Information technology and economic growth in Canada and the U.S.

Information and communication technology was the largest contributor to growth within capital services for both Canada and the United States during the late 1990s, but the contribution of this capital asset in Canada was lower than that in the United States

Tarek M. Harchaoui,
Faouzi Tarkhani,
Chris Jackson,
and
Philip Armstrong

Information and communication technology (ICT) equipment appears to be almost everywhere—in the office, on the factory floor, in the classroom, at home, and, even in people's pockets. By all accounts, ICT appears to be rapidly changing the way many enterprises conduct business and communicate. The proliferation of ICT has made the world seem much smaller, as computer-related innovations, such as the Internet, let individuals on opposite sides of the world interact in ways that were unimagined 20 years ago.

The explosion of ICT spending over the last few decades has sparked renewed interest in the role of investment and capital accumulation as sources of economic growth. While productivity growth, capital accumulation, and the impact of technology were topics once reserved for academic debates, the success of the U.S. economy during the late 1990s has moved such issues into the popular domain.[1]

Using revised data on output and capital input, this article sheds some new light on the changing composition of investment and the growth of capital services in Canada during the 1990s and makes comparisons to the 1980s.[2] It discusses the data sources and the historical trends of investment and capital formation and then analyzes the effect of these trends on labor productivity and multifactor productivity performance.

In particular, this article employs well-tested and familiar methods to estimate annual indexes of capital services for the Canadian business sector from 1981 to 2000 and introduces a decomposition into quantity and quality components for broad asset classes, including ICT equipment. While much of the recent Canadian economic literature has documented the growing importance of computers, this article examines and compares the extent to which ICT and other types of capital have contributed to economic growth in Canada. Finally, it examines the underpinnings of the productivity performance of the Canadian and U.S. business sectors over the last two decades, using comparable methodologies.

Our approach distinguishes between *capital quantity* growth due to investment, and compositional change of asset types (sometimes referred to as *capital quality* growth) due to substitution between different types of capital assets. Much of the investment boom during the 1990s reflects substitution towards high-tech assets as their relative price steadily fell. We also introduce quantity and quality decompositions for broad asset classes, such as ICT, other machinery and equipment (made of low-tech equipment), and various types of structures.

Our primary conclusion is that the Canadian business sector has experienced a steady and pervasive increase in the growth rate of capital

Tarek M. Harchaoui is chief of Statistics Canada multifactor productivity program, Micro-Economic Analysis Division Statistics Canada, Ottawa, Canada. **harctar@statcan.ca** and Faouzi Tarkhani, Chris Jackson, and Philip Armstrong are economists in various areas at Statistics Canada. The opinions expressed herein are those of the authors and do not necessarily reflect the opinions of Statistics Canada.

Exhibit 1. Classification of total capital by asset class

Information and communication technology

Computers and office equipment
Communication equipment
Software-own account
Software-pre-packaged
Software-custom design

Other machinery and equipment

Office furniture, furnishing
Household and services machinery and equipment
Electrical industrial machinery and equipment
Nonelectrical industrial machinery and equipment
Industrial containers
Conveyors and industrial trucks
Automobiles and buses
Trucks (excluding Industrial trucks) and trailers
Locomotives, ships and boats, and major replacement parts
Aircraft, aircraft engines, and other major replacement parts
Other equipment

Structures

Nonresidential building construction
Road, highway and airport runway construction
Gas and oil facility construction
Electric power, dams, and irrigation construction
Railway and telecommunications construction
Other engineering construction
Cottages
Mobile homes
Multiple dwellings
Single dwellings
Inventories
Land

services during the second half of the 1990s. The growth of capital services—including fixed reproducible capital, land, and inventories—has increased from an average annual growth rate of 3.5 percent over the 1981–88 period to 4.2 percent over the 1995–2000 period.

Data on Canadian economic growth in output from 1995 to 2000 show that capital and labor continue to make important contributions to overall growth. One primary source of growth is in investment. The increase in the growth of investment, from 1.7 percent per year over 1981–88 to 11.9 percent over 1995–2000, has led to an increase in the contribution of capital services from 1.4 percent to 1.7 percent per year between these two periods. Due to strong investment and an increasing input share, high-tech equipment is the only class of fixed reproducible assets that is making a significantly larger contribution to output growth in the second half of the 1990s relative to the 1980s.

Labor input, another primary source of growth, has advanced during the post-1995 period mainly as a result of the increase in hours worked. The contribution of labor quality declined, a reflection of a falling unemployment rate, as more workers with relatively lower marginal products were drawn into the workforce during this period.

