, mainly M&E investment, and sixty per cent by TFP growth.

3.3 Trend Labour Productivity Growth

Our average estimates of trend labour productivity growth for the same sub-periods are presented in Table 5. They suggest that trend labour productivity growth has increased to about 2 per cent on average over the 1996-2001 period, up from an average of 1.1 per cent over the 1988-1996 period. Although its contribution is reduced at the expense of capital deepening, TFP growth remains a key source of the increase in labour productivity growth. TFP growth now accounts for half of the increase in trend labour productivity growth, while capital deepening contributes to the other half.[13] Excluding capital structure that contributes negatively to the change in labour productivity growth, M&E capital deepening added ½ percentage points to labour productivity growth from 1988-1996 to 1996-2001. With respect to the increase in M&E capital deepening, ICT—mainly computer—accounts for about sixty per cent and other M&E equipment for about forty per cent.

[10] Since labour quality is not taken into account in our analysis, labour quality effect must be added to TFP growth in the Oliner and Sichel (2002) results before comparing to our TFP growth results.

[11] This striking difference between the two countries may possibly, at least to some extent, reflects differences in methodologies and data definition. For example, Oliner and Sichel (2002) use the non-farm business output, while we use total-economy output. See Armstrong *et al.* for a consistent comparison of the sources of output growth in the Canadian and U.S. business sector.

[12] Over the 1995-2001 period, ICT capital deepening contribute 1 percentage point to labour productivity growth in the U.S. according to Oliner and Sichel (2002), but only about 0.5 percentage point in Canada according to our results (capacity unadjusted). The higher contribution in the U.S. may reflect higher growth in ICT capital, lower growth in hours worked or higher ICT capital income share. Although this investigation is beyond the scope of this paper, information included in Oliner and Sichel (2000, 2002) suggests that with respect to capital, differences reside more in income shares than in growth rates.

[13] Higher contribution from capital deepening over the 1996-2001 reflects mainly the lower rate of growth in trend hours worked than in actual hours worked.

As noted above, our estimates suggest that trend labour productivity growth increased to about 2 per cent in recent years. The two major sources of trend labour productivity growth over the 1996-2001 are M&E capital deepening and TFP growth. Chart 1 shows the contribution to trend labour productivity growth from M&E capital deepening. If we exclude a spike in the early 1980s, capital deepening originating from machinery and equipment has recently reached levels never seen in the last three decades, contributing about 1 percentage point to trend labour productivity growth. Most of the M&E capital deepening comes from ICT capital and within ICT, computer is the most important contributor, followed by software and telecommunication. It is also interesting to note that ICT capital deepening is to a large extent acyclical, while, in contrast, other M&E capital deepening is somewhat procyclical.[14]

The other major contributor of trend labour productivity growth is trend TFP growth, which is plotted in Chart 2 along with raw TFP growth. As for M&E capital deepening, trend TFP growth reached in recent years levels never seen in the last three decades, contributing about 1 percentage point to trend labour productivity growth. Trend TFP growth fell from elevated levels during the 1970s, stalled during the 1980s and resumed in the 1990s. As for ICT capital deepening, capacity-adjusted raw TFP growth is acyclical. In contrast, capacity-unadjusted raw TFP growth, used in most growth accounting studies, tends to be highly procyclical.[15]

Estimated trend labour productivity growth is plotted in Chart 3 along with labour productivity growth. Again, aside from a short-lived spike in the early 1980s, trend labour productivity growth in recent years reached levels not seen since the early 1970s. At 2 per cent, how does our estimate of trend labour productivity growth compare to estimates for the U.S. economy? Using the growth accounting framework, Oliner and Sichel (2002) concludes that trend labour productivity growth in the U.S. non-farm business sector fall within the range of 2 to 2.8 per cent. They also survey a dozen of other studies that arrive to similar range estimates and with the same average point estimate of 2.4 percent. Given that productivity growth averages about ½ a percentage point higher in the non-farm business sector than in the total economy in the U.S. in the 1990s, this suggests that total-economy trend labour productivity growth is also around 2 per cent in the United States.

4. Concluding Remarks

This paper argued that labour productivity growth in Canada increased as much as in the U.S. since 1996, particularly when measures covering the whole economy are considered. Standard growth accounting suggests that a marked improvement in TFP growth is the

[14] In our sample, the correlation between real GDP growth and ICT capital deepening is –0.02, while the correlation between real GDP growth and other M&E capital deepening is 0.31.

