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THE IMPACT OF INFORMATION AND COMMUNICATION TECHNOLOGY ON THE PRODUCTIVITY OF THE CANADIAN TRANSPORTATION SYSTEM: A MACROECONOMIC APPROACH FOR THE AIR AND RAIL SECTORS

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The Impact of Information and Communication Technology on the Productivity of the Canadian Transportation System: A Macroeconomic Approach for the Air and Rail Sectors

Abstract

Productivity and ICT use in Canadian air and rail transportation have both increased significantly during the 1997-2010 period. Few efforts have been made, however, to quantify the link between these two variables. This report seeks to address this knowledge gap. It provides a detailed analysis of ICT investment, ICT capital, and productivity trends in Canadian air and rail transportation, comparing these trends to those seen in U.S. air and rail transportation. It then evaluates the role of ICT as a productivity driver in these two sectors. Using industry-level data, we find that the standard neoclassical growth accounting framework does not appear to adequately capture the importance of ICT on air and rail productivity. Econometric approaches using the same data also failed to yield meaningful results, mainly due to the small number of observations, but also possibly due to the level of data aggregation. It is suggested that future work on the topic should focus on econometric approaches using firm-level data or case studies.

The Impact of Information and Communication Technology on the Productivity of the Canadian Transportation System: A Macroeconomic Approach for the Air and Rail Sectors

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The Impact of Information and Communication Technology on the Productivity of the Canadian Transportation System: A Macroeconomic Approach for the Air and Rail Sectors

Executive Summary

Despite the productivity growth slump in Canada during the past decade (both from a historical and an international perspective), productivity in Canadian air and rail transportation has risen significantly. This impressive productivity performance has been accompanied by an increased role for information and communication technologies (ICTs) in both sectors.

A growing consensus in the economics literature identifies ICTs as a key driver in productivity growth. The use of ICTs has led different industries to restructure the way they do business, allowing them to achieve considerable efficiency gains. So far, however, few efforts have been made to quantify the contribution of ICT to productivity in Canadian air and rail transportation. This is the main objective of this report.

This executive summary is divided into three parts. The first part analyzes key ICT investment and capital stock trends in Canadian air and rail transportation, comparing them to those in U.S. air and rail transportation. The second part discusses the main methodologies used in the economics literature to measure the impact of ICT on productivity growth. The last part summarizes the main findings of the report.

ICT Investment and Capital Stock Trends in Canadian Air and Rail Transportation

Air transport

Nominal ICT investment in air transportation grew at a slower pace than in the business sector between 1981 and 2010 (5.9 per cent per year versus 6.7 per cent per year). In spite of this, ICT investment in air transportation as a share of value added is proportionately larger than in the business sector. As a component of the sector's total investment, ICT investment has traditionally been low in air transportation in comparison to the business sector.

ICT investment intensity in the air transportation sector has historically been higher than that of the business sector and remains so, despite declining in recent years from its peak in 2004.

In terms of the relative importance of the three ICT components, telecommunications comprises a smaller share of total ICT investment in air transportation than in the business sector and software a larger share. Between 1981 and 2010 the software component of ICT investment has become increasingly important in both air transportation and the business sector.

Rail transport

ICT investment in rail transportation grew slower than in the business sector between 1981 and 2010. ICT capital stock growth in rail transportation did keep pace with the business sector between 1981 and 2010, with both averaging annual growth rates of about 6 per cent.

ICT investment in rail transportation comprised less than 1 per cent of business sector ICT investment in 2010, having fallen since 1981. In proportion to the sector's value added, ICT investment is relatively large in rail transportation compared to the business sector. Though the ICT capital stock in rail transportation has traditionally been small relative to the sector's value added in comparison to the business sector, the most recent data demonstrates that this trend has recently reversed. For the rail transportation sector, the ICT share of total capital has historically been lower than in the business sector, with a difference between shares being approximately 4 percentage points on average between 1981 and 2010.

ICT investment intensity in rail transportation in 2010 was twice as high as the business sector, having grown significantly since the early 2000s.

In terms of composition, software is much more important as a share of ICT investment in rail transportation than in the business sector, while computers and telecommunications account for much smaller shares of total ICT investment than in the business sector as a whole. Historically, the role of software in rail transportation grew substantially between 1981 and 2010, outpacing the business sector. Similarly, the importance of computers in rail transportation fell over this period significantly more than it did in the business sector. Telecommunications has waned in relative importance in both sectors, with rail transportation seeing a smaller decline than in the business sector.

Comparisons with the United States

Seven indicators are used for comparing ICT performance in Canada and the United States: 1) growth rates of ICT investment and ICT capital stock (nominal); 2) growth rates of ICT investment and ICT capital stock (real); 3) growth rates of ICT investment and ICT capital intensities (nominal); 4) growth rates of ICT investment and ICT capital intensities (real); 5) levels of ICT investment and ICT capital intensities (nominal); 6) the share of the sector's total investment and capital stock comprised by ICT (nominal); 7) the relative proportion of the sector's value added represented by ICT investment and ICT capital stock (nominal).

The Canadian air transportation sector compares favorably to its American counterpart, with six of seven indicators for investment performing better in this country than in the United States either in 2010 for levels or between 2000 and 2010 for growth rates. Only the share of the air transportation sector's total investment comprised by ICT investment was lower than that of the United States. For the ICT capital stock, Canada outperformed the United States in four of seven indicators, all of which are growth rates. This faster performance for growth compared to levels lead to an increase in the relative ICT investment intensity of Canadian air transportation, though the sector still lagged behind that of the United States on this indicator in 2010. Additionally, ICT capital stock is smaller in proportion to the air transportation sector's total capital stock and value added in Canada than in the United States.

For rail transportation, Canada enjoys a superior performance relative to the United States for all indicators, both for growth and levels, investment and capital stock. Rail transportation ICT investment in Canada grew faster than it did in the United States between 2000 and 2010. The same is true for the ICT capital stock. In 2010, both ICT investment and ICT capital stock were proportionately larger compared to the rail transportation sector's total investment, capital stock and value added in Canada than in the United States. ICT investment and capital stock per worker in Canadian rail transportation were also larger than that of its American counterpart, suggesting ICT use is more prominent in Canada than the United States in this sector.

Measuring the Impact of ICT on Productivity Growth

Studies that analyze the links between ICT and productivity growth can generally be divided into three groups: growth accounting studies, econometric studies, and case studies. While case studies refer to the impact of ICT investment in the production process of a particular firm or industry, growth accounting studies generally refer to the aggregate economy level (either business sector or total economy) or to the industry level. Although econometric studies can also refer to the aggregate economy level, they tend to deal with the productivity impact of ICT either at the firm level or at the industry level.

The starting point of the standard neoclassical growth accounting framework is a production function which combines inputs (such as labour, non-ICT capital, and ICT capital) and transforms them into output. Under certain simplifying assumptions (perfect competition and constant returns to scale), it can be shown that the contribution of a particular input to output growth is equal to the growth rate of that input weighted by its compensation share.

While useful as a workhorse model to quantify the impact of ICT capital on productivity, the standard neoclassical growth accounting framework has a number of important limitations:

- It is a descriptive model. Thus, input contributions to productivity growth should not be understood as *causing* labour productivity growth;

- Assumptions such as constant return to scale and perfect competition can be quite strong (and untested assumptions), which, in the end, have a decisive impact on the estimated contribution of ICT to productivity growth. While it is reasonable to believe that these assumptions lead to fairly good estimates at the aggregate economy level, it is very hard to make the same argument for the transportation sector, where perfect competition (for example) tends to be a very poor description of reality.

- The impact of ICT on productivity does not necessarily occur in the same period in which investment takes place. In fact, there is significant evidence that ICT has a lagged impact on economic performance. According to the economics literature, the main reason for these lags is that ICT appears to be a general purpose technology (GPT). GPTs are technologies that fundamentally change the production process of firms that make use of them. Several authors argue that, either because of spillover effects or because of complementarities between ICT and intangible organizational capital, the effects of ICT on firms' production processes are not immediate.

There are two main econometric approaches used in the literature to measure the contribution of ICT to productivity growth:

- The MFP approach examines the relationship between multifactor productivity (MFP) and ICT capital. Multifactor productivity (MFP) reflects output growth that is not accounted for by input growth. Since MFP, by definition, already excludes ICT capital input growth, regressing MFP growth on ICT capital growth should yield an ICT coefficient equal to zero if ICT has "normal returns", but greater than zero if ICT has "excess returns".

- The production function approach allows for the standard assumptions of the neoclassical growth accounting framework to be relaxed. With the help of econometrics, flexible functional forms can be estimates and simplifying assumptions can be relaxed. Furthermore, different econometric techniques can correct potential endogeneity problems, as well as other biases identified by the economics literature.

The methodologies described above can be very useful in an effort to quantify the impact of ICT at a more aggregate level (be it total economy, business sector, a particular industry, or a group of firms). However, they also have important limitations: simplifying assumptions might distort the estimated contribution of ICT to productivity; intangible inputs such as organizational capital can be very hard to measure, etc. Due to these limitations, case studies can complement both growth accounting and econometric studies by providing concrete examples of how ICT affects productivity gains either at the industry level or at the firm level.

Main Findings

- Labour productivity in Canadian air and rail transportation experienced robust growth in the 1997-2010 period (5.0 per cent per year and 3.4 per cent per year, respectively) compared to the business sector (1.3 per cent per year).

- ICT capital intensity growth (defined here as real ICT capital stock per hour worked) has been very rapid in both the air and rail sectors (11.8 per cent per year and 12.1 per cent respectively), nearly twice that of the business sector (7.0 per cent).

- Using the standard neoclassical growth accounting framework, we find that ICT capital intensity accounted for only 2.6 per cent of labour productivity growth in both air and rail transportation during the 1997-2010 period, less than it accounted for in the business sector (15.0 per cent).

- The smaller role of ICT capital intensity in explaining air and rail labour productivity growth is due to the smaller share of ICT capital compensation in value added in these sectors when compared to the business sector as a whole.

- These results, however, are not conclusive. The standard assumptions of the neoclassical growth accounting framework (perfect competition, constant returns to scale, etc.) appear to be an ill fit to the realities of the air and rail transportation sectors, which are highly regulated.

- Econometric estimations using an MFP-based approach yielded coefficients that were not statistically significant, implying that there were no "excess returns" associated with ICT use in air and rail productivity.

- These econometric results should also be taken with a grain of salt. Since only annual data for the 1997-2010 period were available, the econometric estimations relied on very few observations. It is hard to reach any definitive conclusion on the impact of ICT on productivity growth when dealing with such a small sample. Furthermore, as previous literature has shown, the level of data aggregation matters, and industry-level data might not be appropriate to deal with this issue.

