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Abstract

Productivity growth in the U.S. economy jumped during the second half of the 1990s, a resurgence that the literature linked to information technology use. We contribute to this debate in two ways. First, using the most comparable Canadian and U.S. data available, we quantify in a comprehensive way the contributions of information technology to output, capital input, and productivity performance. Second, we examine the extent to which information technology-producing and information technology-using industries have contributed to the aggregate multifactor productivity revival. Our results suggest that while information technology is indeed the story in the U.S. productivity revival, it is only part of it in the Canadian context. The U.S. labour productivity revival is primarily attributable to information technology capital deepening and multifactor productivity gains of information technology-producing industries, a finding that somewhat contrasts with the common U.S. wisdom. The Canadian evidence points towards the importance of multifactor productivity gains in information technology-using industries as a major source of productivity acceleration. These results stand even after a 'correction' for the methodological differences in the measurement of information technology prices at the industry level, thereby indicating important differences in the economic structures between the two countries.

Keywords: productivity, information technology, prices

Executive summary

After a quarter century of lacklustre gains, the U.S. economy experienced a remarkable resurgence in productivity growth during the second half of the 1990s. A large body of the U.S. productivity literature linked this improved performance to the information technology revolution use that has spread through the U.S. economy. Indeed, by 2000, this emphasis on the role of information technology had become the consensus view.

If a new way to increase productivity growth and economic growth has arisen in the U.S., it raises the potential for Canada to follow and ride the new productivity wave. It is therefore important to examine whether an information technology-related wave of productivity acceleration is already at work in Canada and which of production or use of information technology played the main role.

This paper updates our earlier work, using a unified framework that examines all the channels through which information technology operates. We add to the existing literature in four ways.

First, in order to establish a meaningful Canada-U.S. comparison in terms of information technology, we discuss the ways information technology is currently reflected in the statistical infrastructure of the existing statistical systems. This entails the delineation and the analysis of the structures of information technology commodities and industries, the behaviour of information technology prices at the aggregate and industry levels and the need to use a consistent dataset to properly account for the sectoral allocation of the aggregate productivity growth.

Second, using a comparable dataset, we provide a comprehensive investigation on the role of information technology in Canada-U.S. output growth, inputs growth and productivity growth. These results continue to support the basic story in our earlier work; namely, compared to the U.S., the Canadian data show a moderately high pickup in labour productivity growth and indicate that substantial efficiency gains which are captured by multifactor productivity gains were central factors in that resurgence.

Third, we examine how information technology-producing and information technology-using industries contributed to the acceleration of aggregate multifactor productivity performance in the Canada-U.S. productivity revival. We find that Canada's multifactor productivity revival between the early and late 1990s is almost entirely ascribed to productivity gains in information technology-using industries. In contrast, for the U.S., the evidence points towards the information technology-producing industries as the major source of the U.S. productivity revival, thereby giving support to Gordon (2000) who stands alone in attributing all of the gains to information technology-producing industries. Our results suggest that while information technology is indeed the story in the U.S. productivity revival, it is only part of it in the Canadian context. This suggests that different forces have contributed to the recent productivity revival in the two countries.

Fourth, we trace the sources of the difference between Canada and the U.S. in the contribution of information technology to the productivity revival. At the aggregate level, the larger contribution of information technology in favour of the U.S. is attributable to a larger share of information technology in GDP and capital input—a reflection of major differences in the structures of the two economies. At the industry level, in addition to differences in the technological structures of information technology-producing industries, there are important differences in the measurement of information technology output prices between the two countries.

Where the price behaviour appeared substantially different, we attempt to identify the potential source of the difference and to make a 'structured guess' on what would be Canada-U.S. productivity performance had the two countries shared similar price series. This exercise suggests that:

a) The role of output price differences in the productivity growth gap of information technology-producing industries between the two countries is important;
b) The methodological differences in prices of information technology-producing industries do not, however, appear to explain, in a significant way, the differences in the sectoral allocation of the aggregate productivity revival in the two countries—information technology-using industries in Canada, as opposed to information technology-producing industries in the United States.

This finding suggests that differences in the industrial structures explain much of the difference in the role of information technology between Canada and the U.S., a result that is consistent with the one obtained at the aggregate level.

I. Introduction

Some of the recent 'hype' about how advances in technology are forging a 'new economy' has evaporated. Interest in 'dot.com' start-up companies in the U.S. has waned with the decline in stock market valuations. Some of the more extravagant claims—in particular, that the 'new economy' would see the end to recessions—have been tempered by the recent slowdown in the U.S. economy.

But a central, underlying issue—whether information technology raises a country's productivity performance over the long term—remains relevant. The U.S. economy is viewed in many respects as a technology and productivity 'leader'. The new information technology-based source of productivity growth that has emerged in the U.S. economy (putting aside the short-term cyclical downturn) raises the potential for countries such as Canada to follow suit.

The motivation for the present study is the striking increase in the growth of U.S. labour productivity that occurred in the second half of the 1990s. This increase was accompanied by an investment boom in information technology equipment. There now seems to be general agreement that a large part of the increase in output can be accounted for by rapid growth in information technology equipment (see Bosworth and Triplett 2000, Gordon 2000, Jorgenson and Stiroh 2000, Oliner and Sichel 2000 and Council of Economic Advisers (CEA) 2001). The information technology investment boom in turn was driven by the rapid rate of decline of computer prices, which accelerated in the second half of the 1990s (see Tevlin and Whelan 2000). The fall in computer prices has been mainly due to rapid technical progress in semi-conductors (see Jorgenson 2001, Jorgenson and Stiroh 2000, and Oliner and Sichel 2000).

However, there are differing views outside the U.S. on the links between information technology and productivity performance. A recent OECD study (OECD 2001) reached the conclusion that *'ICT (information and communication technology) is important for growth but having an ICT-production sector is not a prerequesite.'* Australia, which enjoyed a remarkable improvement of productivity largely due to information technology use, is an interesting case in point (Parham 2002).

What is the story for Canada—a country with economic structures similar to those of Australia? Using revised Canadian data that accord with the best practice in the area of productivity measurement (see Baldwin and Harchaoui 2002), Harchaoui *et al.* (2002) stressed that the mechanisms underlying the structural transformation of the Canadian business sector are already at work. As an illustration, consider the role that information technology plays as a source of economic growth. For the 1981-1988, information technology capital input contributed 12% to Canadian economic growth. During this period, information technology prices have continuously fallen and businesses substituted towards relatively cheaper inputs. During the late 1990s, following a major slowdown in the Canadian economy in the early 1990s, information technology prices continued to fall, reaching 3.2% per year on average. In response, investment in information technology has exploded but the growth contribution of information technology capital input increased moderately, reaching 14% on average between 1995 and 2000.

Next, consider the productivity performance that accompanied the remarkable 4.9% economic growth in the late 1990s. Labour productivity grew 1.7% per year during 1995-2000, almost half of a percentage point faster than during 1981-1988. A detailed decomposition shows that capital deepening—the direct consequence of price-induced substitution and rapid investment—contributed 0.4 percentage points, up from 0.3 percentage points during the 1980s. Labour composition added 0.3 percentage points, compared to 0.5 in the 1980s, a reflection of the exhaustion of the pool of available workers. Faster multifactor productivity contributed an additional one percentage point, an unprecedented performance since 1981.

It turns out that information technology had played a lesser role in the Canadian productivity performance than that of the United States. Unfortunately, the empirical record reported in our earlier work remains incomplete and so much remains to be done before definitive assessments can be made about the complete role of information technology. Clearly, there are some important issues to be examined for Canada and sorted out irrespective of the 'new economy hype'.

This paper addresses these issues. It takes a wider view than our recent study since it quantifies, within a unified framework, the contributions of each of the information technology components (computers, software and telecommunication equipment) to output, capital services and labour productivity growth. It also provides an empirical record on the sectoral (i.e., information technology-producing vs. information technology-using industries) sources of the Canadian productivity revival and the extent to which these gains are linked to information technology use. Comparisons with the U.S. are also examined using the most comparable data available and the evidence on the sectoral sources of the U.S. productivity surge is also revisited.

This paper reaches several conclusions, some of which were untapped by the existing economic literature.

First, the paper concludes that information technology has contributed modestly to the Canadian growth resurgence and productivity gains, compared to the U.S. where it played a central role. This result holds even when we control for the methodological differences in the measurement of information technology prices at the industry level.

Second, this paper also traces the sources of the modest contribution of information technology in Canada at the aggregate level. Information technology output and information technology capital input grew virtually at the same pace in both Canada and the United States. In contrast, Canada's information technology share of the value of output and capital cost is about half of those of the U.S., a reflection of major difference in the structures of the two economies.

Finally, the difference between Canada and the U.S. performance is attributable to differences in the sectoral sources of productivity gains. Virtually all of the recent Canadian productivity gains are ascribed to information technology-using industries, a sharp contrast with the U.S. where information technology-producing industries contributed to the bulk of the aggregate productivity gains. Contrary to the common U.S. wisdom, this finding therefore leaves very little room for multifactor productivity gains from other industries.

The remainder of the paper is organized as follows. An augmented growth accounting framework is set out in Section II where the empirical strategy is to separately distinguish the information technology effects on output, capital input, labour productivity performance and the sectoral allocation of the aggregate productivity growth between information technology-producing and information technology-using industries. This section also discusses issues related to the delineation of information technology in terms of products and industries and the measurement of prices, all of which are critical for a meaningful Canada-U.S. comparison in terms of information technology. Section III provides a comprehensive comparison between Canada and the U.S. in terms of the various channels through which information technology operates. It provides evidence in two different, albeit complementary, directions: first, it quantifies the differences in the contributions of information technology in the two countries. Second, it ascertains the impact of methodological differences in the prices between the two countries on the productivity performance of the Canadian information technology-producing industries and, along the way, on the sectoral allocation of aggregate productivity growth. Section IV summarizes the findings and suggests some directions for future research.

II. Information technology in the Canadian and U.S. economic accounts

1. What is information technology?

The essence of information technology—faster, better, cheaper—reflects the speed of technological change and product improvement in semiconductors and the precipitous and continuing fall in their prices (see Jorgenson 2001 for an overview). The price declines are transmitted to the prices of products that rely heavily on semiconductor technology, like computers and telecommunications equipment. This technology has also helped to reduce the cost of aircraft, automobiles, scientific instruments, and a host of other products. The result of the technological change in the microprocessors is not just that computers and software are getting better or that communications are becoming more rapid. They are improving at very rapid rates that have never been seen in the recorded economic statistics. The rough trend in the performance improvement of the microprocessor technology was foreseen by Gordon Moore, co-founder of Intel, who observed in 1965 what has become Moore's Law—that the capacity of semiconductors doubles every 18 months to 2 years.

The U.S. has been the main 'laboratory' for analysing the effects of information technology on output and productivity growth. It is therefore critical to outline the underlying statistical infrastructure utilized in the U.S. productivity literature to establish a meaningful Canada-U.S. base of comparison.[1] The statistical infrastructure is defined to include the product and industry classifications along with the type of data utilized to support the accounting frameworks for economic growth and labour productivity performance.

1. The OECD, which attempts to harmonize definitions across countries to assist international comparisons, provides a broader notion of information technology. See Beckstead and Gellatly (2003) for the implementation of OECD approach to information, communication technologies in Canada.

According to the U.S. literature, the development and the deployment of information technology is the foundation of the new economy, that part of the economy that involves the acquisition, processing, transformation, and distribution of information. The major commodities are the hardware that processes the information, the microprocessors that store and retrieve information in binary form, the communications systems that acquire and distribute the information, and the software which, with the human help, manages the entire system.[2]

The hardware comprises computers and peripheral equipment and its components, including mainframes, PC's, storage devices, other peripheral equipment, and terminals. Communications equipment includes transmission gear, connecting data, voice, and video terminals to switching equipment. Software is composed of three components—pre-packaged, custom, and own-account software. Microprocessors, a type of integrated circuit, printed circuits, semiconductors and memory chips are products of the semiconductor industry. As it turns out, the definition used in U.S. information technology covers information technology equipment, but not the provision of information technology services (for example, telecommunication services are excluded).