[15] In our sample, the correlation between real GDP growth and capacity-adjusted raw TFP growth is –0.02, while the correlation between real GDP growth and capacity-unadjusted raw TFP growth is 0.81.

key source of the resurgence in labour productivity growth in Canada, contrasting with the United States where the production and use of ICT have been identified as key factors.

We also used the growth accounting framework to develop an estimate of trend labour productivity growth for Canada. Our results suggest that trend labour productivity growth has increased steadily in the 1990s, reaching about 2 per cent in recent years[16], in line with recent estimates for the United States. The improvement in trend labour productivity growth does not only reflect higher TFP growth, but also increased capital deepening in ICT and other M&E.[17] Overall, these results tend to confirm findings found earlier in Muir and Robidoux (2001).

There is surely a great deal of uncertainty surrounding any estimate of trend productivity growth. That said, our analysis provides empirical evidence that support a cautiously optimistic view. It also lends support to the view that structural reforms and the adoption of sound monetary and fiscal frameworks have provided the necessary conditions for a transition towards a more productive and innovative economy.

[16] The solid labour productivity growth performance in 2002 suggests that the improving trend continued last year. There is no doubt that the large reduction in business investment during the last slowdown led to slower capital deepening in 2002 and will probably continue to do so this year. At the same time, this suggests that TFP growth is still on an upper trend.

[17] It is somewhat hazardous to compare the sources of trend labour productivity growth between Canada and the United States given differences in methodology and data and hence one has to remain cautious in comparing estimates. Nevertheless, keeping this mind, comparing our estimate of trend labour productivity growth to steady-state estimates of Oliner and Sichel (2002) suggests similar contributions from capital deepening and TFP growth. However, within these two broad aggregates, ICT (use and production) appears to play a larger role in the United States than in Canada.

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TABLE 1
LABOUR PRODUCTIVITY GROWTH*
Per cent

	(1) 1972-1988	(2) 1988-1996	(3) 1996-2001	(3)-(2) Change
CANADA				
Business Sector	1.4	1.1	2.0	0.9
Total Economy	1.2	1.1	1.8	0.7
	(1) 1972-1988	**(2) 1988-1995**	**(3) 1995-2001**	**(3)-(2) Change**
UNITED STATES				
Business Sector	1.6	1.4	2.4	1.0
Total Economy	1.3	1.1	1.8	0.7

* In all tables, labour productivity corresponds to total-economy real GDP per hours worked. Real GDP growth is based on a Fisher-chained index from the National Economic and Financial Accounts and hours worked are from the Labour Force Survey.

TABLE 2
LABOUR PRODUCTIVITY GROWTH
Without Capacity Utilization Rate Adjustment
Per cent

	(1) 1972-1988	(2) 1988-1996	(3) 1996-2001	(3)-(2) Change
Productivity Growth	1.2	1.1	1.8	0.7
Contributions from:				
Capital Deepening	1.0	0.9	0.7	-0.1
Machinery and Equipment	0.6	0.6	0.9	0.3
ICT	0.3	0.4	0.6	0.2
Computer	0.2	0.2	0.3	0.2
Software	0.1	0.1	0.2	0.0
Communication	0.0	0.1	0.1	0.0
Other M&E	0.3	0.2	0.3	0.1
Non-residential Construction	0.4	0.3	-0.1	-0.4
Total Factor Productivity	0.2	0.2	1.0	0.8

* Details may not sum to totals because of rounding.

TABLE 3
COMPARISON WITH OLINER AND SICHEL (2002)
Without Capacity Utilization Rate Adjustment
Per cent

	Oliner and Sichel (2002)			This Study		
	1990-1995	1995-2001	Change	1988-1996	1996-2001	Change
Productivity Growth	1.5	2.4	0.9	1.1	1.8	0.7
Contributions from:						
Capital Deepening	0.5	1.2	0.7	0.9	0.7	-0.1
ICT	0.5	1.0	0.6	0.4	0.6	0.2
Computer	0.2	0.5	0.4	0.2	0.3	0.2
Software	0.2	0.4	0.1	0.1	0.2	0.0
Communication	0.1	0.1	0.1	0.1	0.1	0.0
Other Capital	0.1	0.2	0.1	0.5	0.1	-0.3
Total Factor Productivity	0.6	1.0	0.4	0.2	1.0	0.8
ICT	0.4	0.8	0.4	-	-	-
Other Sectors	0.2	0.2	0.1	-	-	-
Labour Quality	0.5	0.3	-0.2	-		-

* Details may not sum to totals because of rounding.