- In light of these facts, we make two recommendations. First, future studies on the impact of ICT on productivity growth should rely on firm-level data instead of industry-level data. Second, future studies should be less reliant on growth accounting and use econometric techniques or case studies instead.

The Impact of Information and Communication Technology on the Productivity of the Canadian Transportation System: A Macroeconomic Approach for the Rail and Air Sectors[1]

I. Introduction

Despite the productivity growth slump in Canada during the past decade (both from a historical and an international perspective), productivity in Canadian air and rail transportation has risen significantly. This impressive productivity performance has been accompanied by an increased role for information and communication technologies (ICTs) in both sectors.

A growing consensus in the economics literature identifies ICTs as a key driver in productivity growth. The use of ICTs has led different industries to restructure the way they do business, allowing them to achieve considerable efficiency gains. So far, however, few efforts have been made to quantify the contribution of ICT to productivity in Canadian air and rail transportation. This is the main objective of this report.

The report is organized as follows. Section two discusses data sources and provides a short primer on some of the main issues related to productivity analysis. Section three analyzes ICT investment and capital stock trends in Canadian air and rail transportation during the 1981-2010 period. These trends are compared to those observed in the Canadian business sector, as well as to those seen in U.S. air and rail transportation. Section four describes the productivity performance of air and rail transportation in Canada, focusing on the 1997-2010 period. Section five provides a literature review on the links between ICT capital and productivity growth, not only summarizing the main conclusions of the literature so far, but also explaining the main methodologies used to measure the impact of ICT on productivity growth (growth accounting and econometric techniques). Special emphasis is given to the literature on air and rail transportation. Section six applies some of these methodologies to Canadian air and rail transportation. In this section, we provide estimates of the contribution of ICT to productivity growth in the two sectors. Section seven concludes.

[1] This research report was prepared by Blair Long and Ricardo de Avillez, under the supervision of Andrew Sharpe. It represents the views of the Centre for the Study of Living Standards (CSLS). The CSLS would like to thank Transport Canada for the financial support. For comments, Ricardo de Avillez can be reached at ricardo.avillez@csls.ca.

II. Definitions, Concepts and Data Sources[2]

This part of the report is divided into two sections. In the first section, we review some of the key issues related to productivity analysis. In the second, we briefly discuss the data sources used in the report.

A. Understanding Productivity

Productivity can be broadly defined as a measure of how much output is produced per unit of input used. Despite this simple definition, several different productivity measures arise from the use of distinct concepts of output and input, with each of these measures serving different purposes. In this section, we explain important topics related to productivity analysis, define the main concepts used throughout the report, and discuss the reasons why productivity measurement is relevant in economic analysis.

i. Why Measure Productivity?

The OECD (2001) highlights five objectives of productivity measurement:

- Measuring *technical change* – In economics, a production technique can be understood as a particular way of combining inputs (labour, capital, intermediate inputs, etc.) and transforming them into output. Technical change can be either disembodied (e.g. new organizational techniques) or embodied (e.g. better quality capital goods). Economists often try to capture the effects of technical change in the economy or in an industry by using some measure of multifactor productivity (MFP). It is important to keep in mind, however, that the relationship between technical change and MFP is *not* straightforward. First, not all the effects of technical change are captured by MFP. If inputs are quality adjusted, for instance, MFP will not capture embodied technical change, only disembodied technical change. Second, MFP captures a variety of effects, not only technical change – thus, it is a mistake to attribute the entirety of MFP growth to technical change.

- Measuring *efficiency improvements* – From an engineering perspective, a production process is efficient if, for a given technology, it uses the least amount of inputs to produce one unit of output (or alternatively, if it produces the maximum amount of output for a given quantity of inputs). From an economist’s perspective, however, allocative efficiency should also be taken into account, i.e. firms will only make changes to their production process if these changes are consistent with profit-

[2] This section draws on Sharpe and de Avillez (2011).

maximizing behaviour. The OECD (2001:11) notes that: "(…) when productivity measurement concerns the industry level, efficiency gains can either be due to improved efficiency in individual establishments that make up the industry or to a shift of production towards more efficient establishments".

- Measuring *real cost savings* – Closely related to the two objectives discussed above, understanding productivity matters because it allows firms to produce a given amount of output using less input, which implies, *ceteris paribus*, lower costs. In other words, productivity improvements generate real cost savings.

- Measuring *improvements in living standards* – Productivity is linked to living standards via two fronts: 1) Value added labour productivity has a direct link to GDP per capita, which is a commonly used measure of living standards; 2) Long-term value added MFP growth can be used to evaluate the evolution of an economy's potential output.

- *Benchmarking* production processes – At the firm level, productivity measures can be used to identify distortions and inefficiencies across production units. Such measures are often expressed in physical units, e.g. a car company could compare the productivity of two (similar) factories by looking at the number of cars produced per day by each of the factories.

ii. Gross Output Productivity vs. Value Added Productivity

Since productivity is a ratio of output to input(s) used in the production process, different productivity measures can be constructed using: 1) different measures of output; 2) different measures of inputs. In this subsection, we discuss the two most used measures of output: gross output and value added. The next subsection focuses on the choice of one or more inputs when constructing a productivity measure.

Gross output consists of all goods and services produced by an economy, sector, industry or establishment during a certain period of time. Value added (or GDP at basic prices), on the other hand, measures the contribution of primary inputs (labour and capital) to the production process. While gross output refers to an actual physical quantity, there is no physical representation of value added.

When dealing with the economy as a whole, the value added approach is the natural choice, because it avoids double counting of intermediate inputs in the aggregate output. In practice, the value added approach is also the standard choice of most sectoral productivity analysis. Trueblood and Ruttan (1992) argue, however, that when investigating the productivity performance of a particular sector, the focus should be on the total input-output relationship in order to evaluate the overall gains in both primary and intermediate input use. This is particularly true in the case of sectors that experienced significant shifts in the use of inputs through time, such as the primary agriculture sector, where intermediate inputs (feed, fertilizers, pesticides, etc.) play a much more prominent role nowadays than they did in the past.

iii. Partial Productivity Measures vs. Multifactor Productivity

Economists distinguish between partial and multifactor productivity (MFP) measures. Partial productivity measures are a ratio between output and a single input, such as labour, capital, etc. Labour productivity, for example, is commonly defined as the ratio between output and hours worked in a certain activity, while capital productivity is the ratio of output to capital stock (or capital services).

MFP, in turn, is the ratio between output and *combined* inputs used in the production process, e.g. value added MFP is calculated as the ratio of value added to *combined* labour and capital inputs. Therefore, MFP growth is a residual, reflecting output growth that is not accounted for by measured input growth. MFP growth can be explained by a number of very different factors, such as improvements in technology and organization, capacity utilization, increasing returns to scale, etc. It also embeds errors due to the mismeasurement of inputs.

iv. Productivity Growth Rates vs. Productivity Levels

Productivity can be expressed either in growth rates or in levels. The economics literature largely focuses on productivity *growth rates*, which refer to changes in *real* variables (as opposed to *nominal* variables), e.g. value added labour productivity growth represents the increase of real GDP per hour worked over time; gross output MFP growth measures the increase of real gross output per unit of aggregate labour, capital, and intermediate inputs.

In this report, however, we are also interested in making *level* comparisons. Productivity level comparisons are often done in current dollars (i.e., using nominal output), as these estimates capture changes in relative prices, whereas estimates in *constant dollars* do not. However, when real output is calculated using *chained dollars*,[3] changes in relative prices are also incorporated to the estimate, and goods and services which experienced relative price increases receive higher weights than goods and services that experienced price decreases. Productivity level discussions in this report focus on real levels instead of nominal levels for two

[3] Constant dollar and chained dollar measures are calculated using fixed-base quantity indexes and chained quantity indexes, respectively. As the name implies, a fixed-base index has a fixed base period, which is used as a basis of comparison with all the other periods. A chained index, on the other hand, has no fixed base period, but rather takes into account data from two successive periods. For a detailed discussion on this issue, see Appendix A in Sharpe and de Avillez (2010).

reasons: 1) Consistency, i.e. since growth rates are calculated based on real output, having real productivity levels produces a consistent set of estimates; 2) The real output measures used in the report are based on chained dollars, and thus the impact of shifts in relative prices is captured. Nominal productivity levels are also discussed whenever they might provide additional insights. Regardless of whether nominal or real GDP figures are used for interprovincial productivity level comparisons, it is important to note that these comparisons should be used with caution, due not only to differences in industry composition between provinces, but also due to the lack of industry purchasing power parities (PPPs) estimates at the provincial level.

v. Productivity Measures Used in this Report

This report focuses on two value added, partial productivity measures:

- *Value added labour productivity*, defined here as real GDP (at basic prices) per hour worked. Alternatively, value added labour productivity could also have been defined as GDP per employed person. However, the hours worked measure provides more accurate estimates of labour input, since it takes into account: 1) changes in the duration of the work week; 2) shifts from full-time employment to part-time employment.

- *Value added multifactor productivity*, defined here as the ratio between real GDP (at basic prices) and an input aggregate that includes labour and capital.

It is important to note that transportation studies frequently define output not in terms of value added or gross output, but in physical terms. Apostonides (2004), for instance, measures air transportation output in terms of passenger-miles and ton-miles, while rail transportation output is measured in ton-miles. In this report, whenever we refer to a paper that uses physical productivity measures, we add an asterisk to that reference, e.g. Apostonides*(2004).

vi. Interpreting Productivity Measures

Productivity is a multi-dimensional concept, and different productivity measures capture different aspects of reality. Gross output MFP, for instance, can capture efficiency improvements much better than other productivity measures because it captures the effects of substitution between inputs. Value added labour productivity, on the other hand, is a better tool for understanding improvements in overall living standards.

Exhibit 1 discusses how the main productivity measures used in the literature should be interpreted, their purposes, advantages, and limitations.