Still another source of growth, multifactor productivity or the famous Solow residual, grew at 0.2 percent per year on average during the last two decades in Canada, compared with 0.9 percent per year for the United States.[3] The acceleration of multifactor productivity in Canada from –0.3 percent per year over the 1988–95 period to 1.0 percent per year during the post-1995 period (0.5 percent to 1.3 percent in the United States) suggests considerable improvements in technology and increases in the efficiency of production. While the resurgence in multifactor productivity growth in the post-1995 period has yet to surpass the pre-1973 performance, more rapid multifactor productivity growth is critical for sustained growth at higher rates.

During the post-1995 period, multifactor productivity contributed 21 percent of the output growth in Canada (27 percent for the United States), up from 6.1 percent in the 1981–88 period (26 percent for the United States). Although the recent resurgence in multifactor productivity in both countries does not surpass the pre-1973 performance, it is certainly one of the most important stylized facts of the end of the twentieth century.

Description of the data

This article is based on methodologies recently implemented by the productivity program at Statistics Canada.[4] This program constructs new Fisher indexes of output and inputs for the Canadian business sector that are then used to construct multifactor productivity estimates.

The Fisher output indexes use the expenditure based GDP[5] estimates, but exclude out-of-scope components such as the government sector, nonprofit institutions, and the rental on owner-occupied dwellings. Corresponding adjustments are also made to capital stock and hours worked. The GDP estimates incorporate the capitalization of software expenditures, making the Canada-U.S. estimates of economic growth comparable for the first time since October 1999, when the U.S. Bureau of Economic Analysis introduced this change during a comprehensive historical revision to their National Income and Product Accounts.

Table 1. Estimates of capital stock by asset class, Canadian business sector, 1981 and 2000						
Asset class	1981 capital stock			2000 capital stock		
	Value (millions of current dollars)	Fixed capital share (percent)	Total capital share (percent)	Value (millions of current dollars)	Fixed capital share (percent)	Total capital share (percent)
Total capital stock	492,588	…	100.0	1,278,237	…	100.0
Fixed reproducible capital	290,465	100.0	…	929,409	100.0	…
Information, communication, and technology	11,363	3.9	2.3	59,900	6.4	4.7
Computers and software	4,444	1.5	.9	37,493	4.0	2.9
Communication	6,920	2.4	1.4	22,407	2.4	1.8
Other machinery and equipment	80,948	27.9	16.4	238,505	25.7	18.7
Structures	198,153	68.2	40.2	631,008	67.9	49.4
Inventories and land	202,123	…	41.0	348,828	…	27.3
Structures, land, and inventories	400,276	…	81.3	979,832	…	76.7

For this analysis, the wide number of assets used in the productivity program (28 classes) are grouped into three distinct classes. Exhibit 1 shows the concordance that produces three broad asset classes—ICT, other machinery and equipment, and structures (which includes inventories and land).[6] This taxonomy not only distinguishes long-lived structures from short-lived equipment, but also ICT from other machinery and equipment.

This article also uses estimates of labor growth that take into account differences in marginal productivity across labor types.[7] Contrary to the method that just sums all hours worked across all workers, the method used in this analysis considers differences across labor types and sums the growth in hours worked of different classes of labor weighted by their relative wage rates or their share of labor compensation. Much like the estimates of capital input that capture substitution across asset classes, the approach for aggregate labor input allows for substitution between various types of labor, for example, workers cross-classified by education, experience, and other characteristics.[8] This approach allows for a breakdown of the growth of labor input into growth of labor hours and a labor composition or labor quality effect that is similar to the breakdown in capital growth between the straight sum of all capital and changes in its composition.

Capital stock estimate in current price

Table 1 contains a breakdown of assets into major groupings and the 1981 and 2000 value of capital stock by asset class. The perpetual inventory calculations result in a net stock of fixed reproducible assets of $929 billion in current dollars in 2000, up from $290 billion in 1981. Adding in the estimated value of land and inventories yields a total capital stock of $1.3 trillion in 2000.

The investment in ICT in constant prices has grown at an average annual rate of 16.2 percent during the 1981–2000 period, much faster than the other two classes of assets. (See table 2.) Despite this rapid growth, however, ICT equipment remains a small share of the business sector's aggregate capital. In 2000, ICT capital stock in nominal terms accounted for 6.4 percent of fixed reproducible capital, which includes equipment and structures, up from 3.9 percent in 1981. (See table 1.) In our broader definition of capital stock that includes residential assets, land and inventories, ICT assets account for an even smaller share (4.7 percent in 2000, compared with 2.3 percent in 1981).