TABLE 4
LABOUR PRODUCTIVITY GROWTH
With Capacity Utilization Rate Adjustment
Per cent

	(1) 1972-1988	(2) 1988-1996	(3) 1996-2001	(3)-(2) Change
Productivity Growth	1.2	1.1	1.8	0.7
Contributions from:				
Capital Deepening	1.2	0.6	0.8	0.3
Machinery and Equipment	0.7	0.5	0.9	0.4
ICT	0.3	0.3	0.6	0.3
Computer	0.2	0.2	0.3	0.2
Software	0.1	0.1	0.2	0.1
Communication	0.0	0.0	0.1	0.0
Other M&E	0.3	0.1	0.3	0.2
Non-residential Construction	0.5	0.1	-0.1	-0.1
Total Factor Productivity	0.0	0.5	0.9	0.4

* Details may not sum to totals because of rounding.

TABLE 5
TREND LABOUR PRODUCTIVITY GROWTH
Per cent

	(1) 1972-1988	(2) 1988-1996	(3) 1996-2001	(3)-(2) Change
Productivity Growth	1.1	1.1	1.9	0.8
Contributions from:				
Capital Deepening	1.1	0.5	1.0	0.4
Machinery and Equipment	0.6	0.5	0.9	0.5
ICT	0.3	0.3	0.6	0.3
Computer	0.2	0.2	0.4	0.2
Software	0.1	0.1	0.2	0.1
Communication	0.0	0.0	0.1	0.0
Other M&E	0.3	0.1	0.3	0.2
Non-residential Construction	0.5	0.1	0.0	-0.1
Total Factor Productivity	0.0	0.5	0.9	0.4

* Details may not sum to totals because of rounding.