Exhibit 1: Interpreting Productivity Measures

	Gross Output	Value Added
Labour Productivity	*Purpose*: Can be useful in the analysis of labour requirements by industry. *Interpretation*: Describes how much (physical) output is produced per unit of labour used. Changes in gross output labour productivity can be decomposed into four sources (*proximate* causes of growth): 1) changes in labour quality; 2) changes in capital intensity; 3) changes in intermediate input intensity; 4) gross output MFP growth. *Advantages*: Easy to measure (only requires price indexes for gross output, not intermediate inputs) and understand. *Limitations*: As a partial productivity measure, it does not control for changes in the use of other inputs, and thus reflects the influence of several different factors. *Attention:* Gross output labour productivity is *not* a good measure of technical change.	*Purpose*: 1) Can help in the analysis of micro-macro links, e.g. understanding industry contributions to aggregate labour productivity and economic growth; 2) At the total economy level, can be used to analyze improvements in living standards; 3) Used as a reference statistic in wage bargaining. *Interpretation*: Describes how much value added is generated per unit of labour used. Changes in value added labour productivity can be decomposed into three main sources (*proximate* causes of growth): 1) changes in labour quality; 2) changes in capital intensity; 3) value added MFP growth. *Advantages*: Easy to measure and understand. *Limitations*: As a partial productivity measure, it does not control for changes in the use of other inputs, and thus reflects the influence of several different factors. *Attention:* Value added labour productivity is *not* a good measure of technical change.
Capital Productivity		*Purpose*: "Changes in capital productivity indicate the extent to which output growth can be achieved with lower welfare costs in the form of foregone consumption" (OECD, 2001: 17). *Interpretation*: Describes how much value added is generated per unit of capital used. *Advantages*: Easy to understand. *Limitations*: As a partial productivity measure, it does not control for changes in the use of other inputs, and thus reflects the influence of several different factors. *Attention:* Value added capital productivity should *not* be confused with the rate of return on capital.
Multifactor Productivity	*Purpose*: Can help in the analysis of industry-level disembodied technical change. *Interpretation*: Describes how productively capital, labour, and intermediate inputs are combined in order to generate (physical) output. When inputs are quality-adjusted, it captures disembodied technical change reasonably well. It should be clear, however, that it also incorporates other factors that have nothing to do with disembodied technical change, such as economies of scale, changes in capacity utilization, measurement errors, etc. *Advantages*: Industry-level gross output MFP growth can be combined using Domar weights in order to obtain an economy-wide or sectoral estimate of value added MFP growth (for details, see OECD, 2001). *Limitations*: Significant data requirements (input-output tables consistent with national accounts data).	*Purpose*: 1) Can help in the analysis of micro-macro links, e.g. understanding industry contributions to aggregate value added MFP growth; 2) At the total economy level, can be used to analyze improvements in living standards (can help track the evolution of an economy's potential output). *Interpretation*: Describes how productively capital and labour inputs are combined in order to generate value added. At the industry level, it can be seen as "an indicator of an industry's capacity to contribute to economy-wide growth of income per unit of primary input" (OECD, 2001: 16). *Advantages*: Easily aggregated across industries. *Limitations*: Not a good measure of technical change.

Source: Adapted from OECD (2001), pp. 14-18.

B. Data Sources

The data used in this report are broken down at the three-digit NAICS[4] level (air transportation and rail transportation), with the business sector aggregation[5] also being used.

All Canadian data in this report originate from Statistics Canada. Data on ICT investment and capital stock for the business sector (both current and constant dollars), employment, value-added, total non-residential fixed investment and capital stock (both current and constant dollars) are from the CANSIM database. ICT investment and capital stock data for the air and rail transportation subsectors were obtained by CSLS from Statistics Canada via special request. Canadian data spanned the years 1981 to 2011 with the exception of value-added data for the air and rail transportation subsectors, which are available from 1999-2008; employment data, which are available from 1991-2010 for the air and rail transportation subsectors and from 1997-2010 for the business sector; and hours worked data which was available from 1997-2010.

United States data used in this report was obtained primarily from the Bureau of Economic Analysis, with the exception of employment data which was obtained from the Bureau of Labor Statistics. United States data are available from 1981-2010 inclusive, with the exception of employment data for the air transportation subsector, which are available from 1990 to 2010.

Indicators in this report based on shares, relatives, or intensities were calculated by the authors from the above data.

Canada-United States comparisons for intensity are made using Purchasing Power Parity (PPP) data from Statistics Canada to express all figures in $USD.

[4] The acronym NAICS refers to the North American Industry Classification System. NAICS categorizes establishments into two industries based on the similarity of their production processes. It has a hierarchical structure that divides the economy into 20 sectors, which are identified by two digit codes. Below the sector level, establishments are classified into three-digit subsector four-digit industry groups and five-digit industries. At all levels the first two digits always indicate the sector, the third digit the subsector, the fourth digit the industry group, and the fifth digit the industry. For more information on NAICS, see Statistics Canada (2007).

[5] Statistics Canada's general definition of the business sector includes incorporated businesses, self-employed and proprietorships, government business enterprises, and owners who occupy their own dwelling.

III. ICT Investment and Capital Stock Trends in Canadian Rail and Air Transportation Sectors

In this section, we analyze ICT investment and capital stock trends in Canadian air and rail transportation during the 1981-2010 period, with the business sector serving as a benchmark. We also compare these trends to those observed in U.S. air and rail transportation. The section is divided into three subsections. In the first, we describe ICT investment and capital stock trends in air transportation; in the second, our focus is on rail transportation. The third subsection summarizes the main findings of the first two subsections.

A. Air Transportation

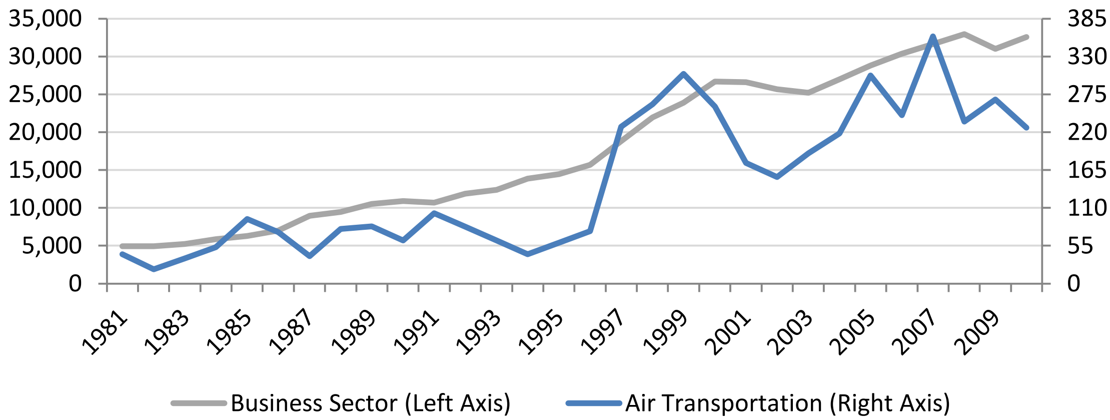
This subsection describes ICT investment and capital stock trends in Canadian air transportation during the 1981-2010 period, comparing these trends to those observed in the Canadian business sector and to those seen in U.S. air transportation. Several indicators are analyzed, including: current dollar ICT investment (total and by component), constant dollar ICT investment, current dollar ICT capital stock, and constant dollar ICT capital stock.

i. Current Dollar ICT Investment

This section outlines trends in ICT investment in the Canadian air transportation sector, providing comparisons to the Canadian business sector and the air transportation sector in the United States. All figures in this section are expressed in current dollars. The terms "total investment" and "total non-residential fixed investment" are used interchangeably.

In 2010, nominal ICT investment in air transportation in Canada was $226.3 million, up from $42.5 million in 1981, the first year for which ICT estimates are available. In absolute terms, ICT investment in the Canadian air transportation sector has exhibited large fluctuations since 1981 (Chart 1). It grew rapidly from 1996 to 1999 then declined over the 1999 to 2002 period. From 2002 to 2007 it rebounded and has since declined. The air transportation sector's ICT investment has generally been consistent with the steady rise seen in business sector ICT investment until recent years. From 1981 to 2010, ICT investment in air transportation averaged annual growth of 5.9 per cent, slightly below that of the business sector, which grew at 6.7 per cent during this period (Appendix Table 1a). It should also be noted that ICT investment in the air transportation sector fell from its historical high of $359 million in 2007 to $235.5 million in 2008, a decline of 34 per cent.

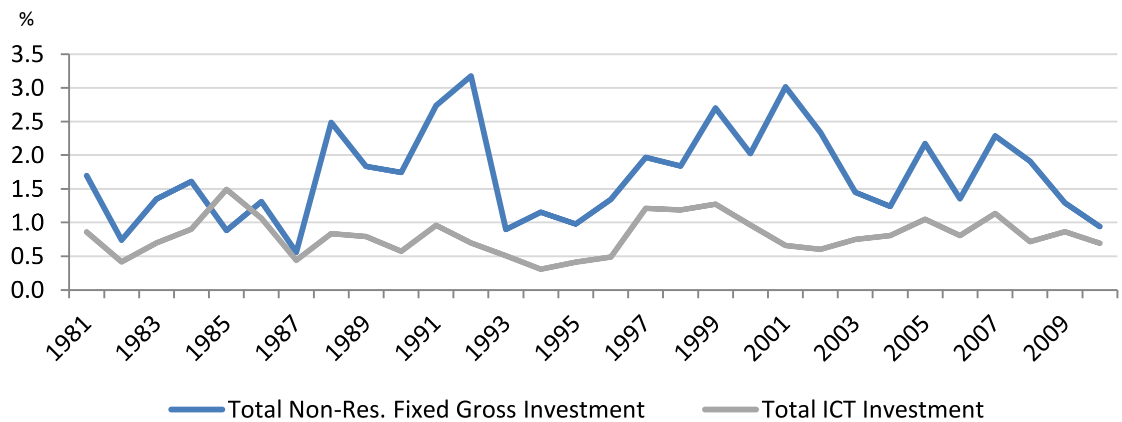
Chart 1: Total Nominal ICT Investment, Air Transportation and the Business Sector, Millions, Canada, 1981-2010



Source: Appendix Table 1a

The air transportation sector accounts for a small share of total business sector ICT investment (Chart 2). This relative importance, while volatile, has been falling. In terms of its importance for the business sector ICT total, ICT investment in air transportation is less important than total investment: 0.7 per cent versus 0.9 per cent. In 2010, ICT investment as a share of business sector ICT investment was 0.7 per cent. Between 1981 and 2010, it fell by 0.2 percentage points from 0.7 per cent. This change was smaller than that of total investment as a share of the business sector, this fell by 0.8 percentage points from 1.7 per cent to 0.9 per cent.