On the industry side, there are two distinctions that are usually made with respect to information technology. First, the information technology commodities listed above are produced by a handful of manufacturing industries. These industries, referred to as information technology-producing industries, usually account for a modest share of the overall manufacturing sector.[3] Secondly, the remainder of the business sector, which includes the services sector and goods-producing industries without information technology-producing industries, is referred to as the information technology-using industries. These information technology-using industries, which represent the bulk of the business sector, purchase information technology products from the information technology-producing industries either to build their information technology capital input (software, hardware and telecommunication equipment) or to use them as intermediate inputs (integrated circuits, printed circuits and semiconductors). These types of intermediate inputs also represent an important component of the cost structure of information technology-producing industries.

2. Framework

A critical first step in understanding the economic impact of information technology is to successfully quantify information technology in a way that is consistent with both economic theory and the available data. The appropriate theory is a production framework that relates output to various production inputs and the level of technology. This framework has two important features: a) it quantifies, at the aggregate level, the various channels through which information technology operates, that is, output, inputs and labour productivity growth and b) it traces the sectoral sources of the aggregate productivity growth.

2. This specification accords with the definition used by the U.S. National Research Council (1994, p.23, note 1).
3. See the structures of information technology-producing industries in Canada and U.S. described below.

2.1. The production possibility frontier

The framework employed here is based on the production possibility frontier introduced by Jorgenson and Griliches (1967) and Jorgenson *et al.* (1987); Jorgenson (1990) provides an exposition of the method and a survey of results for the U.S.; Jorgenson and Stiroh (2000) is a recent study employing this method. This framework captures substitutions among outputs of investment, consumption, exports and imports, as well inputs of capital and labour. For Canada, the implementation of the method is possible particularly as a result of the close ties of the Canadian Productivity Accounts with the Canadian System of National Accounts. We identify information technology with investment, personal expenditures and net exports in computers, software, and communications equipment as outputs. The service flows of the investment assets are also inputs.

We assume the existence of an aggregate production possibility frontier relating final output of consumption, investment goods and net exports to capital and labour inputs.[4] More specifically, the aggregate production possibility frontier can be rewritten in an extended form to highlight the role of information technology

$$Y\left[Y_{IT}(t), Y_{NIT}(t)\right] = A(t)\cdot f\left[K_{IT}(t), K_{OME}(t), K_S(t), L(t)\right], \tag{1}$$

where Y_{IT} and Y_{NIT} are, respectively, real information technology and non-information technology outputs; K_k is capital services generated by capital asset k (k = information technology (IT), other machinery and equipment (OME), and structures (S)), L is a measure of labour input that represents both the composition of the labour force and the number of hours worked and A is often referred to as multifactor productivity, and measures how effectively inputs are transformed into outputs. An increase in multifactor productivity indicates that more output is produced from the same inputs.

Under standard economic assumptions about capital, labour, and output markets, theory suggests that Equation (1) can be transformed into a growth rate version where the weighted growth rates of various outputs equal the weighted growth rates of inputs plus the growth rate of multifactor productivity

$$\begin{aligned} w_{Y_{IT}}\Delta\ell nY_{IT} + w_{Y_{NIT}}\Delta\ell nY_{NIT} &= v_{K_{IT}}\Delta\ell nK_{IT} + v_{K_{OME}}\Delta\ell nK_{OME} + v_{K_S}\Delta\ell nK_S \\ &\quad + v_L\Delta\ell nL + \Delta\ell nA, \end{aligned} \tag{2}$$

where w refers to the nominal share of the subscripted output in nominal GDP, v refers to the nominal share of the subscripted input in nominal GDP, Δ refers to a change or first difference in percentage, and the following equalities must hold

$$w_{Y_{IT}} + w_{Y_{NIT}} = v_{K_{IT}} + v_{K_{OME}} + v_{K_S} + v_L = 1.0.$$

The share-weighted growth of each variable in (2) is referred to as the "contribution" of that variable.

4. This is a much more general concept than the aggregate production *function* (Hulten 1978). An aggregate production function only exists if the industry-level production functions are identical up to a scaling factor, which is a highly restrictive condition (Jorgenson *et al.* 1987).

Equation (2) is a standard "growth accounting" equation that has several attractive features. First, it enables us to identify the contribution of information technology to the growth of output and capital input. Second, it decomposes the sources of economic growth in terms of the different types of capital inputs—information technology, other machinery and equipment and structure—labour input and multifactor productivity growth, a residual defined to balance Equation (2).

2.2. Productivity growth

Rearranging Equation (2) enables us to present results in terms of labour productivity growth

$$\Delta \ell n\left(\frac{Y_t}{H_t}\right) = \bar{s}_{Kt}\Delta \ell n\left(\frac{\tilde{K}_t}{H_t}\right) + \bar{s}_{Lt}\left(\Delta \ell n\tilde{L}_t - \Delta \ell n H_t\right) + \Delta \ell n A_t \qquad (3)$$

where $\frac{Y_t}{H_t}$ and $\frac{\tilde{K}_t}{H_t}$ are, respectively, aggregate GDP per hour worked and the ratio of capital services to hours worked. This gives the familiar allocation of labour productivity growth among three factors. The first is *capital deepening*, the growth in capital services per hour. Capital deepening (also called *capital intensity*) makes workers more productive by providing more capital for each hour of work and raises the growth of labour productivity in proportion to the share of capital. The second term is the improvement in labour composition, defined as the difference between the growth rates of labour and hours worked. Reflecting the rising proportion of hours supplied by workers with higher marginal products, labour composition improvement (also called the *labour composition effect*) raises average labour productivity growth in proportion to labour's share. The third term is *multifactor productivity* growth, which increases labour productivity growth on a point-for-point basis.

Equation (3) also illustrates two channels through which information technology contributes to labour productivity growth:

a) *Information technology capital deepening.* Increased use of information technology capital per hour raises information technology capital intensity. This component captures the gains to the direct users of information technology. It includes cost savings from substituting information technology for other inputs as information technology becomes cheaper.

b) *Multifactor productivity gains*. There are multifactor productivity gains in information technology production, which stem from the ability of producers to generate more output—computing power and other characteristics of information technology—per unit of input. The rapid technological advances in information technology production have led to rapid declines in information technology equipment prices. Cheaper prices have, in turn, fuelled increased demand and use. There may also be multifactor productivity gains from the increasing use of information technology. In principle, these cover externality benefits in using industries. Information technology can bring network economies, increasing returns and spillovers, which would be captured in multifactor productivity gains in using industries.

2.3. Industry productivity growth framework

In the aggregate business sector productivity framework described above, output measured as real GDP—deliveries in constant chained dollars of final goods and services by the business sector to domestic households, investment, government and non-profit institutions, and net exports to other countries—is compared to labour and capital inputs, both of which account for compositional changes.

We now turn our attention to industry framework to trace the sectoral sources of the aggregate multifactor productivity growth (see Gullickson and Harper 1999 for an illustration of this approach). The approach utilizes the internal consistency between the business sector GDP series and the measure of output of its constituent industries. The first component consists of a production function for each industry and the second is the Domar (1961) methodology for aggregating over industries to obtain an aggregate measure of productivity. Recent contributions that applied this methodology to quantify the contribution of information technology-producing industries to the aggregate multifactor productivity revival includes Jorgenson and Stiroh (2000), Jorgenson *et al.* (2004) for the U.S., and Harchaoui *et al.* (2004) for a Canada-U.S. comparison.

Domar's weights, based on the relative importance of each industry output in GDP, have the notable feature that their sum exceeds unity. The Domar weighting scheme captures the impact of sources of growth at the industry level, both in the industry where growth occurs and in the industries that purchase the output of this industry. This implies that the aggregate multifactor productivity growth can grow faster than productivity in any industry, since productivity gains are magnified as they work their way through the production process.

3. The data

The source of information used to implement the production possibility frontier is the income and expenditures accounts and the national income and product accounts ('national accounts') produced, respectively, by Statistics Canada and the U.S. Bureau of Economic Analysis. The national accounts measure of the business sector's GDP is based on deflated expenditures on 'final' goods and services. Expenditures on intermediate inputs of materials and services are excluded. Computers, communications equipment, and software as investments made by businesses and governments, along with net exports to the rest of the world, are part of GDP. GDP also includes the expenditures of information technology products made by households, but not the services flows of information technology consumers' durables.[5] While semiconductors form an important part of the information technology revolution, only their net exports defined as the difference between exports to the rest of the world and imports appear in the GDP.

Table 1 shows for some selected years the structures of GDP in Canada and the U.S. along with the relative importance of information technology in each category of GDP. There are major differences between the two countries. Not surprisingly, the share of exports and imports is higher in Canada than in the U.S. and became even more so in the 1990s as a result of the implementation of the free trade agreement between the two countries. The share of business

5. See Harchaoui *et al.* (2004) for an extension of this framework to include the services flow of consumer durables and housing.

investment is lower in Canada. In contrast, the share of personal expenditures was higher in Canada in 1981 and 1988 but by 2000 it had dropped relative to the United States.

Table 1. The structure of final expenditures in Canada and U.S. (current prices)

	1981		1988		2000	
	Percentage					
	Canada	**U.S.**	**Canada**	**U.S.**	**Canada**	**U.S.**
Consumption	70.0	67.3	74.0	72.9	69.3	73.5
Information technology consumption	1.3	1.3	1.6	1.7	2.0	2.2
Business investment	23.9	27.6	19.9	24.5	18.9	26.5
Information technology business investment	2.1	2.8	2.4	3.5	4.0	5.6
Government investment	4.6	4.5	4.2	4.9	3.4	4.2
Information technology government investment	0.3	0.1	0.5	0.2	0.8	0.2
Exports	41.1	12.8	41.8	11.8	66.4	14.5
Information technology exports	1.1	0.4	1.5	0.6	4.8	0.7
Imports	40.0	13.5	40.6	14.6	59.0	19.3
Information technology imports	2.0	0.1	2.9	0.5	6.5	1.2
Inventories	0.4	1.3	0.7	0.5	1.1	0.6
GDP	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
Share of information technology in final expenditures	**2.8**	**4.6**	**3.2**	**5.5**	**5.1**	**7.6**

The share of information technology exports, imports and government investment in GDP was consistently higher in Canada, compared to the U.S., and vice versa for the share of information technology business investment and information technology personal expenditures in GDP.