Chart 1: Contribution of Capital Deepending to Trend Labour Productivity Growth

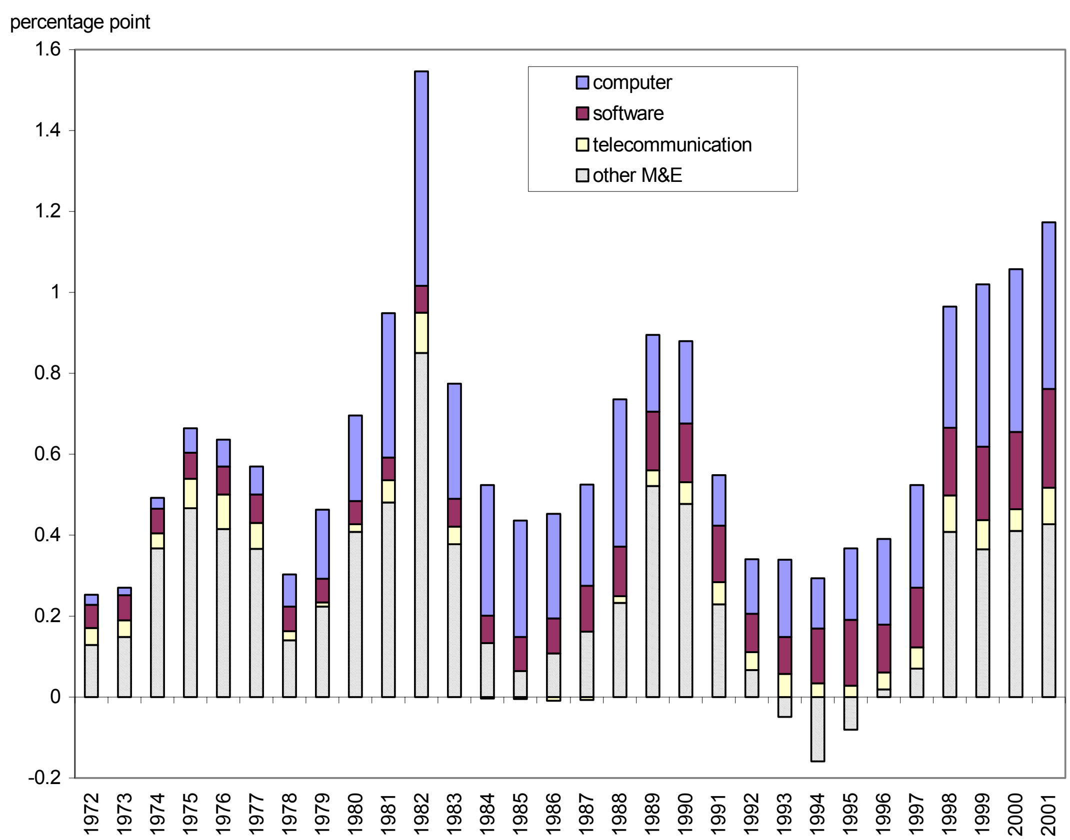


Chart 2: Total Factor Productivity Growth

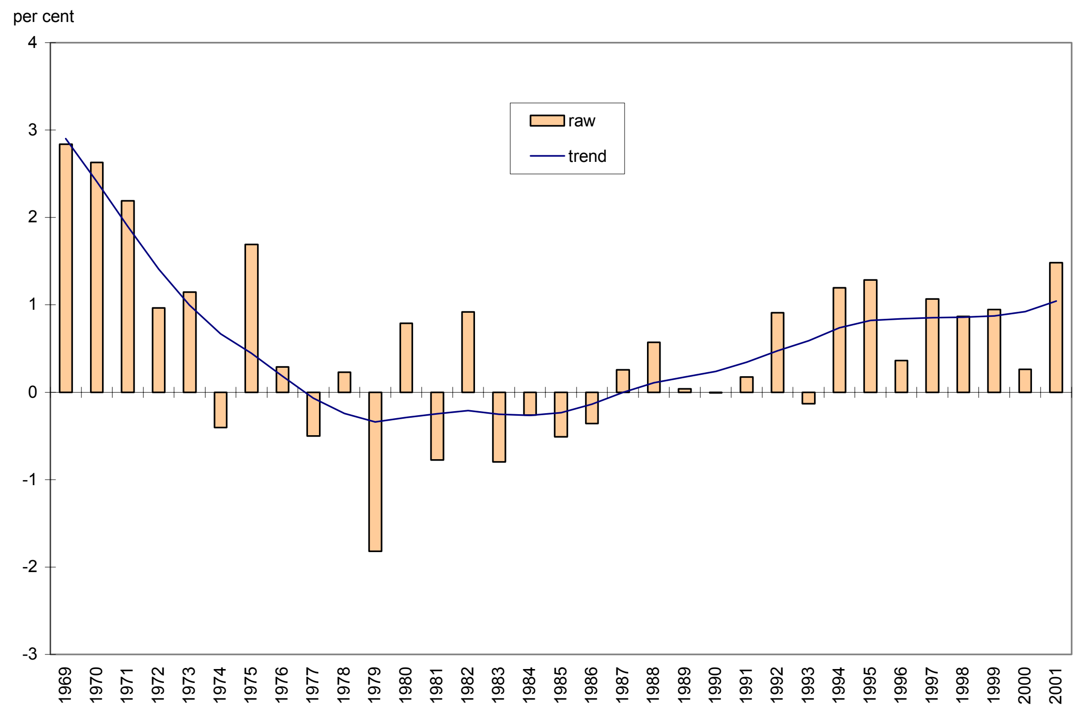
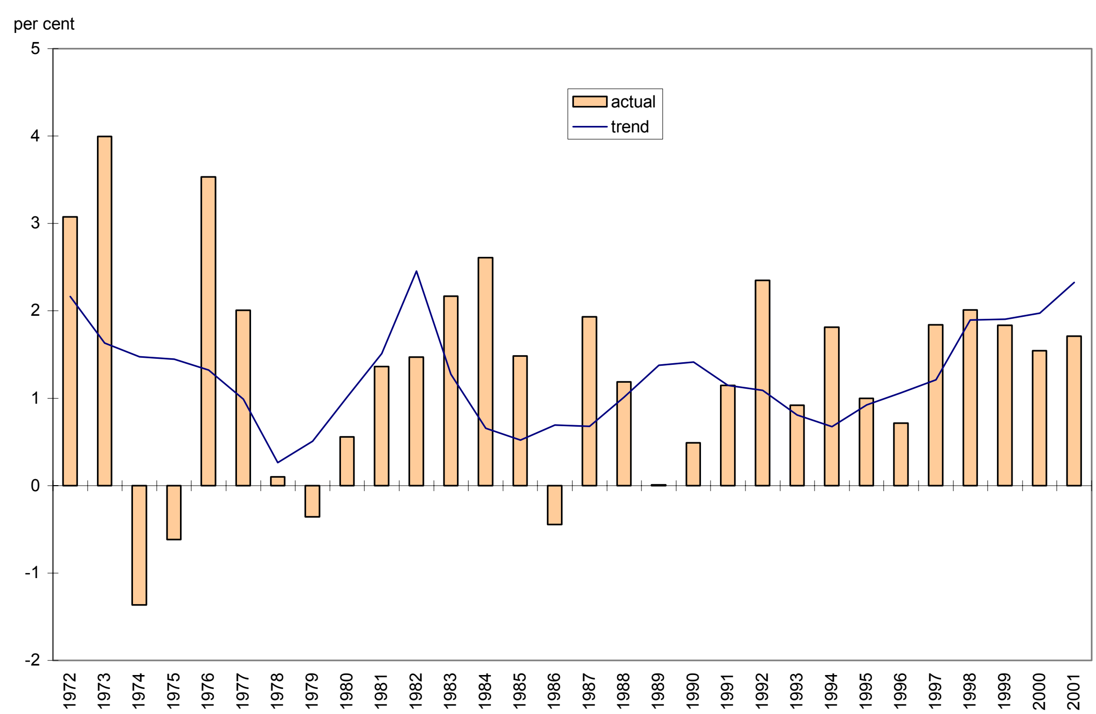