Chart 2: Nominal Investment as Share of the Business Sector Total, Air Transportation, by Type of Investment, Canada, 1981-2010

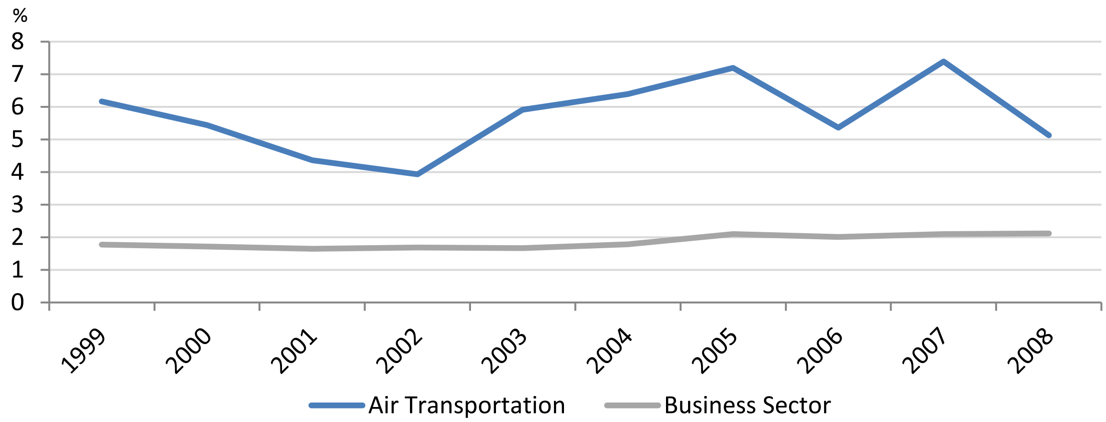


Source: Appendix Tables 1c and 1f

As a proportion of GDP, ICT investment in the air transportation sector represents a relatively high share of value-added, at least compared to the business sector average. Chart 3 demonstrates that ICT has been historically large relative to value-added in the air transportation sector compared to the business sector in Canada since 1999, the furthest back that comparable data are available. While ICT investment of the business sector as a share of value-added has hovered around 2 per cent annually, ICT investment as a share of value added in air transportation has remained between 4 and 7 percentage points between 2000 and 2008.

ICT investment has been proportionately lower than other types of investment in air transportation (Chart 4). That is, the share of investment in the air transportation sector attributable to ICT has traditionally been lower than at the level of the business sector. In 2010, ICT investment in the air transportation sector comprised 13.4 per cent of total investment in the sector compared to 18.1 per cent in the business sector. In terms of absolute change however, ICT investment as a share of total investment in the air transportation sector has almost kept pace with the business sector, increasing by 9.1 percentage points compared to the business sector's increase of 9.6 percentage points between 1981 and 2010.

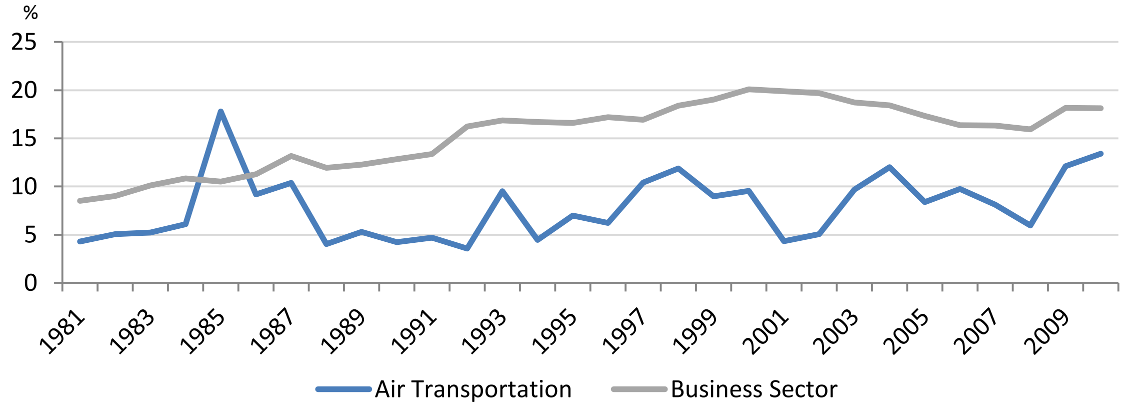
Chart 3: Total Nominal ICT Investment as a Share of Nominal Value Added, Air Transportation, Canada, 1999-2008



Source: Appendix Table 1d

ICT investment intensity is defined as ICT investment in dollars per worker in an industry. In 2010, ICT investment intensity in air transportation was $3,338 per worker, compared to $2,369 for the business sector as a whole—a ratio of 1.4 times higher. Historically, ICT investment intensity in the air transportation sector has been higher than the business sector (Chart 5), with the gap between the two sectors ranging from $650 to $3,000 per worker. It should also be noted than ICT investment intensity has fluctuated more in the air transportation sector than in the business sector as a whole. In terms of growth, air transportation in Canada averaged annual negative growth of 1.9 per cent in ICT intensity between 2000 and 2010, while the business sector as a whole averaged growth of 0.8 per cent.

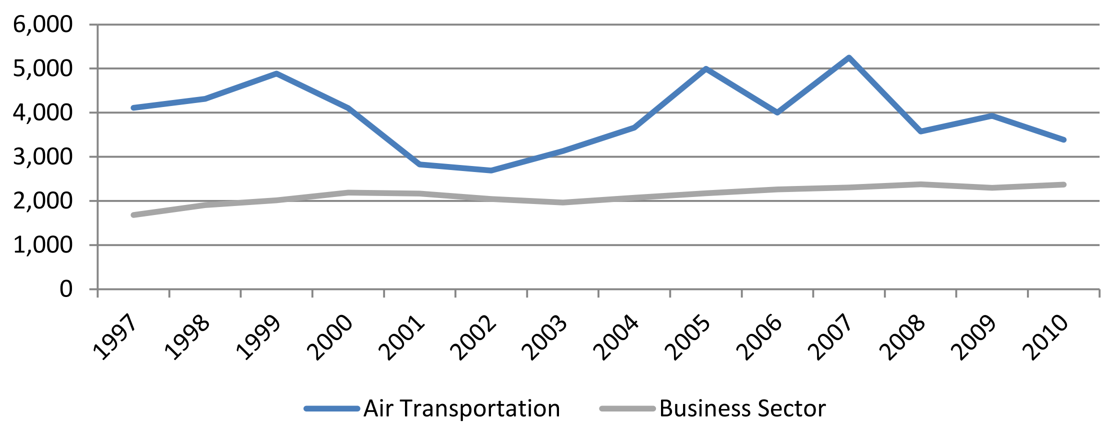
Chart 4: ICT Share of Sector's Total Non-Residential Nominal Fixed Investment, Air Transportation and the Business Sector, Canada, 1981-2010



Source: Appendix Table 1e

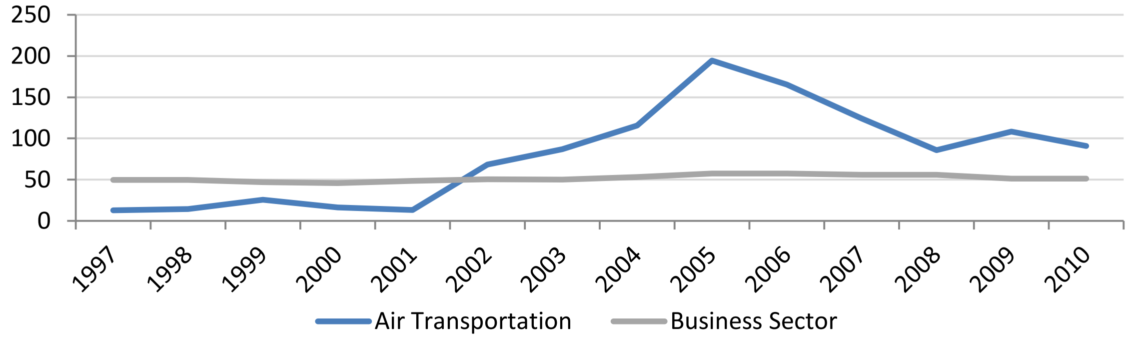
In comparison with the United States, the Canadian air transportation sector fares better than the business sector in terms of ICT investment intensity (Chart 6), historically. In 2010, ICT investment intensity in Canadian air transportation was 91 per cent of ICT intensity in its American counterpart this compares favorably with the 50 per cent for the overall business sector. Showing an absolute change of 78.2 percentage points between 1997 and 2010 compared to 1.5 percentage points for the business sector, it is noteworthy that Canadian air transportation generally fares on par with its U.S. counterpart in terms of ICT investment intensity, whereas the business sector is generally at about half of its U.S. counterpart's performance.

Chart 5: ICT Investment Intensity (Nominal Investment per Worker), Air Transportation and the Business Sector, Canada, 1997-2010



Source: Appendix Table 1i

Chart 6: ICT Investment Intensity Nominal Investment per Worker) Relative to the United States (US=100), PPP, Air Transportation and the Business Sector, Canada, 1997-2010



Source: Appendix Table 9a

Table 1 presents a comparison of Canada and the United States using additional indicators for 2010 or the most recent year for air transportation. ICT investment intensity in Canada and the United States averaged 5.9 per cent growth annually between 1981 and 2010. In Canada, however, ICT investment is proportionately larger as a share of value added than in the United States. This figure decreased for the United States much faster than for Canada between 1981 and 2010. ICT investment in air transportation also comprises a larger share of total business sector ICT investment in Canada than in the United States, 0.7 per cent versus 0.3 per cent. ICT investment accounts for a similar share of the sector's total investment for air transportation in both countries.

In terms of ICT investment intensity, Canada is slightly lower than the United States in terms of levels but most importantly, it has lagged in terms of growth. Between 1990 and 2010, ICT investment intensity declined at an annual average of 1.9 per cent in Canada, whereas it grew at an annual pace of 1.3 per cent in the United States. As a share of the United States, however, ICT investment intensity in Canada grew by 80 percentage points over the same period. ICT intensity in Canada is also proportionately larger compared to the business sector than it is in the United States, 143.0 per cent versus 80.4 per cent.

Table 1: ICT Investment, Air Transportation, Canada-US Comparison, Levels, Growth, and Changes, 2010 or most recent year

	Levels		Growth or Absolute Change		
	Canada	US	Canada	US	Period
Investment, millions of domestic currency	226	1,504	5.9	5.9	1981-2010
Share of Air Transportation's Value-Added	5.1	2.4	-1.0	-12.5	1999-2008
Share of Business Sector ICT Investment	0.7	0.3	-0.2	-0.2	1981-2010
Share of Air Transportation's Total Investment	13.4	13.9	9.1	8.2	1981-2010
Investment Intensity (Absolute), USD at PPP	2,947	3,240	-1.9	1.3	1990-2010
Investment Intensity (Relative to US), USD at PPP	91.0	100.0	80.0	na	1991-2010
Investment Intensity (Relative to Business Sector)	143.0	80.4	-2.7	-873.9	1997-2010

Notes: Investment in $millions. Growth in terms of average annual growth rates. 1981-2010 or longest period available. Changes for shares and relatives use absolute change.