Investment in capital growth

The growth in Canada's use of capital can be traced through an examination of three related data series—an index of the growth in investment, an index of the growth in capital stock (a straight sum of the different assets), and an index of the growth in capital services—from 1981 to 2000. Furthermore, each of these can be decomposed into three components: that arising from investments in ICT, other machinery and equipment, and structures (which include land and inventories).[9]

For a clear view of aggregate trends, average annual growth rates (in terms of both quantities and prices) are presented in table 2 for each series for the major asset classes and for the entire period 1981–2000, and for three subperiods: 1981–88, 1988–95, and 1995–2000. Growth rates for business sector GDP for the same periods are also reported.

The dominant feature of the average annual growth rates is the significant drop of output growth during the early 1990s recession. After rising around 3.3 percent per year during 1981–88, Canada's real GDP growth fell to 1.5 percent per year for 1988–95 and recovered remarkably during the second half of the 1990s to reach an average 4.9 percent per year. Investment, capital stock, and capital services all show similar growth patterns.

Investment. Although investment showed a similar growth pattern to that in output, growth in investment showed more sensitivity to the business cycle. It slowed dramatically from

Table 2. Average annual growth rates of investment, capital stock, capital services, and output, Canadian Business sector, 1981–2000

(In percent)

Item	Investment index		Capital stock index		Capital services index		GDP	
	Price	Quantity	Price	Quantity	Price	Quantity	Price	Quantity
	1981–2000							
GDP	…	…	…	…	…	…	2.9	3.0
All assets	1.0	3.6	1.0	2.0	4.2	3.4	…	…
Information and communication technology	–9.3	16.2	9.3	12.7	1.5	21.0	…	…
Other machinery and equipment	2.5	2.0	2.5	2.1	5.6	3.4	…	…
Structures	1.5	.8	1.5	1.7	6.8	2.1	…	…
	1981–88							
GDP	…	…	…	…	…	4.5	3.3	…
All assets	.5	1.7	.5	1.8	6.4	3.5	…	…
Information and communication technology	–14.5	11.5	–14.5	8.0	–1.4	21.5	…	…
Other machinery and equipment	2.9	2.2	2.9	1.7	7.8	3.7	…	…
Structures	1.7	.4	1.7	1.9	8.5	2.4	…	…
	1988–85							
GDP	…	…	…	…	…	2.4	1.5	…
All assets	1.8	–.2	1.8	1.3	3.7	2.6	…	…
Information and communication technology	–8.0	13.2	–8.0	11.5	–2.8	17.5	…	…
Other machinery and equipment	2.4	–2.1	2.4	1.2	2.2	1.6	…	…
Structures	2.0	–1.9	2.0	1.3	7.2	1.6	…	…
	1995–2000							
GDP	…	…	…	…	…	2.4	1.5	…
All assets	.7	11.9	.7	3.5	1.7	4.2	…	…
Information and communication technology	–3.2	27.6	–3.2	21.3	.3	25.1	…	…
Other machinery and equipment	2.0	7.7	2.0	4.1	7.5	5.5	…	…
Structures	.3	5.6	.3	2.1	4.1	2.5	…	…

1.7 percent per year during 1981–88 to –0.2 percent for 1988–95. However, it surged to 11.9 percent for 1995–2000, helping to boost GDP growth during this period.

There is substantial variation in the growth rates across asset classes and an accelerating trend toward equipment investment, particularly ICT. Real ICT investment growth was high and rising throughout the last two decades. Despite the GDP slowdown, it was 13.2 percent per year even during the slow growth in the early 1990s. In contrast, real investment in nonresidential structures dropped to –1.9 percent and other machinery and equipment fell to –2.1 percent per year, during the 1988–95 period. Investment in all of the asset classes grew at a much higher pace during the 1995–2000 period than that during the 1981–88 period.

The more rapid growth of ICT can be understood by examining the behavior of relative prices. The rate of inflation of the GDP deflator declined from 4.5 percent per year (1981–88) to 2.4 percent per year (1988–95) and then to 1.4 percent per year (1995–2000). The quality-adjusted price of ICT investment goods fell during the same three post–1981 periods (–14.5 percent to –8.0 percent to –3.2 percent per year). Relative to the GDP deflator, ICT prices fell at an average of 12.2 percent per year over the 1981–2000 period. The other categories of investment experienced price increases, but in general, they were still lower than those of the GDP deflator.

Investment patterns directly determine the growth of the capital stock. For example, relatively fast growth in ICT equipment investment leads to faster capital stock growth rates and an increase in the capital stock share of equipment. The long-lived nature of structures, however, means this occurs slowly. The index of real capital stock of ICT equipment, for example, has grown 12.7 percent per year over the last two decades, compared with structures, which grew only 1.7 percent per year. The share of ICT equipment in the stock of fixed reproducible capital in current dollar terms has increased from 3.9 percent in 1981 to 6.4 percent in 2000. This important increase in the value share is due to the large increase in the quantity of ICT capital that more than offset the fall in the price of such capital.