Chart3: Labour Productivity Growth



Annex 1: Data Sources

This annex describes data used in the growth accounting decomposition as described by equations (1) and (2), where output (Y_t) is defined as the total-economy real Fisher-chained GDP.

Capital stocks

Annual Fisher-chained capital stock data are taken from the Investment and Capital Stock Division (ICSD) of Statistics Canada. We only employ business-sector capital stock (i.e. it excludes all capital related to the public sector) in our growth accounting framework. This allows us to do more direct comparisons of capital deepening effects with studies examining the U.S. business sector. There are two main components of the capital stock – machinery and equipment, and non-residential construction (k_{NRS}). The stock of machinery and equipment is further decomposed into information and communication technology equipment (k_{ICT}) and other machinery and equipment (k_{ME}). The stock of information and communication technology corresponds to the stock of computers and office equipment (k_C), software (k_S), and telecommunication equipment (k_T). Our aggregate capital stock is thus defined as

$$\text{(A1)} \quad k_t = k_{NRS,t}^{\beta_{NRS,t}} \, k_{C,t}^{\beta_{C,t}} \, k_{S,t}^{\beta_{C,t}} \, k_{T,t}^{\beta_{T,t}} \, k_{ME,t}^{\beta_{ME,t}} \; ; \qquad \sum_i \beta_{i,t} = 1 \quad , \quad i = NRS, C, S, T, ME.$$

Then capital stocks $k_{i,t}$ are adjusted by the total-industrial capacity utilization rate U_t, normalized to average to unity over the period from 1970-1989, such that:

$$\text{(A2)} \quad K_t = U_t \, k_t \; .$$

Both current-dollar and Fisher chain-dollar capital stock data for software begin in 1981 only. In order to obtain a longer capital stock series for software (and by implication the total factor productivity growth series), we have assumed that software capital had increased at the same trend pace as computer capital stock between 1961 and 1981. This appears to be a reasonable hypothesis based on growth rates observed in the 1980s for both types of capital. The trend growth rate in computer capital stocks has been obtained from an HP filtering of the raw series. While this is an arbitrary procedure, it should not affect much our overall results since the capital stock for software in 1981 is only slightly above $1 billion.

We have also made a small adjustment to the total-industrial capacity utilization rate series from Statistics Canada. Beginning with the third-quarter of 2001 National Accounts update, the industry classification of this series has switched from the SIC to NAICS industrial classification. The switch has resulted in a shorter series, available from 1987 onward only. We extended the series backward by splicing it to the old SIC series, adjusting the level of the latter series by the difference between the two series in 1987.

Labour input

Labour input N_t is represented by total hours worked by all workers, constructed using data from the Labour Force Survey of Statistics Canada.

Income shares

We need to estimate six time-varying income shares corresponding to one labour input and five capital inputs. Following Oliner and Sichel (2000), we use the following system of six equations to solve for capital income shares:

$$\text{(A3)} \quad \phi_{i,t} = (r_t + \delta_{i,t} - \pi_{i,t}) \times \tilde{K}_{i,t} \times \frac{\tau_{j,t}}{\tilde{Y}_t} \quad ; \quad i = NRS, C, S, T, ME; \quad j = ME, NRS;$$