Industry income and product accounts of both countries produce a variety of industry measures of output, all of which reflect in different ways the deliveries to final demand and the inter- and intra-sectoral transactions.[6]

Using KLEMS data based on gross output or gross product originating available at the two-digit 1987 Standard Industrial Classification (SIC) level from the U.S. Bureau of Economic Analysis, several U.S. studies have focused on SIC 35, industrial and commercial machinery and equipment and computer equipment, and SIC 36, electronic and other electrical equipment and components.[7] An alternate KLEMS dataset, based on the notion of sectoral output, available at the same level of industry detail, is also produced by the U.S. Bureau of Labour Statistics.[8] However, all of these data suffer from the disadvantage of mixing information technology

6. There are three possible ways to treat these transactions. First, they could all be netted out, in which case we arrive at the notion of value added (or gross product originating for the United States). Secondly, the intra- and inter-sectoral transactions could be explicitly accounted for, in which case we arrive at the notion of gross output. Third, sectoral output, an intermediate notion between value added and gross output, nets out only intra-sectoral transactions.
7. See for example CEA (2001), Stiroh (2001) and Jorgenson and Stiroh (2000).
8. Domar (1961) proposed definitions of outputs and inputs for sectors (or industries) engaged in intersectoral (or interindustry) trade. The notions of outputs and inputs conforming with Domar's definitions are referred to as "sectoral" outputs and inputs.

producing industries with electrical products industries which are, by definition, remotely linked to the notion of information technology.[9]

There is, however, an additional, albeit less popular, source of information available from the U.S. Bureau of Labor Statistics that provides more industry detail and, as a result, overcomes this problem of coverage of information technology-producing industries. The multifactor productivity program for three-digit SIC manufacturing industries produces a KLEMS database based on the notion of sectoral output from 1987 to 1999 for 102 manufacturing industries, including each of the information technology producing industries:[10] computer and office equipment (SIC 357), communication equipment (SIC 366), and electronic components and accessories (SIC 367). All in all, these industries produce each of the major information technology products, that is, computer hardware for SIC 357, communication equipment for SIC 366, and semiconductors and related products for SIC 367. Software may be produced by each of these industries.[11]

The Canadian productivity accounts construct a variety of productivity measures for 122 industries (1980 SIC-E) of the business sector based on a set of inter- and intra-industries transaction accounts available from Statistics Canada's input-output tables. Information technology-producing industries cover two of these 122 industries: electronic equipment industry (# 335) and office, store and business machine industry (# 336) which produce, respectively, telecommunications equipment, semiconductors, printed circuits and integrated circuits, and computer hardware. Much like the U.S., software products are produced by each of the Canadian information technology-producing industries. The lack of availability of capital prevents the Canadian productivity accounts from having a split between the communication part and the semiconductors and integrated circuits part of the industry #336. Nonetheless, detailed information on outputs and intermediate inputs for these two parts is available from the Canadian input-output tables. This information is particularly useful to examine the structures of the information technology-producing industries in Canada (more on that below).

Given the variety of industry data sources available for the U.S., the issue is which one is more adequate for productivity measurement. In the context of the U.S. statistical system, the notion of sectoral output produced by the U.S. Bureau of Labor Statistics is consistent with the aggregate private business sector GDP (see Gullickson and Harper 1999). This is not the case for the notion of gross product originating used in various United States productivity studies.[12] Gross product originating is based on the income side of national income accounts, an approach that makes the

9. A recent work by Jorgenson *et al.* (2004) uses a KLEMS database based on the notion gross output where information technology-producing industries are not mixed with electrical industries.

10. This dataset does not, however, provide a split of capital input between information technology and non-information technology.

11. This coverage is of course narrower than the one employed by Kask and Sieber (2002) in their profile of the U.S. high tech manufacturing industries, but more consistent with the U.S. literature on the role of information technology in the productivity revival.

12. The U.S. BEA includes the statistical discrepancy in their estimate of 'private industries,' where the statistical discrepancy is defined as GDP expenditures less gross domestic income. Since the U.S. BEA views the expenditure data as more reliable, the statistical discrepancy is added as an industry to the gross domestic income (value-added) accounts. One of the problem with the output of this industry is the impossibility to align it with measured inputs.

productivity revival larger as the estimated income grew more rapidly than the estimated product accounts (see Bailey 2002, 7).

Given the consistency problem associated with the notion of gross product originating, we are left with two options to perform our Canada-U.S. comparison: either to use the notion of gross output produced by the U.S. BEA or the notion of sectoral output. In this paper, we chose to use the notion of sectoral output and we leave the use of gross output for another Canada-U.S. study (see Harchaoui *et al.* 2004).[13]

4. The structures of information technology-producing industries

In the section above, we have delineated the Canada-U.S. information technology-producing industries that are appropriate for the analysis of the structure of the information technology structure in these two countries. This section exploits the information by industry and commodities to examine the structure of the information technology-producing industries in these two countries.

The availability of additional industry and commodity details on these two Canadian information technology-producing industries from the input-output tables allows us to establish a more accurate comparison between Canada and U.S. and, along the way, to track the structural changes experienced by these industries in the two countries.[14]

Table 2 illustrates the structures of the information technology-producing industries in both Canada and U.S. and how they have evolved between 1988 and 1999.[15] For the U.S., the three information technology-producing industries accounted for 11.8% of the manufacturing sector's sectoral output in 1999, up from 8.4% in 1988. Within these industries, computer and office equipment saw its share decline from 40.2% down to 30.7% to the benefit of electronic components and accessories from 35.5% to 41.5% and, to a lesser extent, communication equipment from 24.3% to 27.7%.

Although the output share of Canadian information technology-producing industries within the manufacturing sector increased from 3.3% to 5.1%, it represents only about 40% of its U.S. counterpart. Similar to the U.S., the share of electronic components and accessories industry increased from 16.5% to 31.5% between 1988 and 1999, mostly at the expense of the computers and office stores industry which saw its share drop from 32.5% to 20.8%.

13. This paper differs in many respects from Harchaoui *et al.* (2004). It covers the business sector and makes use of BLS data. In contrast, the latter covers the Canadian and U.S. private economies, which includes the business sector and owner-occupied housing. Another feature of the paper is the use of the flow of services of consumers' durables and housing and the distinction between university and non-university workers to capture the extent to which investments in higher education and information technology have contributed to economic growth and productivity performance.

14. This analysis is performed on the basis of the notion of gross output and intermediate inputs. Data on sectoral output at the commodity level are not available for the United States. But the main thrust of this section holds regardless whether we use gross output or sectoral output.

15. This is the only period for which detailed industry data were comparable.

Table 2. Output structures of Canadian and U.S. information technology-producing industries

	United States		Canada						
	Millions of U.S. dollars		Millions of Canadian dollars			Output share in percentage		Implicit price index of the output (1988=100)	
Industries	**1988**	**1999**	**1988**	**1999**	**Commodities**	**1988**	**1999**	**1988**	**1999**
Communication equipment[1]	**34,343**	**85,638**	**5,105**	**11,752**	Telephone and related equipment, incl. facsimile	49.9	73.2	100.0	113.0
					Broadcasting and radio communications equipment	18.2	17.8	100.0	148.2
					Radar and radio navigation equipment	24.5	8.3	100.0	115.7
					Other	7.4	0.8	100.0	153.7
Share in information-technology-producing industries	24.3%	27.7%	51.0%	47.7%	Total	100.0	100.0	100.0	124.1
Electronic products and accessories	**50,115**	**128,117**	**1,656**	**7,767**	Integrated circuits	50.3	62.7	100.0	57.5
					Printed circuits	21.1	17.7	100.0	86.5
					Semi-conductors	16.2	11.5	100.0	103.5
					Other	12.4	8.1	100.0	78.8
Share in information-technology-producing industries	35.5%	41.5%	16.5%	31.5%	Total	100.0	100.0	100.0	69.1
Computers and office stores[2]	**56,747**	**94,882**	**3,257**	**5,122**	Computers	94.5	98.2	100.0	19.4
					Office equipment	4.6	0.4	100.0	119.6
					Other	0.8	1.4	100.0	112.4
Share in information-technology-producing industries	40.2%	30.7%	32.5%	20.8%	Total	100.0	100.0	100.0	20.8
Information technology-producing industries	**141,206**	**308,638**	**10,018**	**24,641**					
Share in total manufacturing	8.4%	11.8%	3.3%	5.1%					
Total manufacturing	**1,689,803**	**2,618,207**	**303,588**	**483,148**					

1. The Canadian communication equipment industry is composed of telecommunication equipment industries and other communication and electronic equipment industry. In 1999, the sectoral output share of these two industries was respectively 76% and 24%, compared to 51.3% and 48.7% in 1988.
2. The Canadian computers and office stores industry is composed of electronic computing and peripheral equipment industries and electronic and other office, store and business machines industries. In 1999, the sectoral output share of these two industries was respectively 98.8% and 1.2%, compared to 95.6% and 4.4% in 1988.

Despite this similar trend in the share of information technology-producing industries between Canada and U.S., the structures of the information technology-producing sector remain different between the two countries. The communication equipment industry accounts for almost half of the Canadian information technology-producing sector, compared to about ¼ for its U.S. counterpart. Canadian electronic products and accessories and computers and office stores industries, which account for the remaining half, have a lower share than their U.S. counterparts. For example, in 1999 these two industries accounted, respectively, for 31.5% and 20.8%, compared to 41.5% and 30.7% in the United States.

Canadian information technology-producing industries, on which information by commodity is available from the input-output tables, moved from a multiproduct towards a monoproduct technology structure. For example, in 1999 telephone equipment (telephone switching equipment and transmission gear) accounted for almost three-quarters of the output of telecommunication industry, up from 50% in 1988. Similarly, integrated circuits, with almost two-thirds of the output, became the dominant product of the electronic products and accessories industry. This represents an important shift compared to 1988 when this product accounted for half of the output. In contrast, with more than 90% of the output, computers have always been the dominant product of the computers and office stores industry.

A similar trend towards specialization occurred on the intermediate inputs side of Canadian information technology-producing industries (Table 3). For example, in 1999 about two-thirds of the communication equipment industry's intermediate inputs were composed of integrated circuits, printed circuits and semiconductors, up from 57.6% in 1988. Integrated circuits represented about one third of the intermediate inputs of the communication equipment industry between 1988 and 1999. In contrast, printed circuits and semiconductors accounted, respectively for 21% and 18.4% in 1999, a substantial increase since 1988 when they represented, respectively, 13.6% and 12.4%.

Integrated circuits accounted for 78.3% of electronic products and accessories industry's intermediate inputs, up from 73.3% in 1988. In 1999 computers represented 84.9% of the intermediate inputs used by the computers and office stores industry, compared to 62.9% in 1988.

It is important to emphasis two stylized facts on the structures of the intermediate inputs of information technology-producing industries and their implications on output prices. First, information technology products account for a significant portion of the overall intermediate inputs (close to 60% for communication and electronic products and accessories and close to 2/3 for the computer and office machine industry in 1988). Second, in 1999, the products of the semiconductor industry (semiconductors, printed circuits and integrated circuits) accounted for 68.6% and 94%, respectively, of the information technology component of intermediate inputs of communication and electronic products and accessories industries.

As we can see, the products of the semiconductor industry account for the bulk of communication and electronic products industry sectoral intermediate input. The rapid technological change experienced by these information technology products, which ultimately translate into declining output prices, was well documented for the United States.[16] It is therefore important to examine the extent to which these improvements are being reflected in the prices of the commodities produced by Canadian information technology-producing industries. This issue is addressed next through the examination of the prices of these information technology products.

16. See Jorgenson (2001) for a thorough discussion. Triplett (1996) estimated that almost all of the price decline of computer is accounted for by the falling semi-conductor prices.

Table 3. Intermediate inputs structures of Canadian information technology-producing industries

		Value of the information technology intermediate inputs (thousands $)		Commodity share of the information technology intermediate inputs		Trend in the implicit price index of information technology intermediate inputs	
Industries	**Commodities**	**1988**	**1999**	**1988**	**1999**	**1988**	**1999**
Communication equipment[1]	Telephone and related equipment, incl. facsimile	183,589	328,566	12.6	8.1	100.0	141.2
	Semi-conductors	172,911	741,549	12.4	18.4	100.0	115.2
	Printed circuits	205,192	848,130	13.6	21.0	100.0	117.4
	Integrated circuits	451,527	1,180,117	31.6	29.2	100.0	79.9
	Other electronic equipment components	115,608	746,588	8.2	18.5	100.0	117.5
	Other	327,505	194,621	21.6	4.8	100.0	46.5
	Information technology intermediate inputs	**1,456,332**	**4,039,570**	**100.0**	**100.0**	**100.0**	**104.6**
	Total intermediate inputs	**2,402,035**	**7,016,898**				
	Share of information technology in the overall intermediate inputs	60.6%	57.6%				
Electronic products and accessories	Semi-conductors	18,384	294,792	3.1	8.8	100.0	91.9
	Printed circuits	89,485	232,224	15.1	6.9	100.0	89.7
	Integrated circuits	433,461	2,623,616	73.3	78.3	100.0	54.4
	Other	49,811	199,232	8.4	5.9	100.0	81.8
	Information technology intermediate inputs	**591,141**	**3,349,864**	**100.0**	**100.0**	**100.0**	**59.2**
	Total intermediate inputs	1,056,014	**6,143,744**				
	Share of information technology in the overall intermediate inputs	56.0%	54.5%				
Computers and office stores[2]	Computers, video units, printers, etc.	859,851	2,933,570	62.9	84.9	100.0	25.2
	Other	506,714	522,294	37.1	15.1	100.0	71.9
	Information technology intermediate inputs	**1,366,565**	**3,455,864**	**100.0**	**100.0**	**100.0**	**30.2**
	Total intermediate inputs	2,088,434	**4,710,470**				
	Share of information technology in the overall intermediate inputs	65.4%	73.4%				

1. The Canadian communication equipment industry is composed of telecommunication equipment industries and other communication and electronic equipment industry. In 1999, the sectoral output share of these two industries was respectively 76% and 24%, compared to 51.3% and 48.7% in 1988.
2. The Canadian computers and office stores industry is composed of electronic computing and peripheral equipment industries and electronic and other office, store and business machines industries. In 1999, the sectoral output share of these two industries was respectively 98.8% and 1.2%, compared to 95.6% and 4.4% in 1988.