Capital formation. The indexes of the growth of Canadian capital stock and capital services show that the post-1995 period has been one of relatively rapid growth in capital stock. The rate of growth of capital fell from 1.8 percent per year over the 1981–88 period to 1.3 percent per year over the 1988–95 period, and rebounded sharply to 3.5 percent per year over 1995–2000. At the asset level, however, while ICT equipment maintained a sustained growth across all periods, both machinery and equipment and structures experienced a significant slowdown during the 1988–95 period, followed by a marked recovery in recent years.

Trends in the growth of the capital stock are major determinants of the growth of capital services. The growth of capital services is, however, higher than the growth of capital stock, reflecting the ongoing substitution of short-lived equipment for long-lived structures. This shift in composition is sometimes referred to as changes in capital quality—in the sense that it results from changes in composition that are associated with changes in marginal productivity. All else being equal, a short-lived asset has a higher depreciation rate, relatively higher service price and, therefore, a higher relative marginal productivity because competitive markets equate user capital cost to marginal productivity. As a consequence, the fast growing short-lived assets receive a higher weight in the capital service aggregation, compared with their weight for the capital stock.[10] For individual asset classes, the results in table 2 show that capital-service growth always exceeds the growth of the capital stock, which implies asset substitution also occurs within asset classes.

These data document an important recovery in the growth rate of Canadian capital services across all asset classes in the post-1995 period. This reflects, in large part, the rapid growth of investment in the second half of the 1990s for all asset classes. This is an important development because it is the growth of capital services and not the level of capital or investment growth that ultimately affects economic growth in output.

It is useful to compare Canada's capital services growth with the U.S. measure of capital services.[11] For the U.S. private business sector, which most closely matches Statistics Canada's estimates, the Bureau of Labor Statistics reports capital services growth of 3.8 percent for all assets in the 1981–99 period, slightly more than Canada's estimate of 3.3 percent for the same period. This may reflect structural differences between the two countries.

For both countries, the trends are quite similar during the various subperiods. BLS reports a decrease in the growth of capital services from 3.9 percent for 1981–88 to 2.8 percent for 1988–95 and then a recovery to 5.3 percent for 1995–99. (For Canada, the estimates are 3.5 percent, 1981–88; 2.6 percent, 1988–95; and 4.2 percent, 1995–99). However, there are marked cross-country differences in the growth of capital services at the asset level. The U.S. ICT equipment capital services grew 17.5 percent during the 1995–99 period, up from 14.5 percent over the 1981–88 period and 8.5 percent over the 1988–95 period This is far below the performance experienced by its Canadian counterpart (25.7 percent, 1995–99; 21.5 percent, 1981–88 period; and 17.5 percent, 1988–95). Although in the United States, other machinery and equipment and structures recovered in the 1995–99 period in comparison with the 1988–95 period, this performance remains below that posted in the previous decade. In contrast, during the 1995–99 period, Canada's other machinery and equipment and structures experienced their fastest growth since 1981.

Decomposing the growth in capital services. To identify and quantify the sources of the increase in capital services, in terms of changes in composition of investment within asset classes and between asset classes, we provide a framework that decomposes the growth in capital services into three major components. In this framework, capital services increase for three reasons—substitution towards short-lived, high marginal product assets within asset classes (within quality effect), substitution between asset classes (between quality effect), and accumulation of capital stock (capital accumulation effect).

The growth of aggregate capital services (the log represents the growth rate) is decomposable as follows[12]:

(1)

$$ln\left(\frac{\tilde{K}_t}{\tilde{K}_{t-1}}\right) = \sum \bar{v}_t^{\,j} ln\left(\frac{\Delta_t^j}{\Delta_{t-1}^j}\right) + \sum_j (\bar{v}_t^{\,j} - \bar{w}_t^{\,j}) ln\left(\frac{\bar{K}_t^j}{\bar{K}_{t-1}^j}\right) + \sum_j \bar{w}_t^{\,j} ln\left(\frac{\bar{K}_t^j}{\bar{K}_{t-1}^j}\right)$$

where $\tilde{K}_t$ = aggregate capital services

Δ_t^j = quality change of the asset class j = ICT,

$\bar{K}_t^j$ = other machinery and structures and the capital stock of the asset class j at period t

$\bar{v}_t^j$ = average rental cost share for the asset class j at period t and

$\bar{w}_t^j$ = average value share of capital stock for the asset class j at period t

Each of these three components has a specific economic interpretation. The first term on the right-hand side will be referred to as the "within quality effect," which measures substitution and capital quality growth within distinct asset classes. The second term represents the "between quality effect," which measures substitution between distinct asset classes. The last term is the "capital accumulation effect," which measures capital stock accumulation.