$$\sum_i \phi_{i,t} = 1 - \alpha_t \quad .$$

$\phi_{i,t}$ is the time-varying income share of capital type *i* (equivalent to $(1-\alpha_t)\beta_{i,t}$); r_t is the nominal rate of return, assumed to be common to all capital stocks; $\delta_{i,t}$ is the depreciation rate for capital type *i*, calculated as chained depreciation divided by the one-period lag capital stock; $\pi_{i,t}$ is a three-year moving-average rate of change of the investment deflator *i*; $\tilde{K}_{i,t}$ is current-dollar capital stock from Statistics Canada; $\tau_{j,t}$ is the tax adjustment taken from the CEFM database, and assumed to be common among all M&E capital types but different for non-residential construction capital; $\tilde{Y}_t$ is the nominal level of total-economy GDP; the time-varying labour share α_t is calculated as the ratio of wages and salaries and supplementary labour income to nominal GDP at factor cost. There are six equations in (A3) to solve for the six unknowns: The five income shares and the nominal return r_t. Simulation starts in 1968 and ends in 2001.

Total factor productivity growth

TFP growth is the Solow residual calculated by rearranging equation (1):

$$\text{(A4)} \quad \Delta \log(TFP_t) = \Delta \log(Y_t) - \frac{(\alpha_t + \alpha_{t-1})}{2} \cdot \Delta \log(N_t) - \sum_i \frac{(\phi_{i,t} + \phi_{i,t-1})}{2} \cdot \Delta \log(K_{i,t}) \, ;$$

$$i = NRS, C, S, T, ME \, .$$

Note that all the capital stocks K_i are adjusted by the capacity utilization rate. For estimates where no capacity adjustments are made, $K_{i,t}$ is replaced by $k_{i,t}$.

Trend labour input and TFP

Trend TFP growth is estimated by applying an HP filter[18] to raw TFP growth. The trend growth in capital stocks simply corresponds to the growth in capital stocks unadjusted for capacity utilization rate. Trend total hours worked are calculated according to the expression:

$$n_t = \frac{lf_t}{LF_t} \times lfe_t \times lfah_t \times 52 \qquad \text{(A5)}$$

where *lf* is denotes the trend labour force (the labour force when participation rates are at trend), *lfe* is the natural level of employment (derived from an estimate of the natural rate of unemployment and of the actual labour force), and *lfah* is the trend average weekly hours per worker. All these estimates are taken from the most recent estimates of CEFM (see Robidoux and Wong (1988) for details on the estimation methodology).

[18] The smoothing parameter is set at 6.25 following Ravn and Uhlig (2002) suggestion.

Table A1: Contributions to Labour Productivity Growth

Per cent

	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
1. Actual labour productivity growth	1.19	0.01	0.49	1.15	2.35	0.92	1.81	1.00	0.71	1.84	2.01	1.83	1.55	1.71
(Adjusting capital stocks for capactity utilization rate)														
Contributions from:														
2. Capital deepening	0.61	-0.03	0.49	0.97	1.41	1.05	0.60	-0.29	0.35	0.76	1.12	0.87	1.27	0.21
3. Machinery and equipment	0.63	0.42	0.62	0.61	0.63	0.58	0.36	0.15	0.43	0.66	1.00	0.96	1.14	0.76
4. ICT	0.48	0.28	0.35	0.33	0.34	0.40	0.35	0.34	0.38	0.49	0.56	0.64	0.67	0.64
5. Computer	0.36	0.16	0.19	0.13	0.15	0.21	0.14	0.17	0.21	0.26	0.30	0.40	0.41	0.38
6. Software	0.12	0.12	0.13	0.14	0.11	0.11	0.15	0.15	0.12	0.16	0.17	0.18	0.20	0.20
7. Telecommunication	0.01	0.00	0.03	0.06	0.07	0.08	0.05	0.02	0.05	0.06	0.09	0.07	0.06	0.06
8. Other machinery and equipment	0.15	0.14	0.27	0.28	0.30	0.18	0.01	-0.18	0.05	0.18	0.43	0.32	0.47	0.12
9. Non-residential construction	-0.02	-0.46	-0.12	0.36	0.78	0.46	0.24	-0.44	-0.08	0.09	0.13	-0.09	0.13	-0.55
10. Total factor productivity	0.57	0.04	-0.01	0.17	0.91	-0.13	1.19	1.28	0.36	1.07	0.87	0.95	0.26	1.49
11. Log approximation error	0.01	0.00	0.00	0.01	0.03	0.00	0.02	0.00	0.00	0.02	0.02	0.02	0.01	0.01