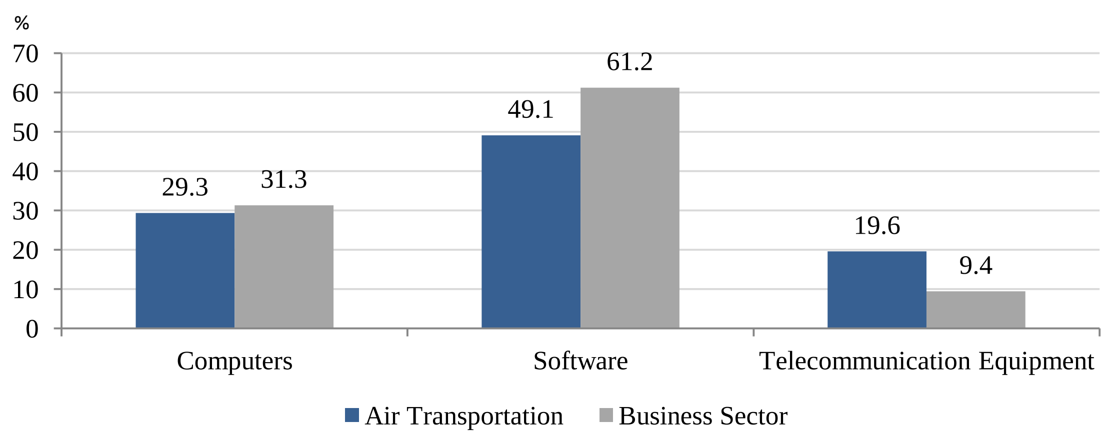
Source: Appendix Tables 1a, 1d, 1f, 1i, 1j, 5a, 5d, 5f, 5i, 5j, 9a

ii. Current Dollar ICT Investment by Component

This section provides trend and cross-sectional analysis of ICT investment by component in the Canadian air transportation sector, comparing the sector to its American counterpart as well as the Canadian business sector. All figures in this section are expressed in current dollars. The components of ICT investment are investment in computers, software and telecommunications.

In 2010, the largest share of ICT investment in air transportation was attributable to software, consisting of 49.1 per cent of total ICT investment (Chart 7). Computers and telecommunications followed, with shares of 29.3 per cent and 19.6 per cent respectively. The relative importance of these three components was similar to that of the business sector, where software comprised 61.2 percent of total investment, followed by computers and telecommunications with 31.3 and 9.4 per cent, respectively. It is immediately noticeable that air transportation devotes relatively fewer resources toward investment in computers and software than the business sector, but more towards telecommunications equipment.

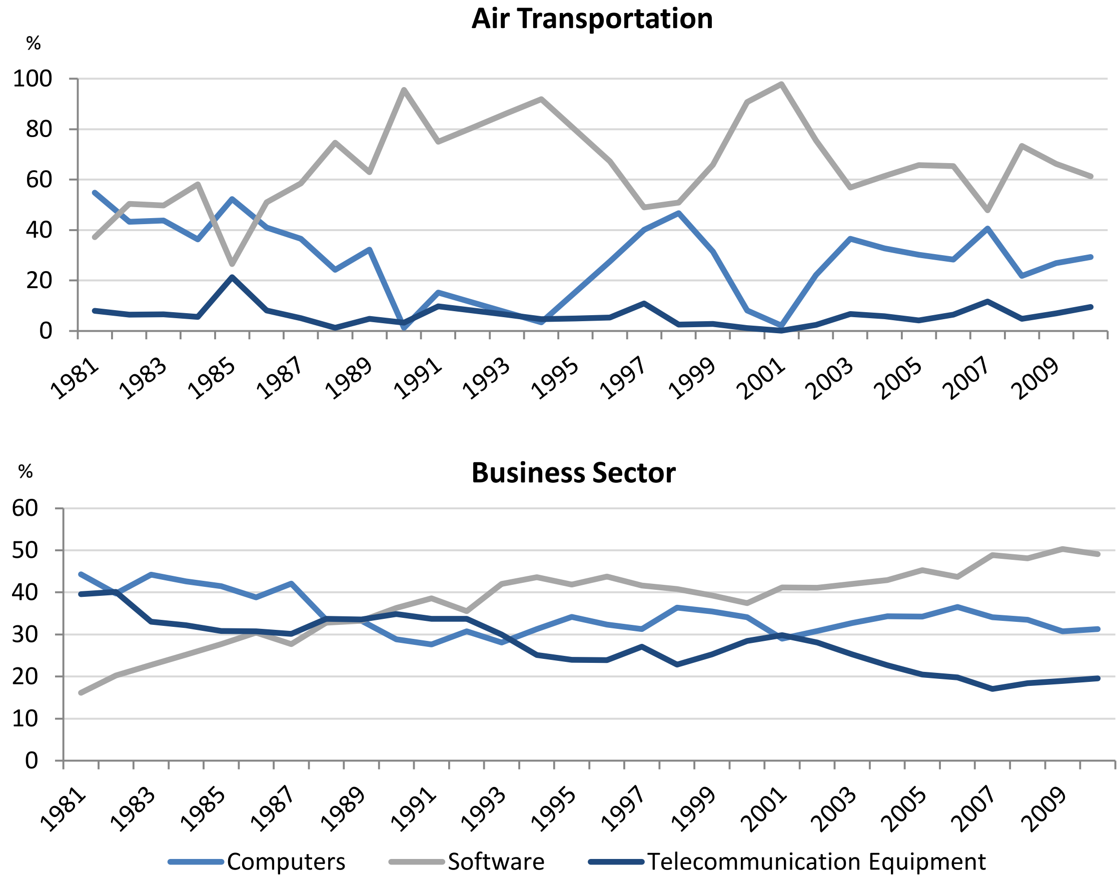
Chart 7: Nominal ICT Investment by Component, as a Share of Sector's Total ICT Investment, Air Transportation and the Business Sector, Canada, 2010



Source : Appendix Table 1g

In terms of trends, software has been the largest component of ICT investment historically in both air transportation and the business sector since the mid-1980s, followed by computers and telecommunications equipment (Chart 8). For air transportation, software's share of total ICT investment has risen over time, exhibiting an absolute change of 24.0 percentage points between 1981-2010, while the share of computers fell by 25.5 percentage points during the same period. Telecommunications investment as a share of ICT increased slightly over this period, a change of 1.5 percentage points. This differs from the case of the business sector, which saw a similar 33.0 percentage point increase in the share of total ICT investment for software, a 13.0 percentage point decline in the share of total ICT investment for computers, but saw a significant 20 percentage point decline in the share of ICT investment attributable to telecommunications equipment.

Chart 8: Nominal ICT Investment by Component, as a Share of Sector's Total ICT Investment, Air Transportation and the Business Sector, Canada, 1981-2010

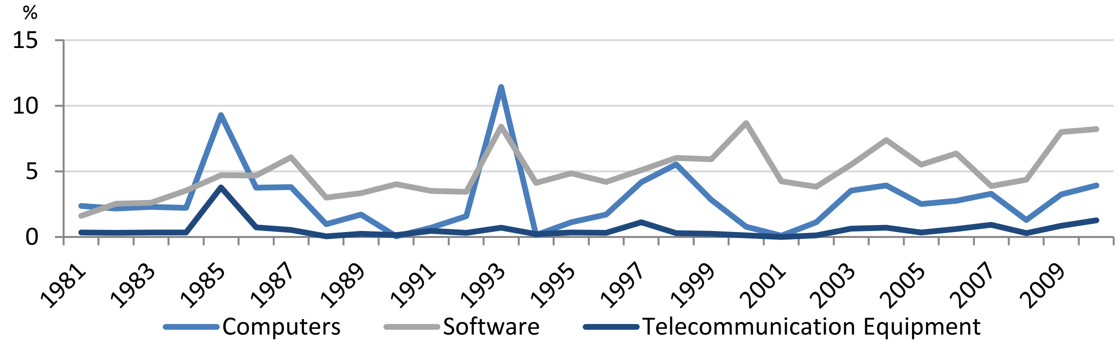


Source: Appendix Table 1g

Historically, the shares of total investment for each ICT component in air transportation have risen, but remained relatively constant in recent years (Chart 9). Between 2003 and 2010, the share of total investment attributable to computers in air transportation has ranged from 2 to 4 per cent. In the case of software, it has ranged from 4 to 8 per cent during this period. The share of total investment attributable to telecommunications has remained below two percent historically.

In terms of the evolution of relative importance, the share of total investment attributable to each ICT component in air transportation rose between 1981 and 2010. Software saw the most impressive growth over this period, with an absolute change of 6.6 percentage points. The shares for computers and telecommunications grew by 1.6 and 0.9 percentage points over this period. The shares of total investment for all components have exhibited an upward trend since 2008.

Chart 9: Nominal ICT Investment, as a Share of Sector's Total Non-Residential Fixed Investment, Air Transportation, Canada, 1981-2010

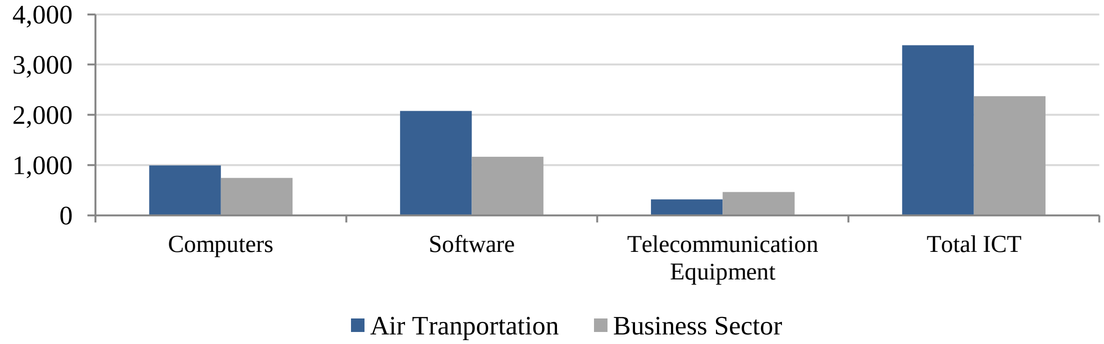


Source : Appendix Table 1e

For the components of ICT investment, ICT investment intensities compare favorably to the business sector for both computers and software (Chart 10). In 2010, software investment intensity in air transportation was $2,074 per worker, 1.4 times that of the business sector ($1,164 per worker). For computers, investment intensity was $994 per worker, significantly more than computer investment intensity in the business sector ($742). For telecommunications, air transportation exhibited lower investment intensity than the business sector, $319 v. $464 per worker.

In historic terms, two components of ICT investment intensity generally compare favorably to the business sector as a whole. Chart 11 depicts the trends for computer, software and telecommunications ICT investment intensities in the air transportation sector relative to their business sector counterparts for the period 1997 through 2010. The air transportation sector's investment intensity for software has been consistently higher than that of the business sector during this period, reaching 4.5 times at its peak in 2001. This being said, it has leveled off significantly since then and has fallen further since 2008.