Table 3 presents the contribution to the growth in total fixed capital services from each component for 1981–2000 and subperiods. The decomposition allows us to identify the sources of increase of capital services growth by comparing each component across asset classes and over time. Table 3 should be read in the following manner. Consider the 3.4-percent per year growth of capital services for the 1981–2000 period (last column, first row). This is made up of a 1.2-percent

Table 3. Decomposition of the growth in capital services by asset class, Canadian business sector, 1981–2000

Asset class	Within quality effect[1]	Between quality effect[1]	Weighted capital accumulation[1]	Capital services growth[2]
	1981–2000			
Fixed capital	0.9	0.3	2.1	3.4
Information and communication technology	.4	.3	.5	1.2
Other machinery and equipment	.3	.1	.4	.8
Structures	.2	–.1	1.2	1.4
	1981–88			
Fixed capital	1.4	.1	2.0	3.5
Information and communication technology	.6	.2	.2	1.0
Other machinery and equipment	.5	.1	.3	.9
Structures	.3	–.1	1.4	1.6
	1988–95			
Fixed capital	.7	.3	1.7	2.6
Information and communication technology	.4	.3	.4	1.1
Other machinery and equipment	.1	.1	.3	.4
Structures	.2	–.1	1.0	1.1
	1995–2000			
Fixed capital	.7	.6	2.9	4.2
Information and communication technology	.2	.6	.8	1.6
Other machinery and equipment	.3	.1	.8	1.2
Structures	.2	–.1	1.3	1.4

[1] Average annual percentage point contribution.
[2] Average annual growth rate.

contribution from ICT, 0.8 percent from other machinery and equipment and 1.4 percent from structures. Looked at from the decomposition outlined in equation 1, this 3.4 percent comes from 0.9 percent of a within-class effect (substitution across assets within an asset class), 0.3 percent from a between-class effect (substitution across asset classes), and 2.1 percent of a capital-accumulation effect (general growth across all asset classes).

The estimates show that at the aggregate level, the capital-accumulation effect is the primary source behind the growth of total capital services for all periods. However, this varies across asset classes: the total quality effect (the sum of the within and between quality effect) constitutes the major source behind the growth of ICT capital services for all periods, whereas the capital-accumulation effect tends to dominate for other machinery and equipment and structures. Substitution across asset groups within an asset class becomes increasingly important over time, particularly for ICT.

For all periods and all asset classes, the total quality effect is primarily driven by the within quality effect. However, the 0.7-percentage point annual increase of capital services between 1981–88 and 1995–2000, which is mainly attributable to ICT and other machinery and equipment, is mostly driven by the between-effect, which increased by 0.5 percentage points per year and the capital-accumulation effect, by 0.9 percentage points per year.

Sources of economic growth

Framework. The growth of capital services along with the growth in labor input and multifactor productivity are the three primary determinants of the economic growth in output. This type of growth accounting exercise has a rich history beginning with the seminal work of Robert M. Solow, who integrated the aggregate production function with national income data to produce an estimate of productivity growth that captured disembodied technical change.[13] Aggregate output Y_t is considered to be produced from capital services $\tilde{K}_t$ and labor services L_t. Representing productivity as a 'Hicks-neutral' augmentation A_t of aggregate input, output can be written as:

$$Y_t = A_t F(\tilde{K}_t, \tilde{L}_t) \tag{2}$$

Under the assumptions of competitive product and factor markets, and constant returns to scale, growth accounting gives the growth of output as the sum of the share-weighted growth of inputs and growth in multifactor productivity:

$$\Delta ln Y_t = \bar{s}_{k,t} \Delta ln \tilde{K}_t + \bar{s}_{L,t} \Delta ln \tilde{L}_t + \Delta ln A_t \tag{3}$$

where

$\overline{s}_{K,t}$ = capital's average share of nominal value-added

$\overline{s}_{L,t}$ labor average share of nominal value-added

$\overline{s}_{K,t} + \overline{s}_{L,t} = 1$

A_t the augmentation factor, captures multifactor productivity

Δ refers to a first difference.

Equation (3) has several attractive features. It facilitates the decomposition of the growth in output into the contributions made by labor and capital inputs on one hand, and a residual that is called multifactor productivity growth, on the other hand. It also allows for the quantification of the contributions of different types of capital, such as ICT, to the growth of output.