5. The issue of information technology prices

The construction of a consistent time series of constant price series on information technology requires the availability of 'constant-quality price indexes.' These prices effectively capture the quality improvements across successive generations of information technology products and treats these quality gains as a reduction in the price of information technology.

Given that the examination of the sources, concepts and method utilized in both Canada and U.S. is beyond the scope of this paper, we proceeded as follows.[17] For each information technology product and industry, we examined the two countries' price behaviour over the 1981-2000 period for which we have consistent information. Where the price behaviour appeared substantially different, we attempted to identify the potential source of the difference and to explain the extent to which it will impact on the result using commodity as well as industry data to the extent that they are both available. Our examination, which is available on request, led to the following conclusions at both the aggregate and industry levels:

1. First, from the examination of the final demand information technology prices, we conclude that the overall trends of Canadian and U.S. prices are for the most part similar. This is particularly the case for imports on one hand and computers that appear under the investment category, on the other hand. There are, however, some differences between the two countries in the prices of software and telecommunication assets in the investment category and information technology products that appear under personal expenditures. Canada's software prices decline more rapidly and vice versa for telecommunication and information technology personal expenditures. This reflects perhaps a combination of methodological differences in the structure of the economy and even the exchange rate. However, at the level at which we have established the comparison between the two countries (information technology-GDP), these differences are likely to offset one another.
2. There are, however, several issues related to the implicit price indexes of sectoral output and information technology sectoral intermediate inputs that have some important bearing on Canada-U.S. comparison of productivity trends for the three information-technology-producing industries.

   First, there seems to be a pass-through mechanism from the prices of information technology sectoral intermediate inputs to those of sectoral output in Canada. The implicit price indexes of sectoral output for each of the information technology-producing industries mirror those of their corresponding sectoral intermediate inputs, thereby reflecting the fact that technical change that occurs in upstream industries is transmitted to downstream industries.

   Second, there is a difference in the behaviour of the Canadian output implicit price index of electronic products and accessories, compared to its U.S. counterpart. Canada does not collect prices for integrated circuits, printed circuits and semiconductors, but rather uses the Bureau of Labor Statistics producer price indexes for the corresponding products based on the matched model technique. These indexes are adjusted by Statistics Canada for exchange rate variations. Yet, the implicit price index of the output of electronic

17. See Grimm *et al.* (2002) for details on the U.S. methodology.

products and accessories for this industry fell by about 75% in the U.S., while only 25% in Canada. Differences in the weighting schemes and the fluctuations of the exchange rates may explain this difference.[18]

Third, Canada's implicit price index of communication industry's output behave differently from its U.S. counterpart. Canada applies the matched model technique to telephone equipment based upon purchased prices collected from domestic companies. In contrast, the U.S. employs a quality-adjusted price indexes based on hedonic estimates only for telephone switching equipment; conventional price deflators are employed for transmission gear and other components.

The largest information technology-producing industry in Canada–communication industry—is the one that reports a trend of the output price index that is different from its U.S. counterpart. The productivity growth gap in information technology-producing industries in favour of the U.S. is, therefore, largely attributable to this industry.

Similarily, differences in the output price behaviour of the electronic components and accessories industry in favour of the U.S. also contribute to this gap.

In the Section III.3 of this paper, we will attempt to quantify how much of these differences in the output price indexes of these two industries contribute to the difference in the productivity trends.

6. Measurement of primary inputs

The previous sections have discussed the structures of information technology in terms of output and intermediate inputs and the trends reported by their implicit price indexes. This section deals with the primary inputs, capital and labour.

6.1. Capital

The capital input for the multifactor productivity measures in both Canada and the U.S. is computed in accordance with a service flow concept for physical capital assets. We employ a broad definition of capital, including tangible assets such as machinery and equipment, structures, as well as land and inventories.

The estimates of the services price of capital assets incorporate differences in asset prices, service lives and depreciation rates, and the tax treatment of capital incomes (see Harchaoui and Tarkhani 2003 for a description of the methodology for Canada). Capital inputs for major sectors are determined in three main steps: 1) a detailed array of capital stocks is developed for various asset types in different industries; 2) asset-type capital stocks are aggregated for each industry to

18. Eldridge and Sherwood (2001) have reached the same conclusion for the implicit price indexes of value added in two countries.

measure capital input for the industry; and 3) industry capital inputs are aggregated to measure sectoral level capital input.[19]

The Canadian asset detail consists of 16 types of machinery and equipment (28 for the U.S.), 6 types of non-residential structures (22 for the U.S.), 4 types of residential structures[20] (9 for the U.S.), 3 types of inventories (by stage of processing), and land.

Statistics Canada's procedures are applied to 122 industries of the business sector (109 manufacturing industries for the U.S.) in the business sector corresponding, approximately, to the 2- and 3-digit 1980 SIC level (3-digit 1987 SIC for the United States). These measures of capital stocks are aggregated using a Fisher (Törnqvist for the U.S.) chain index procedure. The weight for each asset type is based on the share of property income estimated to be accruing to that asset type in each industry averaged over 2 years. Property income in each industry is allocated to asset types by employing estimates of the 'implicit rental prices' of each asset type. Because some asset types tend to deteriorate much more quickly than others and because of tax rules that are specific to asset types, the economic cost (rental price) of employing a dollar's worth of stock varies substantially by asset type.

At the sector level, aggregate capital input is obtained by a Fisher chained index for Canada and a Törnqvist index for the U.S. by aggregating each industry's capital input using each industry two-period average share of total capital income as weights.

The top panel of Tables 4a and 4b highlights the rapid increase in the importance of information technology assets in Canada and the U.S., reflecting the accelerating pace of relative price declines. In the 1990s, the service price for information technology assets fell 7.2% per year (5.0% for the U.S.), compared to an increase of 1.6% and 3.2%, respectively, for other machinery and equipment and structures capital (3.6% and 2.4% for the United States). As a direct consequence of this relative price change, information technology capital services grew 16.8% (14.8% for the U.S.), compared to only 2.8% and 1.9% for the services of other machinery and equipment and structures in the 1990s (2.2% and 1.9% for the United States).

19. Both Statistics Canada's and BLS' capital input estimates for the business sector are based on the bottom-up approach. Alternatively, one could exploit a top-down approach which consists of using the investment series available from the final demand. The latter is more consistent with the production possibility frontier and it has been exploited in Harchaoui *et al.* (2004). Comparability with the BLS' methods has prevented us from using this approach in this paper.

20. Owner-occupied housing is excluded for both countries.

Table 4a. General trends in GDP and primary inputs, Canadian business sector

	1981-2000		1981-1988		1988-2000		1988-1995		1995-2000	
	Price	**Quantity**	**Price**	**Quantity**	**Price**	**Quantity**	**Price**	**Quantity**	**Price**	**Quantity**
GDP	2.8	3.1	4.3	3.3	1.9	2.9	2.1	1.5	1.7	5.0
Information technology GDP	-3.1	13.3	-0.5	10.2	-4.6	15.2	-5.4	10.4	-3.6	22.3
Information technology -consumption	-0.1	8.3	2.3	7.8	-1.5	8.6	-1.3	7.1	-1.6	10.7
Information technology -investment	-6.6	17.8	-6.3	18.2	-6.8	17.5	-6.9	14.2	-6.6	22.3
Information technology -others	-7.2	16.6	-10.1	25.9	-5.6	11.5	-4.1	14.2	-7.6	7.8
Non information technology GDP	3.1	2.6	4.5	3.0	2.2	2.4	2.4	1.2	2.0	4.2
Capital services	2.8	3.3	4.3	3.4	1.9	3.3	1.5	2.5	2.4	4.3
Information technology	-6.1	17.2	-4.1	18.0	-7.2	16.8	-9.0	15.7	-4.6	18.4
Computers	-14.9	28.6	-14.4	28.5	-15.1	28.7	-16.8	25.7	-12.8	32.9
Software	3.5	8.6	8.5	5.8	0.7	10.3	-2.0	9.0	4.5	12.2
Telecommunications	-1.7	12.5	4.0	17.2	-4.9	9.8	-6.7	11.7	-2.3	7.2
Other machinery and equipment	3.2	3.1	6.0	3.7	1.6	2.8	2.0	1.4	1.1	4.8
Structures	3.7	2.0	4.5	2.1	3.2	1.9	2.6	1.5	4.1	2.3
Labour input	3.2	2.4	4.7	2.8	2.4	2.2	2.2	1.2	2.7	3.6
Hours at work	1.6		2.0		1.4		0.3		3.1	
Labour composition	0.8		0.8		0.8		1.0		0.5	

Memo ($ million)	**1981**		**2000**	
Total capital stock[a]	492,588		1,278,237	
Fixed reproducible capital stock[a]	290, 465		929,409	
Information technology	11,363		59,900	
Business sector nominal GDP	258,873		770,562	
Labour compensation	158,736	61.3%	457,198	59.3%
Capital compensation	10,138	38.7%	313,364	40.7%

Notes: [a]Canadian Productivity Accounts

The rapid accumulation of information technology, however, appears to have different origins. During the 1990s, the prices of telecommunications and software investments have declined much more slowly, -2.0% and -3.1% per year, respectively, versus -14.9% for computers (-1.5%, -0.3% and -16.0%, respectively, for the United States). This decline in investment prices was not strong enough to lead to a rapid decline in service prices for telecommunications and software capital assets, -4.9% and 0.7%, respectively (0.5% and -1.7% in the United States). Nonetheless, industries have been accumulating telecommunications and software quite rapidly, with real capital services growing 9.8% and 10.3% per year in the 1990s, respectively for these two assets (6.1% and 15.2% in the United States). Complementarity between telecommunications, software and computers is one possible explanation. Industries responded to the decline in relative computer prices by accumulating computers and investing in complementary inputs like telecommunications equipment and software to put the computers into operation.