	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
12. Trend labour productivity growth	1.01	1.38	1.41	1.15	1.09	0.81	0.68	0.92	1.06	1.21	1.90	1.90	1.97	2.33
Contributions from:														
13. Capital deepening	0.90	1.21	1.17	0.80	0.62	0.22	-0.06	0.10	0.22	0.35	1.04	1.03	1.05	1.28
14. Machinery and equipment	0.74	0.90	0.88	0.55	0.34	0.29	0.13	0.29	0.39	0.52	0.97	1.02	1.06	1.17
15. ICT	0.50	0.37	0.40	0.32	0.27	0.34	0.29	0.37	0.37	0.45	0.56	0.66	0.65	0.75
16. Computer	0.36	0.19	0.20	0.13	0.13	0.19	0.12	0.18	0.21	0.25	0.30	0.40	0.40	0.41
17. Software	0.12	0.14	0.14	0.14	0.10	0.09	0.13	0.16	0.12	0.15	0.17	0.18	0.19	0.24
18. Telecommunication	0.02	0.04	0.05	0.06	0.04	0.06	0.03	0.03	0.04	0.05	0.09	0.07	0.05	0.09
19. Other machinery and equipment	0.23	0.52	0.48	0.23	0.07	-0.05	-0.16	-0.08	0.02	0.07	0.41	0.36	0.41	0.43
20. Non-residential construction	0.16	0.31	0.30	0.25	0.28	-0.07	-0.19	-0.19	-0.17	-0.17	0.07	0.01	-0.01	0.11
21. Total factor productivity	0.11	0.17	0.24	0.34	0.47	0.59	0.74	0.82	0.84	0.86	0.86	0.87	0.92	1.04

	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
22. Actual labour productivity growth	1.19	0.01	0.49	1.15	2.35	0.92	1.81	1.00	0.71	1.84	2.01	1.83	1.55	1.71
(No capactity utilization rate adjustment for captial stocks)														
Contributions from:														
23. Capital deepening	0.07	0.74	1.84	2.53	1.46	0.19	-0.53	0.14	0.52	0.05	0.80	0.29	0.55	1.99
24. Machinery and equipment	0.43	0.72	1.14	1.21	0.65	0.28	-0.03	0.30	0.49	0.42	0.88	0.74	0.87	1.45
25. ICT	0.44	0.34	0.45	0.46	0.34	0.34	0.26	0.37	0.39	0.43	0.54	0.59	0.60	0.82
26. Computer	0.34	0.18	0.22	0.16	0.15	0.19	0.11	0.18	0.22	0.25	0.29	0.38	0.39	0.43
27. Software	0.11	0.14	0.16	0.18	0.12	0.09	0.12	0.16	0.13	0.14	0.16	0.16	0.17	0.27
28. Telecommunication	-0.01	0.02	0.07	0.11	0.07	0.06	0.02	0.03	0.05	0.04	0.08	0.05	0.04	0.11
29. Other machinery and equipment	-0.01	0.38	0.68	0.75	0.31	-0.06	-0.28	-0.07	0.10	-0.01	0.34	0.15	0.27	0.63
30. Non-residential construction	-0.36	0.02	0.71	1.32	0.81	-0.09	-0.51	-0.16	0.03	-0.37	-0.08	-0.46	-0.32	0.55
31. Total factor productivity	1.11	-0.74	-1.36	-1.39	0.86	0.73	2.33	0.86	0.19	1.77	1.19	1.53	0.98	-0.30
32. Log approximation error	0.01	0.00	0.00	0.01	0.03	0.00	0.02	0.00	0.00	0.02	0.02	0.02	0.01	0.01