In addition, rearranging equation (3) enables us to present results in terms of labor productivity growth as:

(4)

$$\Delta \ln\left(\frac{Y_t}{H_t}\right) = \overline{s}_{K,t}\Delta ln\left(\frac{\tilde{K}_t}{H_t}\right) + \overline{s}_{L,t}(\Delta lnH_t) + \Delta lnA_t$$

where

$\frac{Y_t}{H_t}$ = output per hour worked

$\frac{\tilde{K}_t}{H_t}$ = the ratio of capital services to hours worked

This gives the familiar formula that allocates labor 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 labor productivity in proportion to the share of capital. The second term is the improvement in labor quality, defined as the difference between the weighted growth rates of each category of labor and the growth in the simple sum of hours worked across all worker categories. Reflecting the rising proportion of hours supplied by workers with higher marginal products, labor quality improvement (also called the *labor composition effect*) raises average labor productivity growth in proportion to labor's share. The third term is *multifactor productivity* growth, which increases labor productivity growth on a point-for-point basis. Long-term labor productivity growth arises from three sources: multifactor productivity growth, the contribution of increased capital intensity, and the contribution of shifts in labor composition.

As shown in equation (4), labor productivity (output per hour) can differ from multifactor productivity (output per unit of combined capital and labor inputs) if capital deepening occurs or if labor quality improves.

The results associated with equations (3) and (4) provide two different, but related, perspectives on the sources of growth: the latter decomposes the sources of labor productivity growth and the former identifies the sources of economic growth of real GNP.

Sources of labor productivity growth. The contribution of capital intensity to labor productivity growth equals the growth in the capital-hours ratio multiplied by capital's share of nominal value-added. The contribution of labor composition equals the difference between the growth rates of labor input and of hours worked multiplied by labor's share of nominal value-added. Historically, capital's share has been slightly more than one-third of nominal value-added in the business sector.

Table 4 indicates that from 1981 to 2000, Canada's labor productivity grew at an annual rate of 1.4 percent in the business sector. Of the 1.4 percent growth in labor productivity, 0.2 percent can be attributed to increases in multifactor productivity, 0.6 percent to the contribution of capital intensity, and 0.5 percent to changes in labor composition. Table 4 displays a moderate labor productivity increase during the 1980s and early 1990s, and an acceleration of labor productivity growth in the late 1990s. This acceleration reflects the remarkable pickup in multifactor productivity growth in recent years.

During the 1988–95 period, multifactor productivity decreased –0.3 percent per year in the business sector. At the same time, the average annual contribution of capital intensity to labor productivity growth increased to 0.9 percent, and

Table 4. Annual average percentage point contribution to labor productivity, Canadian business sector, 1981–2000

Item	1981–2000	1981–88	1988–95	1995–2000
Labor productivity growth (annual average growth rate)	1.4	1.3	1.2	1.7
Capital deepening	.6	.6	.9	.4
Information and communication technology	.4	.3	.4	.4
Other machinery and equipment	.1	.1	.1	.1
Structures	.1	.1	.3	–.1
Labor quality	.5	.5	.6	.3
Multifactor productivity	.2	.2	–.3	1.0

labor composition made a 0.6-percentage point contribution. Labor productivity, therefore, increased 1.2 percent per year from 1988 to 1995. ICT capital began to play an increasingly important role during this period, contributing 0.4 percent per year, or more than two-fifths of the contribution of capital deepening to labor productivity growth.

During 1995–2000, labor productivity grew 1.7 percent per year in the business sector, 0.5 percentage points faster than during the 1988–95 period. This acceleration is attributed entirely to the remarkable resurgence of multifactor productivity growth, which increased by more than one percentage point. Continuing the trend in substitution of ICT for other forms of capital, ICT capital accounted for the whole contribution of capital deepening to labor productivity growth. Growth in labor quality slowed relative to the growth in hours in the 1995–2000 period.

Sources of economic growth. Using the framework previously explained, we combine the capital and labor inputs with output data to estimate the components of equation (3) to quantify the sources of economic growth in output 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 total growth.

Table 5 illustrates in the second column, for the period 1981–88, that output grew at 3.3 percent per year, of which aggregate capital services contributed 1.4 percent, labor input 1.7 percent, and multifactor productivity 0.2 percent. The 1.4 percent capital contribution is from the growth rate of capital services multiplied by the share $\bar{s}_{K,t}$ and may also be decomposed into an 0.8-percent contribution of capital accumulation and 0.6 percent of quality change. Similarly, the 1.7-percent labor input contribution can be decomposed into a 1.2-percent contribution from increased hours worked and a 0.5-percent contribution from quality change due to substitution toward more highly educated workers.

For 1995–2000, output grew 4.9 percent per year, capital services contributed 1.7 percentage points, labor input contributed 2.2 percentage points, and multifactor productivity contributed 1.0 percentage points.

As reported earlier, there has been an increase in the contribution of capital services during 1995–2000 as the growth contribution increased to 1.7 percent from 1.4 percent per year over the 1981–88 period. ICT shows the largest increase in the contribution of capital services between the two periods, nearly doubling from 0.4 percent to 0.7 percent. In addition, the most recent estimates show an increase in the growth of multifactor productivity that is more than any rate since 1981.