Table 4b. General trends in GDP and inputs, U.S. business sector

	1981-2000		1981-1988		1988-2000		1988-1995		1995-2000	
	Price	Quantity	Price	Quantity	Price	Quantity	Price	Quantity	Price	Quantity
GDP	2.7	3.6	3.4	3.5	2.2	3.6	2.8	3.0	1.4	4.5
Information technology GDP	-4.0	13.7	-2.2	12.2	-5.0	14.6	-3.6	10.4	-6.9	20.6
Information technology-consumption	-2.2	11.6	2.2	8.0	-4.6	13.7	-2.6	11.1	-7.4	17.5
Information technology-investment	-4.8	15.8	-3.4	13.9	-5.5	16.9	-4.1	12.2	-7.6	23.7
Information technology-others	-6.6	19.3	-8.5	15.3	-3.2	21.8	-4.7	-7.0	-9.2	77.6
Non information technology GDP	3.1	3.0	3.7	3.0	2.7	3.0	3.2	2.6	2.0	3.5
Capital services	2.4	3.9	4.0	3.9	1.6	3.9	2.1	2.8	0.8	5.4
Information technology	-4.5	16.5	-3.7	19.5	-5.0	14.8	-1.5	10.3	-9.6	21.3
Computers	-13.2	28.1	-12.0	34.0	-13.9	24.8	-8.0	13.8	-21.5	41.8
Software	-0.8	15.4	1.0	15.7	-1.7	15.2	-1.4	14.3	-2.3	16.4
Telecommunications	1.6	6.8	3.5	8.1	0.5	6.1	4.1	4.4	-4.3	8.5
Other machinery and equipment	4.6	1.9	6.3	1.4	3.6	2.2	4.3	1.5	2.8	3.1
Structures	3.1	2.3	4.1	2.9	2.4	1.9	1.9	1.7	3.1	2.2
Labour input	4.0	2.2	4.7	2.4	3.6	2.1	3.0	1.8	4.5	2.4
Hours at work	1.7		1.9		1.5		1.2		2.0	
Labour composition	0.5		0.5		0.5		0.6		0.4	

Memo ($ million)	1981		2000	
Total capital stock[a]	8,685,677		19,412,347	
Fixed reproducible capital stock [a]	5,943,138		13,738,125	
Information technology	244,589		1,217,850	
Business sector nominal GDP	2,215,871		7,110,466	
Labour compensation	1,510,872	68.2%	4,808,844	67.6%
Capital compensation	704,999	31.8%	2,301,622	32.4%

6.2. Labour

The distinction between labour input and labour hours is analogous to the distinction between capital services and capital stock. Growth in labour input reflects the increase in labour hours, as well as changes in the composition of hours worked as firms substitute among heterogeneous types of labour.

Both Canada and the U.S. make use of the same concept of labour input in their business sector estimates of multifactor productivity. Canada makes use of household survey data to disaggregate total hours into hours worked by different types of workers classified by demographic variables such as age and education. Labour input is calculated as a weighted sum of hours worked by different types of workers to take into account differences in labour composition; the weights are defined in terms of relative wage rates.

At the level of the business sector, the BLS breaks the hours worked down into three categories—educational attainment, work experience, and gender. Statistical regression techniques are used to remove the impact of other worker characteristics such as marital status on average wage rates in each of these three groups. The BLS then uses predicted wage rates for each of the categories. Canada uses educational attainment, age and worker type for its groupings and uses average wage rates in each of the categories as weights without correcting for other worker characteristics.[21] In contrast to the practice followed for the business sector, U.S. labour input for manufacturing is measured as the sum of hours at work of all persons. Therefore, in order to provide cross-country comparability in this study, Canadian labour input estimates both for the business sector as a whole and for the manufacturing sector were brought to the lowest common denominator, which is the straight sum of hours worked.

Hence, this study uses the notion of labour input for the decomposition of economic growth and labour productivity growth at the business sector level. In contrast, due to the lack of data on labour input for U.S. industries, the analysis of the sectoral allocation of aggregate productivity growth requires the use of the notion of hours at work. In the latter case, data on hours for both Canada and the U.S. are directly aggregated across all worker groups and the resulting growth rates that are calculated from this sum do not include the effects of changing labour composition.

Our estimates, reported in the bottom panel of Tables 4a and 4b, show a value of labour cost in Canada of $457B in 2000 ($4.8T for the U.S.), roughly 59% (67.6% for the U.S.) of the value of current dollar GDP. The growth of the index of labour input L_t appropriate for our model of production in Equation (2), accelerated to 3.6% for 1995-2000 in Canada (2.4% for the U.S.), from 1.2% for 1988-1995 (1.8% for the United States). This is primarily due to the growth of hours worked, which rose from 0.3% for 1988-1995 (1.2% for the U.S.) to 3.1% for 1995-2000 (2.0% for the U.S.), as labour force participation increased and unemployment rates plummeted, particularly in Canada.

III. Information technology in Canada and U.S.: What is the story?

1. Preliminary remarks

We have explored the Canada-U.S. data sources that are adequate for the examination of the role of information technology in economic growth and productivity performance. We now turn our attention to Canada-U.S. comparison in terms of the contribution of information technology to output, capital input and the productivity revival experienced by these two countries.

The acceleration in U.S. productivity growth in the second half of the 1990s has attracted much attention. There has also been particular interest in the role that information technology played in sustaining the strong U.S. performance. The U.S. productivity acceleration coincided with an acceleration in advances in information technology, investment in information technology equipment and the takeoff in the wider use of the Internet.

The role of information technology in promoting productivity and output growth is of considerable interest to Canada as well. As a productivity leader, the U.S. economy does not catch up—it is at the forefront. The U.S. economy essentially relies on technology breakthroughs to step up its rate of productivity growth. If a new way to increase productivity growth is found

21. Not taking worker characteristics into account has little effect on the estimates (See Gu *et al.* 2002).

in the U.S., it raises the prospects for other countries like Canada to follow and ride on a new productivity wave.

The U.S. studies have analysed the labour productivity acceleration in the second half of the 1990s—that is, before and after 1995, the point of take-off in advances in technology, declines in information technology prices, growth in investment in information technology and growth in labour productivity. Gordon (2000), Oliner and Sichel (2000, 2002), Jorgenson and Stiroh (2000), the BLS in its own published work and the CEA (2001) all compared periods up to and including 1995 with the period from 1995 on. These studies are briefly reviewed below.

2. A brief review of the U.S. evidence

Three studies have been particularly influential in the analysis of the role of information technology in the U.S. acceleration in output and productivity growth—Oliner and Sichel (2000, 2002), Jorgenson and Stiroh (2000) and the more skeptical view of Gordon (2000).[22]

Oliner and Sichel (2000, 2002) and Jorgenson and Stiroh (2000) consider three related factors to be prominent in the relationship between information technology and U.S. growth and productivity performance:

1. There have been rapid advances in multifactor productivity in the production of information technology—especially through the production of more powerful semiconductors, with little or no more input requirements;
2. These productivity advances have enabled relative and absolute price declines for information technology equipment—prices have declined by 18 per cent a year from 1960 to 1995 and by 27.6 per cent a year from 1995;
3. Lower prices have helped to stimulate very strong demand for information technology, especially in the second half of the 1990s.

These factors imply aggregate labour productivity gains via multifactor productivity gains in computer production and capital deepening in using industries as firms raise the ratio of information technology capital services to labour.

Oliner and Sichel (2000) conducted what has become a central study. They found that information technology contributed about 0.7 of a percentage point (or about two-thirds) of the 1 percentage point acceleration in U.S. labour productivity growth between the first and second halves of the 1990s (specifically, between 1991-1995 and 1996-1999). This comprised 0.42 of a percentage point from information technology capital deepening and 0.26 of a percentage point from multifactor productivity growth in information technology production. Capital deepening from other forms of capital contributed almost nothing to the acceleration, leaving multifactor productivity growth in industries outside of information technology production to account for the rest (see Table 5).

22. The U.S. studies restrict their analysis to information technology goods, covering the manufacture of computer hardware and software and communications equipment. The delivery of information technology services (for example, communications and Internet services) is excluded.

Table 5. Estimates of contributions to the U.S. multifactor productivity acceleration in the 1990s

	Gordon (2000)	Jorgenson and Stiroh (2000)	Oliner and Sichel		CEA (2001)
			(2000)	(2002)	
Multifactor productivity acceleration	0.29	0.63	0.68	0.62	1.19
Information technology-producing industries	0.29	0.18	0.26	0.26	0.18
Information technology ICT -using industries	0.00	0.44	0.42	0.36	1.00

Despite the results that show the highest multifactor productivity acceleration in information technology using industries, Jorgenson and Stiroh (2000) were unconvinced about the importance of multifactor productivity gains associated with information technology in the non-information technology producing-sector as the majority of its constituent industries continues to experience productivity measurement problems. Gordon (2000) has been the most prominent sceptic. He removed what he considered to be a transient cyclical component from the aggregate labour productivity acceleration and made a further correction for mismeasurement. The remaining structural acceleration in labour productivity growth of 0.8 of a percentage point, less the contribution from capital deepening, virtually equalled his estimate of the multifactor productivity gains from computer production. This left virtually no room for any multifactor productivity gains from any other industries (see Table 5).

The widespread reporting of Gordon's conclusion has undoubtedly contributed to a fairly common view that production of information technology is the only way to access 'new economy' productivity gains (even though Gordon accepted that information technology use did contribute to labour productivity growth through capital deepening). However, the evidence of multifactor productivity gains in industries outside of information technology production found in other studies is hard to 'explain away'.

More recent studies reveal stronger multifactor productivity acceleration in the U.S. economy (up to the year 2000). An update from Oliner and Sichel (2002) and the CEA (2001) found a stronger labour productivity acceleration to the year 2000, most of which is attributed to stronger multifactor productivity acceleration. Around three-quarters of the multifactor productivity acceleration was attributed to non-information technology-producing industries (see Table 5).

More detailed industry studies are now showing evidence of productivity acceleration in information technology-using industries. Nordhaus (2001) found that industries outside of broadly-defined 'new economy' production contributed about a half of the aggregate labour productivity acceleration. Stiroh (2001) found that (a narrower group of) information technology production industries contributed about one-fifth of the aggregate acceleration and information technology-using industries contributed nearly all of the remainder, with little acceleration in industries outside of information technology production or use. Studies of firms have shown very substantial gains from information technology use (see Brynjolfsson and Hitt 2000 for the U.S. and Baldwin and Sabourin 2001 for Canada).

Whilst this evidence of productivity acceleration in using industries does not establish conclusive proof of information technology-related effects, since non-information technology factors could still be at work in information technology-intensive industries, it strongly suggests that information technology use has contributed to productivity acceleration in information technology-intensive industries. This conclusion is also supported by the findings from a major OECD study of factors contributing to differences in growth rates across economies in the 1990s (OECD 2001). It found that productivity gains came from information technology use, as well as production.

3. Canada-U.S. estimates of information technology contributions compared

3.1. Motivation

Because the three seminal studies have been much reviewed and compared, this paper does not dwell on their details. This section focuses on official and more up-to-date estimates produced by the BLS and provides comparisons with Statistics Canada's productivity accounts data.

This section explores the contribution of information technology to Canada's real GDP, capital input and productivity growth. The information technology contributions to output growth are assessed over output cycles, which are defined as periods between peaks in GDP growth. The peaks are defined as points where the gaps between the actual and a trend output series turn from increasing to decreasing. The use of output cycles is one method for defining and examining underlying trends in output growth.

A number of studies, including those reviewed in the introduction, have compared growth rates for the second half of the 1990s with earlier periods. The use of 1995 as the dividing point between these periods may be defensible in terms of delineating the acceleration in investment in information technology from 1995, due to the change in the life cycle of semiconductors. But these periods are essentially arbitrary with respect to productivity growth and would only accidentally reveal underlying trends for analysis in the growth accounting framework. (Comparisons of contributions in the two halves of the 1990s are nevertheless presented below because of the general tendency of the literature to do so).

There is some disagreement about the extent to which the measured acceleration represents an uplift in the underlying trend rate of growth or merely a transient or cyclical effect. For the U.S., Gordon (2000) believes that there is a sizeable cyclical component in the productivity acceleration and has made an adjustment to extract it. He believes that the extent of the reduction in unemployment and the increase in the current account deficit in the 1990s make the high rate of output and productivity growth unsustainable. Gordon's treatment has attracted some controversy. But, on the other hand, most other studies do not explicitly consider the issue, and report measured productivity accelerations as though they are trend shifts.

In this paper, we use the Hodrick-Prescott technique to distinguish the trend from the cyclical component. The common use of the Hodrick-Prescott filter has been criticized, particularly for the accuracy of trend calculations at the start and end of series. But it can be reasonably used here to show that for Canada and the U.S., the appropriate periods are 1981-1988 and 1988-2000 and the year 1995 was above the trend.