Chart 10: ICT Investment Intensity (Nominal Investment per Worker), Air Transportation and the Business Sector, Canada, 2010



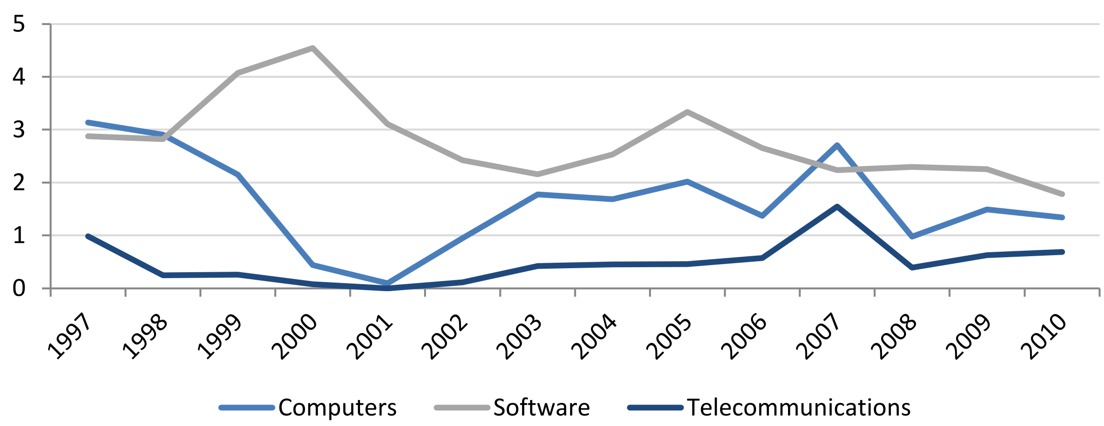
Source: Appendix Table 1i

For computers, investment intensity in the air transportation sector varied significantly between 1997 and 2010. Currently, computer investment intensity is demonstrating a downward trend.

Consistent with previously mentioned indicators, telecommunications investment intensity in the air transportation sector has typically fallen well below that of the business sector. With the exception of telecommunications investment intensity in air transportation reaching 1.5 times that of the business sector in 2007, it has been generally stable at about half of the business sector's telecommunications investment intensity since 2003. It is noteworthy that since 2008 this figure has displayed an upward trend, while investment intensities for the other components of ICT investment have declined (Chart 11).

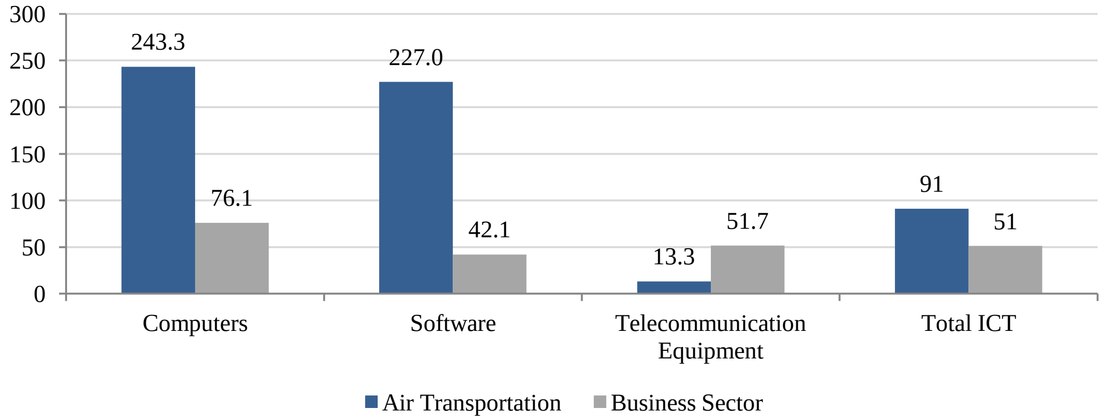
In comparison to the United States, the Canadian air transportation sector fares very well in terms of investment intensities for individual components of ICT investment (Chart 12). In 2010, computer investment intensity in Canadian air transportation was 2.4 times that of air transportation in the United States. For software, this ratio was 2.3 times. It is noteworthy that the Canadian business sector was significantly below its American counterpart in terms of computer and software investment intensities. For telecommunications investment intensity, Canadian air transportation was only 13.3 per cent of air transportation in the United States, which may reflect differences in the definition of telecommunications investment between countries.

Chart 11: ICT Investment Intensity (Nominal Investment per Worker), Relative to the Business Sector, by Component, Air Transportation, Canada, 1997-2010



Source: Calculated from Appendix Table 1i

Chart 12: ICT Investment Intensity (Nominal Investment per Worker), PPP, Relative to the United States (US=100), Air Transportation and the Business Sector, Canada, 2010



Source: Appendix Table 9a

iii. Constant Dollar Investment

Constant dollar data for previous ICT investment indicators can be used to more accurately assess growth rates and make comparisons between air transportation in Canada and air transportation in the United States. Table 2 depicts growth rates for air transportation in Canada and the United States for total ICT investment as well as ICT components for a selection of indicators. In terms of total ICT investment, Canada's air transportation sector grew at an average annual rate of 5.9 per cent between 1981 and 2010, while air transportation in the United States grew at 9.3 per cent annually. In recent years, however, Canada's air transportation sector has fared well, averaging annual growth of 2.4 per cent between 2000 and 2010 while air transportation in the U.S. averaged a decrease of 15.0 per cent per year over the same period. This is generally the case for ICT components as well, with shorter-term growth rates for the 2000 to 2010 period being much higher for Canadian air transportation than for American air transportation. It is noteworthy that in the case of software, average annual growth between 1981 and 2000 for Canada was 9.3 per cent, almost double that of the United States, 4.5 per cent.

For ICT investment intensity, average annual growth in Canadian air transportation was higher than of its American counterpart between 2000 and 2010 for total ICT, as well as each ICT component. Growth for computer investment intensity was particularly strong during this period, averaging 24.2 per cent per year while the United States experienced negative growth of 2.9 per cent per year.

Table 2: Growth rates, Selected Investment Indicators, $2002, Air Transportation, Canada and the United States

	ICT Investment		ICT Investment Intensity	
	Canada	**United States**	**Canada**	**United States**
Total ICT Investment				
1981-1990	1.3	21.5	na	na
1990-2000	14.1	27.7	na	25.8
2000-2010	2.4	-15.0	1.7	-12.6
1981-2010	5.9	9.3	na	na
Computers				
1981-1990	-18.7	31.1	na	na
1990-2000	63.6	40.9	na	38.8
2000-2010	25.0	-5.6	24.2	-2.9
1981-2010	20.0	20.0	na	na
Software				
1981-1990	16.4	7.7	na	na
1990-2000	16.3	25.7	na	23.8
2000-2010	-3.0	-15.5	-3.6	-13.1
1981-2010	9.3	4.5	na	na
Telecommunications				
1981-1990	-8.1	35.4	na	na
1990-2000	4.1	27.6	na	25.7
2000-2010	-1.2	-16.4	-1.8	-14.0
1981-2010	-1.6	12.3	na	na

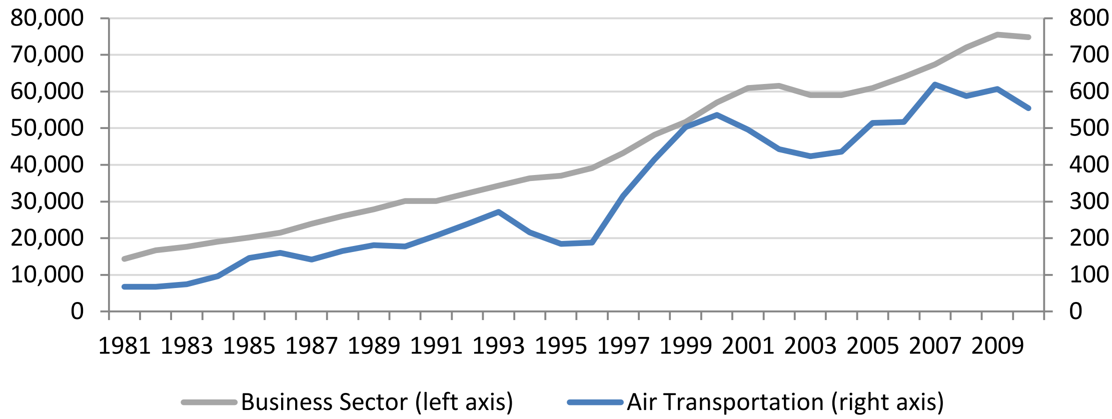
Source: Appendix Tables 2a, 2c, 2e, 6a, 6c, 6j

iv. Current Dollar Capital Stock

This section outlines trends in the ICT capital stock of the Canadian air transportation sector, providing comparisons with the Canadian business sector and the air transportation sector in the United States. All figures are expressed in current dollars. The terms “total capital stock” and “total non-residential fixed capital stock” used interchangeably.

In 2010, the ICT capital stock in the air transportation industry amounted to $554 million dollars (Chart 13). This figure has increased consistently between 1981 and 2010, averaging annual growth of 7.6 per cent (Appendix Table 3a). Similar to ICT investment, the most pronounced movements in this time series occurred during the late 1990s and early 2000s, with the capital stock increasing by $349 million between 1996 and 2001, a gain of 185 per cent. In 2009, the ICT capital stock increased in the air transportation sector by 3 per cent, decreasing in 2010 by 9 per cent.

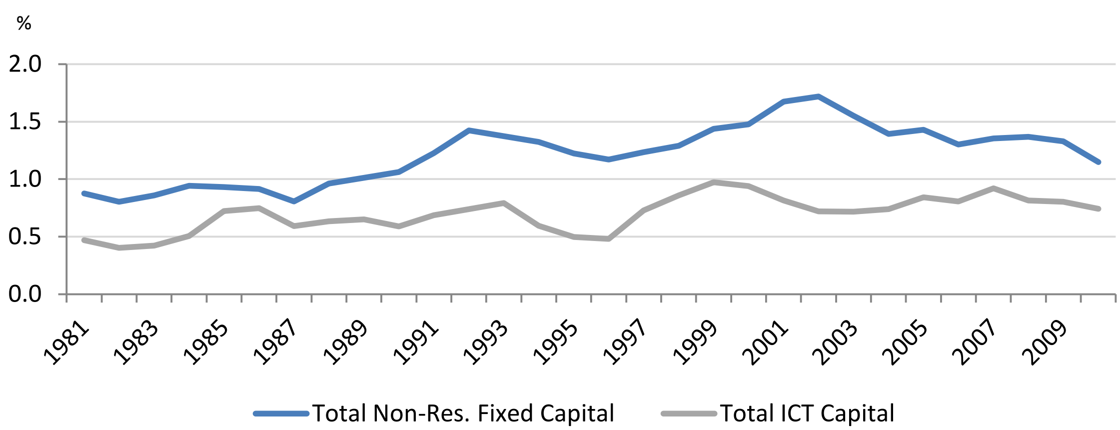
Chart 13: Total Nominal ICT Capital Stock, Air Transportation and the Business Sector, Millions, Canada, 1981-2011



Source: Appendix Table 3a

Compared to total non-residential capital stock in the air transportation sector, ICT capital comprises a smaller share of the business sector total (Chart 14). In 2010, ICT capital in the air transportation sector accounted for 0.8 per cent of business sector ICT capital whereas total capital in the air transportation sector accounted for 1.2 per cent of total capital. Between 1981 and 2010, the ICT capital stock in air transportation as a share of the business sector ICT capital stock increased by 0.27 percentage points, keeping pace with its total non-residential fixed equivalent, which increased by the same amount.