Multifactor productivity growth. Canada's multifactor productivity grew at an average 0.2-percent per year, compared with 0.9 percent per year for the United States during 1981–99, the most recent period for which U.S. multifactor productivity estimates are available. (See table 6.) This productivity gap between the two countries is largely attributable to Canada's relatively modest multifactor productivity performance from 1981 to 1995. The lack of multifactor productivity gain in Canada from 1981 to 1995 (0.0 percent, compared with 0.7 percent in the United States) reflects a 2.4-percent increase in output (3.3 percent in the United States) and a 2.4-percent increase in combined inputs of capital and labor (2.5 percent in the United States).

In the late 1990s, output grew at an average annual rate of 4.8 percent in Canada (4.9 percent for the United States), a 3.2-percentage point increase relative to the early 1990s (2.7 percentage points for the United States). Multifactor productivity growth makes an important recovery to 1.0 percent in Canada (1.3 percent for the United States as well), while capital services' contribution to growth recovered to 1.7 percent in Canada (1.8 percent in the United States), and labor's contribution rebounded to 2.1 percent points (1.8 percent for the United States).

Multifactor productivity growth is the source of 21 percent of output growth in Canada (27 percent in the United States), up from 6.1 percent in the 1981–88 period (26 percent for the

Table 5. Sources of economic growth, Canadian business sector, 1981–2000

(Annual average percentage point contribution)

Source	1981–2000	1981–88	1988–95	1995–2000
Output growth (annual average growth rate)	3.0	3.3	1.5	4.9
Contribution of capital services	1.3	1.4	1.0	1.7
Information communication technology	.5	.4	.4	.7
Other machinery and equipment	.3	.4	.2	.5
Structures	.5	.6	.4	.5
Contribution of labor Input	1.5	1.7	.8	2.2
Multifactor productivity (annual average growth rate)	.2	.2	–.3	1.0
Contribution of capital stock	.9	.8	.6	1.4
Contribution of capital quality	.5	.6	.4	.3
Contribution of labor hours	1.0	1.2	.1	1.9

Table 6. Sources of economic growth, Canada and U.S. business sectors, 1981–99

Source	Canada	U.S.	Canada	U.S.	Canada	U.S.	Canada	U.S.
	1981–99		1981–88		1988–95		1995–99	
Output (annual average growth rate)	2.9	3.6	3.3	3.9	1.5	2.2	4.8	4.9
Contribution of labor Input	1.4	1.5	1.7	1.6	.8	.9	2.1	1.8
Contribution of capital services	1.3	1.2	1.4	1.3	1.0	.8	1.7	1.8
Contribution of information and communication technology	.5	.5	.4	.4	.4	.3	.7	1.1
Contribution of other machinery and equipment	.3	.3	.4	.4	.2	.2	.5	.4
Contribution of structures	.5	.4	.6	.4	.4	.2	.6	.4
Multifactor productivity (annual average growth rate)	.2	.9	.2	1.0	–.3	.5	1.0	1.3

NOTE: Numbers may not add due to rounding.

United States). The acceleration in multifactor productivity growth in Canada and the United States is perhaps the most remarkable feature of the data. Its acceleration in Canada from –0.3 percent per year to 1.0 percent per year (0.5 percent to 1.3 percent in the United States) between 1988–95 and 1995–99 suggests considerable improvements in technology and increases in the efficiency of production. While the resurgence in multifactor productivity growth in the post-1995 period has yet to surpass the pre-1973 performance, more rapid multifactor productivity growth occurred in the last part of the 1990s.

Conclusion

In both Canada and the United States, the growth in output in the post-1995 period has been substantially above that in the earlier part of the decade and of the previous decade. In addition, after almost two decades of lackluster performance, the productivity statistics, beginning in 1995, have begun to reveal the impact of increasing capital formation in ICT technologies. Progress in ICT is driving down relative prices of computers, software, and communication equipment and inducing firms to invest in these assets (16.2-percent per year growth on average during the 1981–2000 period).

The article also examines the pattern of growth in capital services in terms of both quantity and quality components. It distinguishes between capital quantity growth due to investment, and capital quality growth due to substitution between different types of capital assets. Much of the recent investment boom has been associated with substitution across assets as the relative price of high-tech assets steadily fell. Capital quality grew in Canada over the 1981–2000 period at 1.2 percent per year on average, of which 75 percent was due to changes within asset classes.

For Canada, in terms of the sources of the 3.3-percent annual average growth over the 1981–88 period, capital input contributed 1.4 percent per year (0.6 percent for quality and 0.8 percent for capital quantity) and labor input contributed 1.7 percent per year (1.2 percent for hours and 0.5 percent for labor quality). This is somewhat similar to the 1995–2000 period, when capital input, at 1.7 percent, contributed less than labor input, at 2.2 percent per year to output growth.