3.2. Aggregate trends

This section examines the contributions of information technology to the aggregate output and inputs in Canada and the United States. It also highlights and updates several trends, some of which were already reported in Harchaoui *et al.* (2002) for the 1981-1999 period.

3.2.1. Contributions to GDP growth

The top panel of Tables 4a and 4b summarizes for Canada and the U.S., respectively, the growth rates of prices and quantities for information technology-GDP and for everything else, labelled non-information technology GDP, during the 1981-2000 period. The most striking feature of the data is the rapid increase in information technology-GDP, 13.3% per year from 1981 to 2000, compared with a modest 2.6% for non-information technology-GDP (13.7% and 3%, respectively, for the United States). Since 1995, information technology-GDP grew 22.3% per year in Canada, more than five times the increase experienced by non-information technology GDP (23.7% per year for the United States).

The more rapid growth of information technology-GDP can be understood by examining the behaviour of relative prices. The rate of inflation of the non-information technology-GDP deflator in Canada declined from 4.5% per year in the 1980s to 2.2% per year in the 1990s (from 3.7% to 2.7% for the United States). The quality-adjusted price of information technology GDP fell more rapidly during the 1990s, compared to the 1980s (-4.6% compared to -0.5% for Canada; -5.0% compared to -2.2% for the United States). Relative to the non information technology-GDP deflator, information technology-GDP prices fell at an average of -6.8% in the 1990s, compared to -5.0% during the 1980s (-7.7% compared to -5.9% for the United States).

Investments in information technology increased almost as rapidly in the 1990s as in the 1980s in Canada (17.5% compared with 18.2%), a sharp contrast with the U.S. where growth was more rapid in the 1990s (16.9% compared to 13.9% during the 1980s). The rapid increase in the 1990s is largely attributable to the performance during the post-1995 period where information technology investment increased 22.3% per year in Canada (23.7% in the United States). Households' expenditures in information technology increased 8.6% during the 1990s (13.7% in the U.S.), a more rapid pace than in the 1980s, particularly in the United States

This moderate increase in information technology household spending is largely due to information technology consumer prices that reflect only partly the quality change observed for information technology investment. Information technology net exports, the main component of the category Other Information Technology, shows a consistent decline in the quantity, reflecting Canada's net importer status for information technology goods over the last two decades. The relatively rapid increase of information technology imports over exports is in part attributable to the decline of information technology import prices relative to export prices in Canada.

Table 6: Sources of growth GDP and capital services, business sector (percentage)

	1981-2000		1981-1988		1988-2000		1988-1995		1995-2000	
	Canada	U.S.	Canada	U.S.	Canada	U.S.	Canada	U.S.	Canada	U.S.
A. Capital Input and Its Components										
	Average annual growth rate									
Capital services	3.3	3.9	3.4	3.9	3.3	3.9	2.5	2.8	4.3	5.4
Information technology	17.2	16.5	18.0	19.5	16.8	14.8	15.7	10.3	18.4	21.3
Computers	28.6	28.1	28.5	34.0	28.7	24.8	25.7	13.8	32.9	41.8
Software	12.5	15.4	17.2	15.7	9.8	15.2	11.7	14.3	7.2	16.4
Telecommunications	8.6	6.8	5.8	8.1	10.3	6.1	9.0	4.4	12.2	8.5
Other machinery and equipment	3.1	1.9	3.7	1.4	2.8	2.2	1.4	1.5	4.8	3.1
Structures	2.0	2.3	2.1	2.9	1.9	1.9	1.5	1.7	2.3	2.2
	Average cost of capital share of assets									
Capital services	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Information technology	6.8	12.0	5.5	8.9	7.6	13.9	7.1	12.9	8.3	15.3
Computers	39.0	31.9	43.1	35.4	36.5	29.9	35.4	30.0	38.0	29.2
Software	28.2	31.8	19.4	26.6	33.6	34.6	33.1	32.0	34.7	38.2
Telecommunications	32.8	36.4	37.5	38.0	29.9	35.5	31.5	38.0	27.3	32.6
Other machinery and equipment	24.7	29.1	24.3	28.5	25.1	29.5	25.2	28.9	25.0	30.5
Structures	68.4	58.8	70.2	62.5	67.2	56.6	67.7	58.2	66.7	54.3
B. GDP and its components										
	Average annual growth rate									
GDP	3.0	3.6	3.3	3.6	2.9	3.6	1.5	3.0	4.9	4.5
Information technology GDP	13.5	13.7	10.5	12.2	15.3	14.6	10.3	10.4	22.6	20.6
Non-information technology GDP	2.7	3.0	3.1	3.1	2.4	3.0	1.2	2.6	4.2	3.5
	Average nominal GDP share of output components									
GDP	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Information technology GDP	3.2	5.6	2.7	5.1	3.5	5.8	3.1	5.2	4.0	6.1
Non-information technology GDP	96.8	94.4	97.3	94.9	96.5	94.2	96.9	94.8	96.0	93.9

Panel B of Table 6 shows the share of information technology GDP in overall business sector GDP—defined as the ratio of the expenditure on information technology over total expenditures in current prices. The share was 2.7% in the 1980s in Canada (5.1% in the U.S.), but has risen fairly steadily and reached 4.0% in the late 1990s (6.1% in the United States).

Recall that the contribution of information technology to GDP growth is the share of final output of information technology in GDP multiplied by the growth rate of information technology-GDP. The data show that despite its small share in GDP in both Canada and the U.S., information technology accounted for almost 18% of GDP growth in Canada during the 1995-2000 period (27.8% for the U.S.), up from the 8.6% contribution made during the 1981-1988 period (17.3% for the United States). The information technology contribution is clearly rising. The rising level of the information technology contribution is due to information technology GDP growing more rapidly in the last decade, but also to the steadily rising information technology share.

3.2.2. Contributions to the capital input growth

This section presents the information technology contribution to capital input for the Canadian and U.S. business sectors for the period 1981-2000. The stock of information technology business assets (computers, software, and communications equipment) has grown dramatically in recent years, but remains relatively small. In 2000, combined information technology assets accounted for only 4.2% of the Canadian tangible capital and 6.4% of reproducible private assets (6.3% compared to 8.9% for the U.S.), up from 2.3% and 3.9%, respectively, in 1981 (2.8% compared to 4.1% for the U.S.) (see Tables 4a and 4b).

While information technology assets are about 4% of total capital in Canada in the late 1990s (compared to about 2% in the 1980s) (respectively 3% and 6% for the U.S.), the information technology service shares, or the cost of capital shares, of these assets are twice as high as the corresponding asset shares. In the late 1990s, it was 8.3% compared to 5.5% during the 1980s (15.3% compared to 8.9% in the United States). This reflects the rapid price declines and high depreciation rates that enter into the rental prices for information technology.

Panel A of Table 6 presents a decomposition of the role of information technology as a production input which saw its contribution rising even more dramatically than the GDP side. Information technology capital services contributed 36% to the growth of broadly defined capital during the late 1990s, up from 29% during the 1980s (60% compared to 45% for the United States). Computers are the single largest information technology contributor on the input side, which reflects the growing share and rapid growth rates of the late 1990s. Price changes lead to substitution toward capital services with lower relative prices such as computers.

During this period, GDP prices rose 1.7% in Canada (1.4% in the U.S.), compared to a 4.6% price decline of information technology capital services (9.6% decline for the U.S.) (see Tables 4a and 4b). In response to these price changes, industries accumulated computers, software, and telecommunications equipment more rapidly than other forms of capital. Investment other than information technology actually declined as a proportion of GDP. These substitutions suggest that gains of the computer revolution accrue to industries and households who restructured their activities to respond to these relative price changes.

3.2.3. Contribution to productivity growth

We now turn to assess the contribution of information technology to capital deepening and to see how much of the growth of labour productivity it can account for, based on Equation (3). Tables 7a and 7b reflect, respectively, the major sources of the Canadian and U.S. business sector labour productivity growth—capital deepening, labour composition and multifactor productivity growth.

The 1.3% average annual growth of Canadian labour productivity during the 1980s (1.9% for the U.S.) is attributable to a modest growth of multifactor productivity (0.3 percentage points in Canada, compared to 0.9 percentage points for the U.S.), but a rather rapid increase of both capital deepening (0.6 percentage points for both countries) and labour composition (0.5 percentage points in Canada compared to 0.3 percentage points for the United States).

Labour productivity growth increased moderately to 1.5% during the 1990s (2.0% for the U.S.) solely as a result of the rapid increase of capital deepening, while the percentage points contribution of multifactor productivity and labour composition remained unchanged from the previous decade (0.3 and 0.5 percentage points, respectively).

Table 7a. Compound average annual rates of labour productivity and the contributions of capital intensity, labour composition, and multifactor productivity, Canadian business sector (percentage)

	1981-2000	1981-1988	1988-2000	1988-1995	1995-2000
Labour productivity	1.4	1.3	1.5	1.2	1.8
Capital deepening	0.6	0.6	0.7	0.8	0.5
Information technology	0.4	0.3	0.4	0.4	0.5
Computers	0.3	0.2	0.3	0.2	0.4
Software	0.1	0.1	0.1	0.1	0.0
Communication	0.1	0.0	0.1	0.1	0.1
Other machinery and equipment	0.1	0.2	0.1	0.1	0.2
Structures	0.1	0.1	0.1	0.3	-0.2
Labour composition	0.5	0.5	0.5	0.6	0.3
Multifactor productivity	0.3	0.3	0.3	-0.2	1.1

Table 7b. Compound average annual rates of labour productivity and the contributions of capital intensity, labour composition, and multifactor productivity, U.S. business sector (percentage)

	1981-2000	1981-1988	1988-2000	1988-1995	1995-2000
Labour productivity	1.9	1.9	2.0	1.4	2.7
Capital deepening	0.7	0.6	0.8	0.5	1.1
Information technology	0.6	0.5	0.6	0.4	1.0
Computers	0.3	0.3	0.3	0.2	0.6
Software	0.1	0.0	0.1	0.0	0.1
Communication	0.2	0.1	0.2	0.2	0.2
Other machinery and equipment	0.0	0.0	0.1	0.0	0.1
Structures	0.1	0.2	0.1	0.1	0.0
Labour composition	0.3	0.3	0.3	0.4	0.3
Multifactor productivity	0.9	0.9	0.9	0.5	1.4

Note: The numbers may not add up due to rounding

The first and the second halves of the 1990s portray some features that are worth noting. In both countries, the growth of labour productivity slipped during the 1988-1995 period in comparison with the previous decade with the serious slump in multifactor productivity only partly offset by a revival in the growth of capital deepening in Canada (0.8 percentage points) and labour composition in both Canada and the United States

In Canada, labour composition grew at 0.6% during the 1988-1995 period (compared with 0.5% during the 1981-1988 period) (0.4% compared to 0.3%, respectively, for the U.S.), while hours at work advanced at 0.3% (1.2% for the U.S.) (2% and 1.9 for Canada and the U.S., respectively, during the previous decade) (see Tables 7a and 7b). This increase of labour composition in a period of economic slump may reflect the tendency of firms at the beginning of an economic recession to lay off workers with the least seniority ('last-hired first fired'). Blue-collar workers usually experience more layoffs than well-educated white-collar workers do. As the expansion continues as in the post-1995 period, however, firms often hire workers with lesser qualifications and workers who were not previously in the labour force, with a resulting decline in labour composition.

Canada's labour productivity growth advanced at 1.8% on average during the 1995-2000 period (2.7% for the U.S.) due primarily to the resurgence of multifactor productivity growth which contributed 1.1 percentage points (1.4 percentage points in the U.S.), while capital deepening added 0.5 percentage points, somewhat lower than during the 1988-1995 period. This contrasts with the U.S., where capital deepening contribution more than doubled between the early and the late 1990s. Growth in labour composition slowed, particularly in Canada, as growth in hours accelerated. This reflects the falling unemployment rate and tightening of labour markets as more workers with relatively low marginal products were drawn into the workforce.