TABLE A2: Income Shares and Growth Rates of Input

Per cent

	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Income shares														
1. Capital share	40.03	39.54	38.60	37.29	36.39	36.78	38.43	40.07	40.88	41.11	40.74	40.87	41.58	41.42
2. Total machinery and equipment	14.67	15.03	14.88	14.21	13.40	12.95	13.08	13.51	13.89	14.30	14.77	15.20	15.63	15.93
3. ICT	2.82	2.90	2.94	2.93	2.86	2.86	3.02	3.14	3.23	3.36	3.51	3.61	3.80	4.04
4. Computer	0.95	0.91	0.88	0.83	0.80	0.80	0.81	0.85	0.89	0.95	1.08	1.17	1.24	1.32
5. Software	0.66	0.73	0.81	0.88	0.89	0.93	1.04	1.11	1.13	1.20	1.28	1.36	1.46	1.59
6. Telecomunication	1.21	1.25	1.26	1.23	1.16	1.13	1.16	1.19	1.20	1.20	1.15	1.08	1.09	1.13
7. Other machinry and equipment	11.85	12.13	11.94	11.28	10.54	10.09	10.07	10.37	10.67	10.95	11.26	11.59	11.84	11.89
8. Non-residential construction	25.35	24.51	23.72	23.08	22.99	23.83	25.35	26.56	26.99	26.81	25.97	25.67	25.95	25.49
9. Labour share	59.97	60.46	61.40	62.71	63.61	63.22	61.57	59.93	59.12	58.89	59.26	59.13	58.42	58.58
Capital stock growth rates														
(adjusted for capacity utilization)														
10. Total capital stock	5.20	2.50	0.99	-0.66	2.43	4.24	4.46	1.05	1.74	4.15	4.78	5.57	5.96	0.30
11. Total machinery and equipment	7.97	5.40	3.85	1.05	3.27	5.89	5.64	2.92	4.00	6.96	8.78	9.76	10.20	4.56
12. ICT	20.77	12.34	11.59	8.09	10.27	15.52	14.34	12.48	12.70	16.81	18.11	21.20	20.45	15.65
13. Computer	41.15	20.23	21.14	12.30	17.41	27.40	19.84	21.68	24.97	29.94	29.94	37.26	35.77	28.51
14. Software	21.58	19.14	15.87	12.99	11.36	13.50	17.55	15.39	11.63	15.59	15.30	16.43	16.46	12.52
15. Telecomunication	4.30	2.55	2.15	1.74	4.50	8.72	7.59	3.19	4.65	7.62	10.08	9.77	8.35	5.11
16. Other machinry and equipment	4.92	3.75	1.95	-0.78	1.37	3.16	3.04	0.02	1.37	3.93	5.87	6.20	6.91	0.79
17. Non-residential construction	3.60	0.72	-0.81	-1.71	1.93	3.34	3.86	0.10	0.58	2.66	2.51	3.09	3.41	-2.37
Capital stock growth rates														
(unadjusted for capacity utilization)														
18. Total capital stock	4.40	4.44	3.50	2.54	1.91	1.48	2.11	2.16	2.38	3.85	4.03	4.16	4.49	3.66
19. Total machinery and equipment	7.37	7.30	5.14	3.32	3.45	2.56	3.94	4.41	5.16	7.84	8.20	8.36	8.71	6.43
20. ICT	14.36	15.11	12.17	10.33	13.13	11.31	13.46	13.02	14.86	16.80	19.25	18.57	19.93	16.10
21. Computer	22.20	24.63	16.49	17.54	25.06	16.89	22.75	25.40	28.23	29.15	35.83	34.04	32.82	22.21
22. Software	21.10	19.36	17.18	11.49	11.16	14.60	16.46	12.06	13.88	14.52	15.00	14.73	16.83	14.97
23. Telecomunication	4.52	5.64	5.93	4.63	6.38	4.64	4.26	5.08	5.91	9.29	8.33	6.61	9.42	10.56
24. Other machinry and equipment	5.71	5.44	3.41	1.50	0.82	0.08	1.09	1.80	2.22	5.09	4.76	5.17	5.10	3.15
25. Non-residential construction	2.68	2.68	2.48	2.06	1.01	0.90	1.17	1.01	0.95	1.73	1.66	1.68	1.94	1.93
26. Actual labour input growth	3.67	2.58	-0.29	-3.25	-1.45	1.40	2.90	1.77	0.90	2.31	2.03	3.43	2.90	-0.21
27. Trend labour input growth	1.61	1.41	1.44	1.38	0.86	1.31	1.67	1.87	1.62	1.58	1.46	1.62	1.70	1.51

Annex 2: Comparison with Armstrong *et al* (2002)

TABLE A3
LABOUR PRODUCTIVITY GROWTH
Per cent

	Armstrong et al.(2002)			This Study		
	1988-1995	1995-2000	Change	1988-1995	1995-2000	Change
Productivity Growth	1.2	1.7	0.5	1.1	1.6	0.5
Contributions from:						
Capital Deepening	0.9	0.4	-0.5	0.9	0.4	-0.5
ICT	0.4	0.4	0.0	0.4	0.5	0.1
Other M&E	0.1	0.1	0.0	0.2	0.2	-0.1
Non-res. Construction	0.3	-0.1	-0.4	0.3	-0.2	-0.5
Total Factor Productivity	-0.3	1.0	1.3	0.2	1.1	0.9
Labour Quality	0.6	0.3	-0.3	-	-	-