In both Canada and the United States, ICT is the largest contributor to growth within capital services, during the late 1990s, followed closely by structures in Canada. But the contribution of ICT in Canada is lower than that in the United States.

What is even more remarkable about the post-1995 period, compared with the previous periods, is the recovery in the multifactor productivity performance, posted at 1.0 percent per year in Canada and 1.3 percent in the United States (compared with 0.2 percent in Canada and 1.0 percent in the United States, for the 1981–88 period). □

NOTES

ACKNOWLEDGMENT: The authors appreciate the comments that were made by John R. Baldwin and Wulong Gu.

[1] See D. W. Jorgenson, and K. J. Stiroh, 2000, "Raising the speed limit: U.S. economic growth in the information age," *Brookings Papers on Economic Activity*, vol. 1, pp. 125–211; and for a Canada-U.S. comparison, see H. Khan and M. Santos, *Contribution of ICT Use to Output and Labour-Productivity Growth in Canada,* Bank of Canada Discussion Paper, 2002.

[2] The data used in this study are those available in March 2002. Therefore, they do not reflect the recent revisions that both Statistics Canada and the U.S. Bureau of Labor Statistics have incorporated in their estimates. A more recent Canada-U.S. comparison based on the

last productivity figures can be found in *The Daily* of July 12, 2002, Statistics Canada's news release, on the Internet at: **www.statcan.ca**.

[3] R. M. Solow, "Technical Change and the Aggregate Production Function," *Review of Economics and Statistics*, 1957, vol. 39, pp. 312–20.

[4] Statistics Canada's new methodology for estimating the growth of capital services that is appropriate for an aggregate production function analysis is outlined in T. M. Harchaoui, and F. Tarkhani, "A Comprehensive Revision of the Capital Input Methodology for Statistics Canada Multifactor Productivity Program," in J. R. Baldwin and T. M. Harchaoui, eds., *Productivity Growth in Canada*, ch. 4, Statistics Canada, 15-204XPE, 2002, forthcoming.

The estimation procedure begins with estimates of real investment flows by detailed asset class, then calculates capital stock for each asset class by industry using the perpetual inventory technique. It then estimates the user cost of capital for each industry using input-output tables to derive rates of return at the industry level, micro-economic price data on more than 30,000 sales of used assets to obtain depreciation rates and detailed information on tax rates. The growth rates of the stock of capital by asset type of individual industries are then aggregated using the user cost of capital to derive an estimate of the growth in the flow of capital services by industry. See also G. Gellatly, M. Tanguay, and B. Yan, "An Alternative Methodology for Estimating Economic Depreciation: New Results Using a Survival Model," in Baldwin and Harchaoui, eds., *Productivity Growth in Canada*, ch. 2, 2002, forthcoming.

[5] Note that preliminary GDP data from 1998 onward are used in this analysis. These data were released in the Income and Expenditure Accounts, May 31, 2001.

[6] The definition of information and communications technologies (ICT) assets, which includes computer hardware, software, and telecommunication equipment, is chosen to permit comparisons with the United States. See "Multifactor Productivity Trends, 1999," USDL 00–267 (Bureau of Labor Statistics Sept. 21, 2000), on the Internet at: **http://www.bls.gov/mprhome.htm**. There are currently efforts underway within the Organisation for Economic Co-operation and Development (OECD) to define a broader set of ICT commodities which include not only the investment assets used in our definition, but also intermediate goods and services, and final demand categories.

[7] W. Gu, M. Kaci, J. P. Maynard, and M. Sillamaa, "The Changing Composition of the Canadian Workforce and Its Impact on Productivity Growth," in Baldwin and Harchaoui, eds., *Productivity Growth in Canada*, ch. 3, 2002, forthcoming.

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

[9] See the appendix to Harchaoui and Tarkhani, "A Comprehensive Revision of the Capital Input Methodology," in Baldwin and Harchaoui, eds., *Productivity Growth in Canada*, 2002, forthcoming, for the differences between these various concepts.

[10] Harchaoui, and Tarkhani, "A Comprehensive Revision of the Capital Input Methodology," in Baldwin and Harchaoui, eds., *Productivity Growth in Canada*, ch. 4, 2002, forthcoming.

[11] "Multifactor Productivity Trends, 1999," 2000.

[12] M. S. Ho, D. W. Jorgenson, and K. J. Stiroh, U.S. High-Tech Investment and the Pervasive Slowdown in the Growth of Capital Services, 1999 on the Internet at: **http://www.post.economics.harvard.edu/faculty/jorgenson/papers/hitech.pdf**.

[13] Solow, "Technical Change and the Aggregate Production Function," 1957.