Tables 7a and 7b shows that since 1981 information technology has contributed around two-thirds of the 0.6% increase in deepening in Canada (more than four-fifth of the 0.7% increase in the United States). In the early 1980s, information technology contributed half of the 0.6 percentage point increase in capital deepening in Canada (more than four-fifth for the 0.6 percentage point increase for the United States). Its contribution slipped back in 1988-1995 in Canada, but in the latest period, 1995-2000, it contributed to all of the 0.5% increase of capital deepening (90% of the 1.1% increase in the United States). This suggests that capital deepening grew exceptionally faster during the late 1990s in the U.S., largely as a result of information technology.

3.2.4. The sources of economic growth

To provide a different perspective on the contribution of information technology, we now focus on the sources of GDP growth. Using the framework developed above, the capital and labour inputs are combined with output data to estimate the components of Equation (2) to quantify the sources of economic growth in GDP from 1981-2000. In addition to the standard contribution of aggregate capital services, the analysis also examines the contribution of each broad asset class to economic growth.

The results are reported in Table 8. For the period 1981-1988, output grew at 3.3% per year in Canada (3.9% in the U.S.), of which aggregate capital services contributed 1.4 percentage points (1.3 percentage points in the U.S.), labour input 1.7 percentage points (1.6 percentage points in the U.S.), and multifactor productivity 0.2 percentage points (0.9 percentage point in the United States). The 1.4 percentage points contribution of capital services is largely driven by information technology and other machinery and equipment (altogether 0.8 percentage points). This contrasts somewhat with the U.S. where information technology and structures contributed 1.1 percentage points to the growth of capital input.

Table 8. Sources of the business sector GDP growth, Canada-U.S. (percentage)

	Canada					U.S.				
	1981-2000	1981-1988	1988-2000	1988-1995	1995-2000	1981-2000	1981-1988	1988-2000	1988-1995	1995-2000
GDP	3.1	3.3	2.9	1.5	5.0	3.7	3.9	3.6	2.7	4.8
Information technology GDP	0.4	0.3	0.5	0.3	0.9	0.7	0.6	0.8	0.5	1.3
Non-Information technology GDP	2.6	3.0	2.4	1.2	4.1	2.9	3.2	2.8	2.2	3.5
Contribution of capital services	1.3	1.4	1.3	1.0	1.7	1.3	1.3	1.3	0.9	1.8
Information technology	0.5	0.4	0.5	0.4	0.6	0.6	0.5	0.7	0.4	1.1
Computer	0.3	0.3	0.3	0.2	0.4	0.4	0.3	0.4	0.2	0.6
Software	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.3
Telecommunications capital	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2
Other machinery and equipment	0.3	0.4	0.3	0.2	0.5	0.2	0.1	0.2	0.1	0.3
Structures	0.5	0.6	0.5	0.4	0.6	0.4	0.6	0.4	0.3	0.4
Contribution of labour input	1.5	1.7	1.4	0.8	2.2	1.5	1.6	1.4	1.2	1.6
Multifactor productivity growth	0.3	0.2	0.3	-0.2	1.1	0.9	0.9	0.9	0.5	1.4

For 1995-2000, GDP grew 5.0% per year in Canada (4.8% for the U.S.), capital services contributed 1.7 percentage points (1.8 percentage points for the U.S.); a little more than one-third of this is due to information technology (compared to slightly less than two-thirds for the United States). Labour input contributed 2.2 percentage points (1.6 percentage points for the U.S.), and multifactor productivity added the remaining 1.1 percentage points (1.4 percentage points for the United States).

The second half of the 1990s, compared to the first half, is remarkable. For the 3.5 percentage points acceleration (difference between the late and early 1990s) of GDP in Canada (2.1 percentage points in the U.S.), labour input added 1.4 percentage points (0.4 percentage points for the U.S.), followed by multifactor productivity with 1.3 percentage points (0.9 percentage points in the U.S.), and capital services with 0.7 percentage points (0.9 percentage points for the United States). This increase in the contribution of capital services in the U.S. during this period is due in a large part to information technology (0.7 percentage points). This contrasts with Canada where the contribution of all three asset classes have all equally contributed to the revival of capital input.

The revival of multifactor productivity is a major source of growth in GDP and labour productivity growth for the Canadian and U.S. business sectors. While multifactor productivity growth for the 1990s has yet to attain the peaks of some periods in the golden age of the 1960s and early 1970s, the recent acceleration suggests that the Canadian business sector may be recuperating from the anaemic productivity growth of the past two decades. Of course, caution is warranted until more historical experience is available.

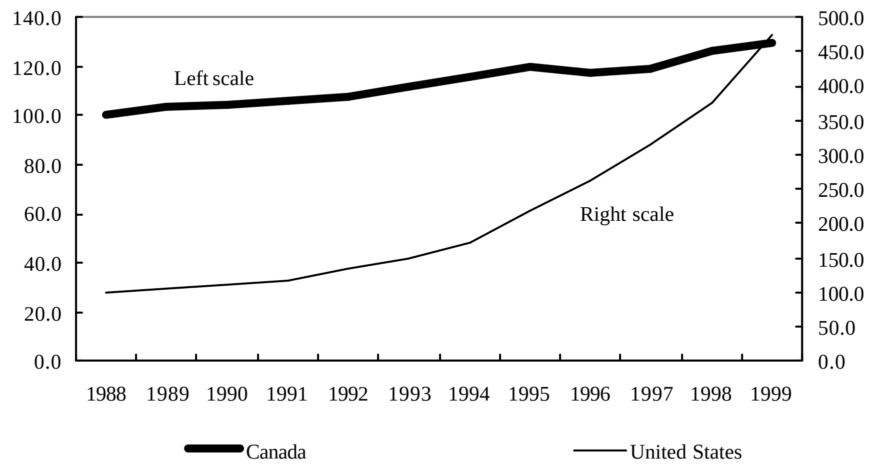
3.3. Sectoral sources of Canada and U.S. productivity revival

We have explored the sources of the Canada-U.S. economic growth at the aggregate level and demonstrated that the acceleration in multifactor productivity growth is an important contributor to the recent growth resurgence. We now examine how information technology-producing and information technology-using industries contributed to the acceleration of aggregate multifactor productivity growth in the Canada-U.S. productivity revival. We base our analysis of information technology-producing industries on the most comparable data that are also consistent with the aggregate trends illustrated above. The analysis also uses KLEMS data available through 1999 at the most detailed industry level of Canada and U.S. SIC systems. The advantage of using this detailed data set is twofold: first, it minimizes the impact of the differences in the industrial structures between these two countries and, secondly, it provides reasonably more precise estimates of the contribution of the information technology-producing industries to business sector multifactor productivity growth.

These data are based on the notions of sectoral output and capital services. In contrast, due to data limitations, U.S. labour input for manufacturing is measured as the sum of hours at work of all persons. As a result, to maintain cross-country comparability for this study, Canadian labour input estimates were brought to the lowest common denominator, which is the straight sum of hours worked. For this particular reason, the multifactor productivity estimates of the Canadian and U.S. business sectors used in this section are not directly comparable with those discussed in the previous section. In particular, the multifactor productivity gains should be higher because they include the labour composition effect.

Figure 1 reports the Canada-U.S. estimates of multifactor factor productivity growth for information technology-producing industries from 1988 to 1999, the period that is closely comparable to the one used in the analysis of the aggregate trends. Over this period, multifactor productivity growth of Canadian information technology-producing industries advanced at 2.4% on average, a much slower increase than that of the U.S., which grew at 15.2%.

Figure 1. Multifactor productivity trends of information technology-producing industries (1988=100)



For the 1995-1999 period, Canadian information technology-producing industries advanced at 2.1% on average, down from 2.6% during the early 1990s. In contrast, the productivity performance of U.S. information technology-producing industries, which grew at 11.8% on average during the early 1990s, almost doubled by the late 1990s (21.3%). As evidenced by Figures 2 and 3, there are some similarities between Canada and U.S.: hours at work showed a moderate declining trend in both countries (-0.4% and -0.2%, respectively) but capital services grew slightly more rapidly in Canada than in the U.S. (9.1% compared to 7.7%).

Figure 2. Chained volume indexes for Canada's information technology-producing industries (1988=100)

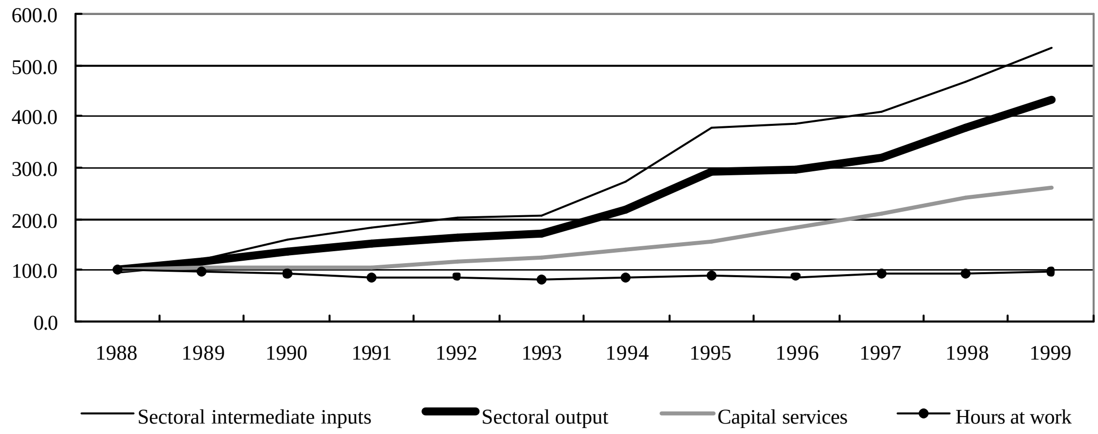
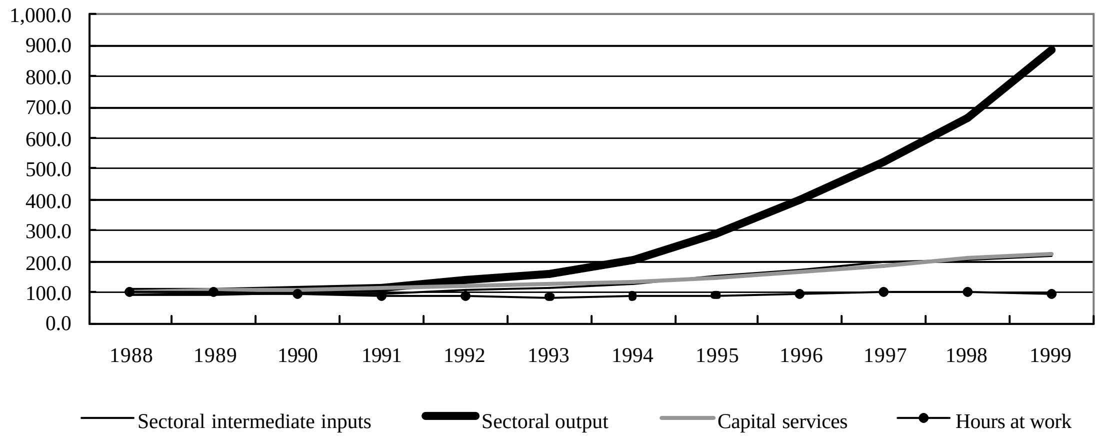


Figure 3. Chained volume indexes of U.S. information technology producing-industries (1988=100)



But there are also major differences that are worth noting. The major difference between the two countries is ascribed to the trends of sectoral output and sectoral intermediate inputs. Canada's sectoral output grew significantly less rapidly that its U.S. counterpart (14.2% compared to 21.9%) and vice versa for the sectoral intermediate inputs (16.4% compared to 7.3%), with the result that Canada posted a negative average growth rate for the productivity of sectoral intermediate inputs compared to major efficiency gains for the U.S. (-4.2% and 14.6%, respectively).