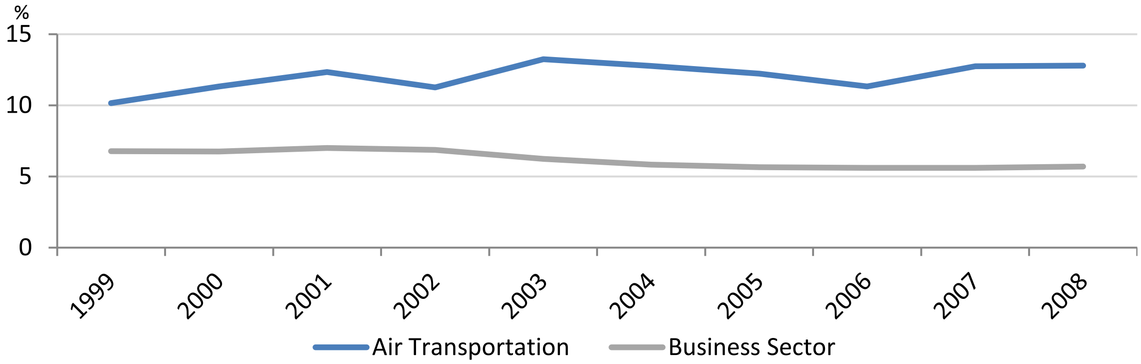
Chart 14: Nominal Capital Stock as Share of the Business Sector Total, Air Transportation, by Type of Capital, Canada, 1981-2010



Source: Appendix Table 3b and 3e

As a share of nominal value-added GDP, the ICT capital stock in the air transportation sector is proportionately large. Compared to the business sector, in which ICT capital typically accounts for 6.0-7.0 per cent of value-added, ICT capital in the air transportation sector was 12.8 per cent of total value added (Appendix Table 3c). In terms of absolute change, ICT capital as a share of air transportation's value added increased by 2.6 percentage points between 1999 and 2008 (Chart 15). Historically, ICT capital represents a share of the sector's value added which ranges between 3-7 percentage points higher than that of the business sector.

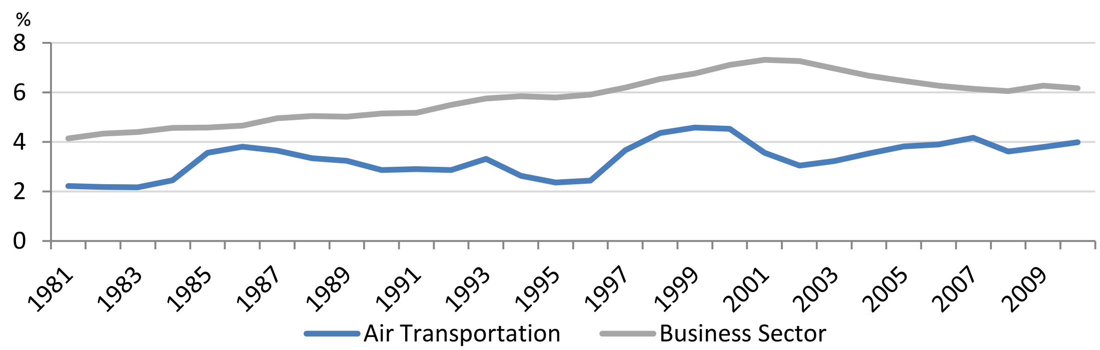
Chart 15: Total Nominal ICT Capital Stock as a Share of Nominal Value Added, Air Transportation and the Business Sector, Canada, 1999-2008



Source: Appendix Table 3c

As a component of the sector's total non-residential fixed capital stock, ICT capital in the air transportation sector has typically been below that of the business sector (Chart 16). In 2010, ICT capital accounted for 4.2 per cent of the sector's total capital stock, compared to 6.1 per cent for the business sector. In terms of absolute change, ICT capital in air transportation as a share of the sector's total capital stock has increased by 1.8 percentage points between 1981 and 2010, effectively keeping pace with the business sector, for which the same indicator increased by 2.0 percentage points during this period.

Chart 16: Nominal ICT Share of Sector's Total Non-Residential Fixed Capital Stock, Air Transportation and the Business Sector, Canada, 1981-2010

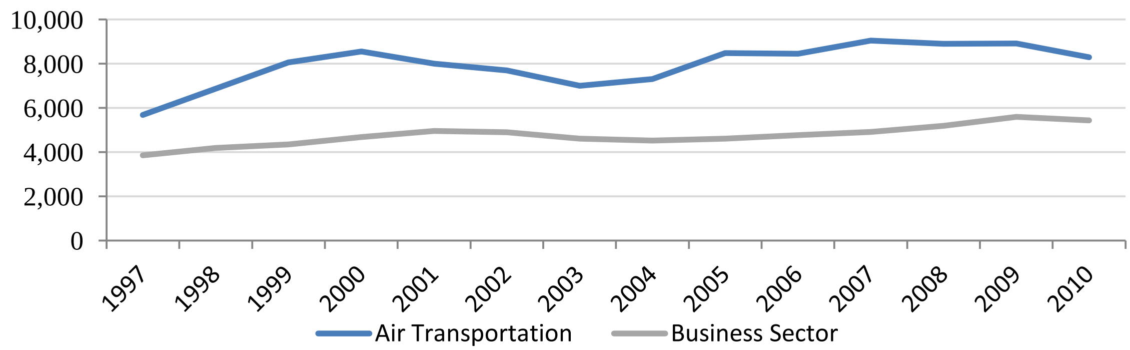


Source: Appendix Table 3d

ICT capital intensity is defined as ICT capital stock in dollars per worker in an industry. In 2010, ICT capital intensity in Canadian air transportation was $8,299 per worker, 1.5 times larger than that of the business sector, which amounted to $5,440 per worker. Historically, the capital intensity of the air transportation sector has typically been higher than that of the business sector, with the difference ranging between $1,800 to $4,200 per worker (Chart 17). In terms of growth, ICT capital intensity averaged annual growth of 3.0 per cent between 1997 and 2010, surpassing that of the business sector (2.7 per cent).

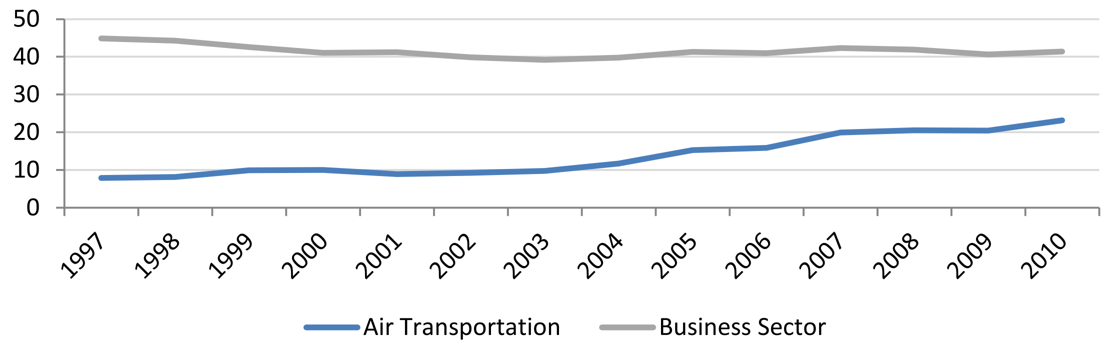
In comparing ICT capital intensity between the Canadian air transportation sector and the American air transportation sector, it is immediately clear that both Canadian air transportation and the business sector as a whole perform at a fraction of their American counterparts (Chart 18). It is noteworthy, however, that while ICT capital intensity in the Canadian business sector relative to the United States has fallen by 3.4 percentage points between 1997 and 2010 while the ICT capital intensity of the air transportation sector has increased by 15.3 percentage points during this period.

Chart 17: ICT Capital Intensity (Nominal Capital Stock per Worker), Air Transportation and the Business Sector, Canada, 1997-2010



Source: Appendix Table 3h

Chart 18: ICT Capital Intensity (Nominal Capital Stock per Worker), PPP, Relative to the United States (US=100), Air Transportation and the Business Sector, Canada, 1997-2010



Source: Appendix Table 9e

Table 3 provides a summary comparison of the ICT capital stock for air transportation in Canada and the United States. Between 1981 and 2010, the capital stock in Canadian air transportation grew at an average annual rate of 7.6 per cent, versus 9.4 per cent in the United States. In proportion to the sector's value added GDP, air transportation in Canada represents 12.8 per cent of value added, versus 22.9 per cent in American air transportation. The ICT capital stock in Canadian air transportation comprised a larger share of the sector's total capital than in American transportation in 1981, but has since fallen below the United States, 4.0 per cent versus 6.8 per cent in 2010. This is attributable to a larger increase in American air transportation (4.8 percentage points) than in Canadian rail transportation (1.8 percentage points) between 1981 and 2010.

Capital intensity in 2010 was substantially lower in Canadian air transportation than in American air transportation. More importantly, the Canadian sector averaged growth of only 3.7 per cent per year between 1981 and 2010 while this figure was 7.4 for the United States. Similar to the trend for ICT investment intensity, ICT capital in Canadian air transportation relative to the United States has grown by 15.3 percentage points between 1981 and 2010.