These diverging trends in the productivity of sectoral intermediate inputs between the two countries are due to both structural and measurement differences. First, Canada imports a significant amount of information technology products that are reflected in the sectoral intermediate inputs. The prices of these products are adjusted for quality change with the result that the sectoral intermediate inputs experience a remarkable increase. In contrast, the same products are netted out for the U.S. intermediate inputs. Second, the output implicit price index of communication equipment industry shows a diverging trend between the two countries while that of electronic products and accessories declined at a slower pace in Canada compared to the United States. This translates in a slower Canadian output growth for these two industries, compared to the United States.

Table 9. Sectoral contributions to aggregate multifactor productivity growth, 1981-1999

	Canada			U.S.		
	1988-1999	1988-1995	1995-1999	1988-1999	1988-1995	1995-1999
Multifactor productivity growth of the business sector	0.73	0.42	1.28	1.08	0.88	1.43
Information technology-producing industries	0.071 (10.2%)	0.072 (17.3%)	0.068 (6.1%)	0.62 (57.6%)	0.44 (49.8%)	0.94 (66%)
Information technology-using industries	0.66	0.35	1.21	0.46	0.44	0.49

Notes: The estimates of multifactor productivity are based on the concept of sectoral output and hours at work. Therefore, they are not directly comparables to those presented in Table 5 for Canada. With the exception of the numbers in parentheses, all other numbers are average annual growth rates. The numbers between parentheses represent the contribution of information technology -producing industries to the business sector multifactor productivity growth.

Table 9 reports the sectoral sources of business sector multifactor productivity growth decomposition estimates. Over the 1988-1999 period, out of the 1.08% average U.S. multifactor productivity growth, information technology-producing industries contributed 0.62 percentage points, or 57.6%. For the early 1990s, these industries contributed for 49.8% to the 0.88% average annual increase of the U.S. business sector multifactor productivity growth. In contrast, for 1995-1999, 2/3 of the 1.43% surge in the U.S. multifactor productivity growth is ascribed to information technology-producing industries, a sharp contrast with most of the U.S. literature findings. This difference in the results is due to the fact that the majority of U.S. studies have used a two-digit SIC that tends to mix information technology-producing industries with electrical industries, an approach that mitigates the contribution of information technology-producing industries. In the case of some studies, such as CEA (2001), this problem with the industry structure is magnified with the use of gross product originating output, a measure that tends to overestimate the contribution of information technology-using industries. This is so because gross output originating is based on the income side of national income accounts, a measure that makes the productivity revival larger as the estimated income grew more rapidly than the estimated product accounts.[23] Given the still relatively small size of the computer and semiconductor sectors, this contribution is substantial and highlights the important impact that information technology is having on the U.S. business sector.

While information technology-producing industries are at the centre stage of the U.S. productivity revival, Canada's experience offers a different story as almost all of its productivity resurgence is due to information technology-using industries. Whilst intensive information technology-using industries contributed most to Canada's productivity surge in the 1990s, even

23. Using the KLEMS data at two-digit industry detail available from the BLS, we reached similar results as the one obtained by the CEA (2001). This clearly highlights that regardless of the ways output is measured, the industrial composition has an important bearing on the estimates.

in those industries, some of the gains are likely to be due to factors such as industry-specific factors. Some detailed comparisons would be needed to distinguish conclusively between these two possibilities.

In terms of the sectoral sources of the multifactor productivity resurgence between the early and the late 1990s, the results are even more startling: out of the 0.55 percentage point increase in the U.S. multifactor productivity between these two periods, information technology-producing industries contributed 0.5 percentage points (91%), which leaves the contribution of information technology-using industries at 9%, quite modest in comparison to the estimates produced by the U.S. productivity literature (see Table 5 above). Our results, therefore, tend to support Gordon's point of view, which gives all of the multifactor productivity gains to information technology production. For Canada, however, the story stands in contrast with the U.S. experience as all of the 0.86 percentage points increase in multifactor productivity acceleration between 1988-1995 and 1995-1999 is due to gains that occurred in information technology-using industries.

4. More on Canada-U.S differences

Having covered the basic results from the growth-accounting exercise, we turn to the critical question as to why has the information technology effect in Canada has not been as large as in the United States. The question can be addressed at a) the aggregate and b) the industry levels.

a) As stated above, the contribution to output growth of any sector is its share in GDP (in current prices) multiplied by the growth rate of its final output. So the effect of information technology output depends on both on its GDP share and its growth. A similar point applies to the input side. Here the contribution of information technology capital services to the growth of aggregate input is the share in GDP of the cost of capital attributable to information technology capital, multiplied by the growth rate of information technology capital services.

There is a discernible pattern across different sub-periods of the last two decades for the aggregate trends of information technology-GDP and information technology capital services between Canada and the United States. As indicated by Table 6, during the 1980s, the U.S. information technology capital services grew at a faster pace than its Canadian counterpart, and vice versa for the 1990s. A similarly pattern is revealed by the information technology-GDP trends in both countries with the result that, over the 1981-2000 period, both information technology-GDP and information technology capital services grew almost at the same pace in Canada and United States. However, over the same period, there are significant differences in terms of the share of information technology in both capital compensation and nominal GDP in favour of the United States. This may underline some differences in the technological structures between the two countries.

Specifically, what determines that the order of magnitude of the share of output generated by information technology capital is higher or lower and hence whether, for a given growth rate of information technology capital, the contribution to aggregate input is higher or lower is the elasticity of substitution between information technology capital and other inputs.[24] The U.S. information technology output and capital shares are higher than their Canadian counterparts, which suggests that that this elasticity in the U.S. has apparently been greater than in Canada (at least at the business sector level). Additional research outside the growth accounting framework is therefore warranted to substantiate this possible structural difference between Canada and the United States.

b) At the disaggregated level, there are some indications that output and intermediate price measurement differences between Canada and U.S. in telecommunication and, to a lesser extent, electronic products and accessories, are not negligible. On the sectoral output side, the output implicit price index has diverged between Canada and U.S. for telecommunication industries (respectively, 1.4% compared to -2.5% for the United States). However, for electronic products and accessories, the implicit prices have declined for both countries, albeit at a different pace (-2.6% for Canada and -11.5% for the United States). These price differences are compounded by the difference in the share of each of these industries between Canada and Unites States.

On the input side, recall that sectoral intermediate inputs are purchased from outside the manufacturing sector and, as a result, they include imported information technology products for Canada and non-information technology products and services for the United States. In principle, Canadian sectoral intermediate input price indexes should decline at a much more rapid pace than their U.S. counterparts. But the data show that this is not the case. Sectoral intermediate input prices indexes advanced at 0.3% and -2.2%, respectively, for the two Canadian industries, compared to 0.7% and -0.25% for their U.S. counterparts.

The different price behaviour between Canada and the U.S. in telecommunication equipment and electronic products and accessories, led us to explore further the impact of using different deflators on the productivity performance of communications and electronic product industry, an aggregate of telecommunication equipment industry and electronic products and accessories industry.

24. On the input side, the crucial share is:

$$\frac{u_{IT} K_{IT}}{pY}$$

On the output side, the crucial share is

$$\frac{p_{IT} Y_{IT}}{pY} = \frac{p_{IT}}{u_{IT}} \times \frac{Y_{IT}}{K_{IT}} \times \frac{u_{IT} K_{IT}}{pY}$$

(Recall that u_{IT} is the rental price and p_{IT} is the price of information technology output Y_{IT}). Whether the shares indicated in the equations above rise or fall will be determined by the elasticity of substitution. If we hold the prices of all other inputs constant, we can aggregate them in to a single input, say X. Then the elasticity of substitution is defined as $\frac{d\,\ell n\left(\frac{K_{IT}}{X}\right)}{d\,\ell n\left(\frac{u_{IT}}{p_X}\right)}$.

Suppose hypothetically that the price indexes of Canadian sectoral output and sectoral intermediate inputs for the communication and electronic product industry decline at the same pace as that of sectoral output for its U.S. counterpart, corrected for the exchange rate.[25] What would then be the impact on multifactor productivity performance trend for this industry?

In this case, the implicit price indexes of sectoral output and sectoral intermediate inputs would advance, respectively, at -5.5% (compared to -0.14% before correction) and -2.7% (compared to 0.14% before correction). These changes would increase the growth of sectoral output and sectoral intermediate inputs. The adjustment to multifactor productivity growth would correspond to the adjusted growth of sectoral output net of the adjusted growth of sectoral intermediate inputs weighted by the share of sectoral intermediate inputs in the total cost. Once these adjustments are implemented, multifactor productivity growth of the Canadian communication and electronic product industry would increase from 1.5% to 5.5% over the 1988-1999 period (11.4% to 17.7% for labour productivity growth), but still remains below that of the U.S. which grew at 15.2%. But given the modest size of this industry in the business sector, our initial conclusion still stands—Canada's productivity revival is largely attributable to information-using industries—but the contribution of information technology-producing industries jumps from 7.1% to 21.6% once the price adjustment is made.

IV. Concluding remarks

This paper extends, in many important respects, our earlier contribution on the extent to which information technology contributes to economic growth and productivity performance in both Canada and the United States. First, it uses an augmented aggregate growth accounting framework that identifies and quantifies all of the information technology channels that contribute to economic growth and productivity performance. Second, it develops a sectoral model fully integrated to the augmented aggregate growth accounting framework to trace the sectoral sources of the productivity revival.

The results of our examination are summarized as follows:

1. The share of information technology output in Canada's business sector GDP has been rising fairly steadily, reaching 4.0% during the 1995-2000 period (6.1% for the U.S.) compared to 2.7% during the 1981-1988 period (5.1% for the United States). The growth of information technology output has contributed about 19% of GDP growth in the second half of the 1990s, compared to 27.9% for the United States.
2. On the input side, information technology experienced a similar pattern, but the differences between the two countries are more important. The share of information technology capital in Canada's business sector GDP has also been rising fairly steadily, reaching 8.3% during the 1995-2000 period (15.3% for the U.S.) compared to 5.5% during the 1981-1988 period (8.9% for the United States). The growth of information technology input has contributed about 35.5% of overall capital services growth in the second half of the 1990s, compared to 60.4% for the United States.

25. We assume a complete pass-through between the price change of sectoral intermediate inputs to sectoral output.

3. The adoption of information technology contributed modestly to Canada's productivity surge in the late 1990s. The contributions of information technology to labour productivity growth has not been as strong in Canada as it has been in the United States.
    - Contributions from information technology capital deepening are very similar in terms of timing (uplift from 1995) but not in magnitude between the early 1990s and the late 1990s (around 0.5 percentage points for the U.S., compared with 0.1 percentage points for Canada).
    - During the late 1990s, information technology capital accounted for half of Canada's capital deepening growth (80% for the United States). Information technology capital deepening contributed 27.8% of labour productivity increase, up only slightly from 23.0% during the 1981-1988 period (respectively 37.0% and 26.3% for the United States).
    - Canada has had a stronger contribution from multifactor productivity growth to the labour productivity revival between the early 1990s and the late 1990s (1.3 percentage points in Canada, 0.9 of a percentage points in the United States). The sectoral sources of multifactor productivity is another major important difference between Canada and the U.S.: Canada's multifactor productivity revival in the late 1990s is almost entirely ascribed to information technology-using industries, while information technology-producing industries contributed 2/3 of the U.S. productivity revival.
4. Canada's stronger productivity growth means Canada benefited more from one or both of two factors:
    - greater productivity gains from information technology use, which would suggest that Canadian businesses were able to use information technology; and
    - greater productivity gains from non-information technology factors.

The coincidence of industries in Canada that are both relatively intensive information technology users and strong productivity performers provides some further evidence to link information technology with productivity growth.

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