Table 3: ICT Capital Stock, Air Transportation, Canada-US Comparison, Levels, Growth and Changes, 2010 or most recent year

	Levels		Growth or Absolute Change		
	Canada	US	Canada	US	Period
Capital Stock, millions domestic	554	14,468	7.6	9.4	1981-2010
Share of Air Transportation's Value-Added	12.8	22.9	1.5	15.0	1999-2008
Share of Business Sector ICT Capital Stock	0.7	1.2	0.3	0.6	1981-2010
Share of Air Transportation's Total Investment	4.0	6.8	1.8	4.8	1981-2010
Capital Intensity (Absolute), USD at PPP	7,220	31,168	3.7	7.4	1990-2010
Capital Intensity (Relative to US), USD at PPP	20.2	1.0	15.3	na	1991-2010
Capital Intensity (Relative to Business Sector)	152.6	272.8	5.6	3.0	1997-2010

Notes: Capital stock in $millions. Growth in terms of average annual growth rates. 1981-2010 or longest period available. Changes for shares and relatives use absolute change.
Source: Appendix Tables 3a, 3c, 3d, 3e, 3h, 3i, 7a, 7c, 7d, 7e, 7h, 7i, 9e

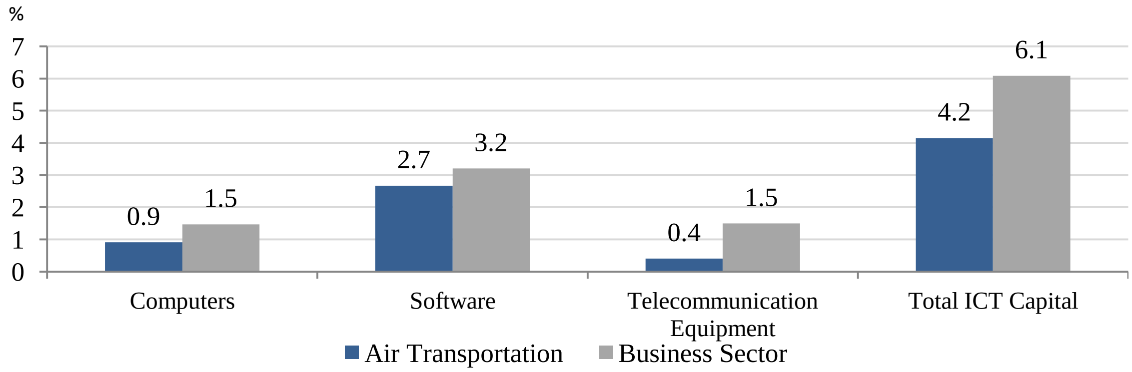
v. Current Dollar Capital Stock by Component

This section provides trend and cross-sectional analysis of the components of the ICT capital stock in Canadian air transportation, making comparisons with the Canadian business sector and air transportation in the United States. All figures are expressed in current dollars.

In 2010, the capital stock of each ICT component in Canadian air transportation comprised a smaller share of the sector's total capital stock than in the business sector (Chart

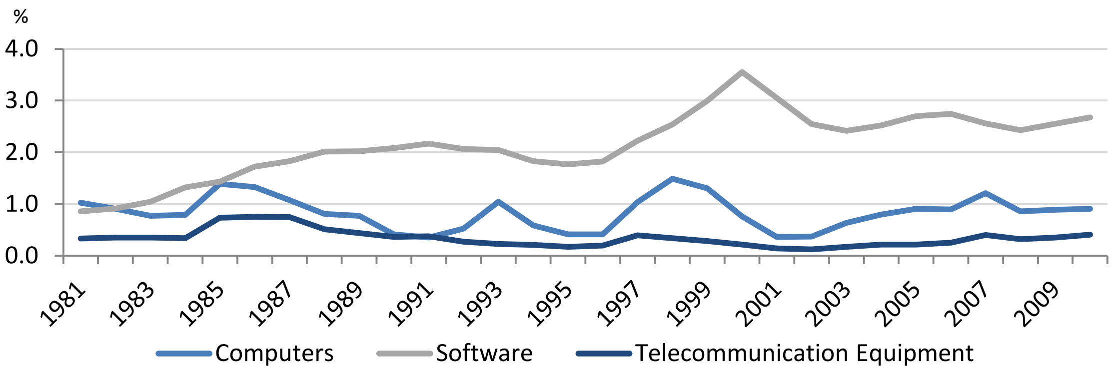
19). The largest share of total capital attributable to ICT in air transportation was that of software, comprising 2.7 per cent. This was followed by computers and telecommunications equipment, with shares of 0.9 per cent and 0.4 per cent, respectively.

Chart 19: Nominal ICT Capital Stock, as a Share of Sector's Total Non-Residential Fixed Capital Stock, by Component, Air Transportation and the Business Sector, Canada, 2010



Source: Appendix Table 3d

Chart 20: Nominal ICT Capital Stock, as a Share of Sector's Total Non-Residential Fixed Capital Stock, by Component, Air Transportation, Canada, 1981-2010



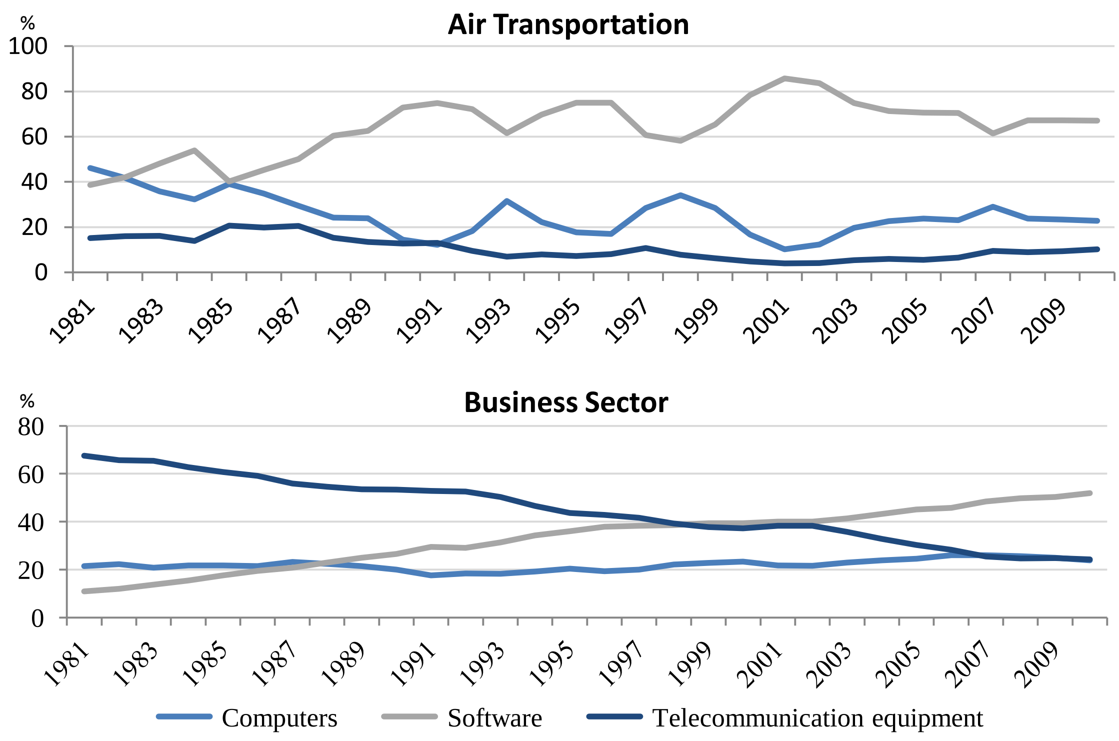
Source: Appendix Table 3d

Historically, software has accounted for the largest share of air transportation's total capital stock, followed by computers and finally, telecommunications (Chart 20). In 2010, the share for software was 2.8 per cent, compared to 0.9 per cent for computers and 0.5 per cent for telecommunications. In terms of growth, the computer and telecommunications shares of total investment has been relatively stagnant between 1981 and 2010, falling by 0.4 percentage points and growing by 0.6 percentage points, respectively. The share of total capital stock attributable to software rose substantially over this period, showing a change of 4 percentage points.

As a component of the sector's total ICT capital stock, software has historically accounted for the largest share amongst ICT components in the air transportation sector, while telecommunications has accounted for the smallest (Chart 21). In 1981, computers and software were about equal in terms of importance in air ICT investment, each at around 40 per cent, with telecommunications at just under 20 per cent. In 2010, software increased to 70 per cent, computers fell to about 20 per cent and telecommunications fell to around 10 per cent. The rising trend seen for software and the decline of computers is also found in the business sector, but the decline in telecommunications seen in air transportation is less severe than that seen in the business sector.

In terms of changes in relative importance, the share of total ICT capital attributable to software in air transportation grew by 28.4 percentage points between 1981 and 2010 (Appendix Table 3f). This figure was lower than that of the business sector, which saw an absolute change of 41.0 percentage points over the same period. The shares of computers and telecommunications of total ICT capital in air transportation declined over this period, falling 23.4 and 5.0 percentage points, respectively. In comparison with the business sector, the computer share of total ICT capital grew by 2.3 percentage points over this period and the telecommunications share fell by 43.3 percentage points. It is also noteworthy that there has been a significant degree of substitution towards software away from computers over time, with periods of growth of software capital corresponding to periods of decrease for computers and vice versa.

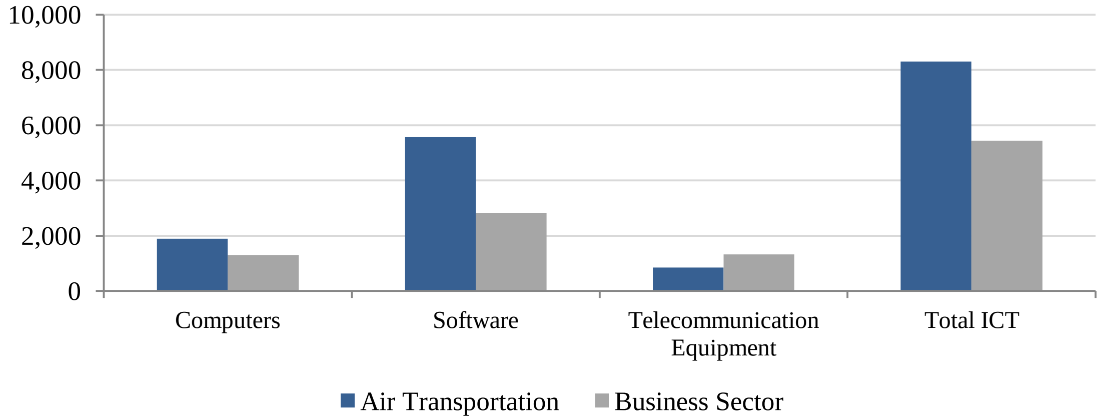
Chart 21: ICT Capital Stock by Component, $Current, as a Share of Sector's Total ICT Capital Stock, Air Transportation and the Business Sector, Canada, 1981-2010



Source: Appendix Table 3f

For components of ICT capital stock, capital intensity in air transportation was higher than the business sector for computers and software and lower than the business sector for telecommunications in 2010 (Chart 22). For computers, capital intensity was $1,891 per worker, compared to $1,297 per worker for the business sector. For software, this difference was substantial; capital intensity for air transportation was $5,564, nearly doubling capital intensity for the business sector, which was $2,823 per worker. For telecommunications, capital intensity in air transportation was $843 per worker, lower than that of the business sector which was $1,319.

Chart 22: Nominal ICT Capital Intensity, Air Transportation and the Business Sector, by Component, Air Transportation Canada, 2010



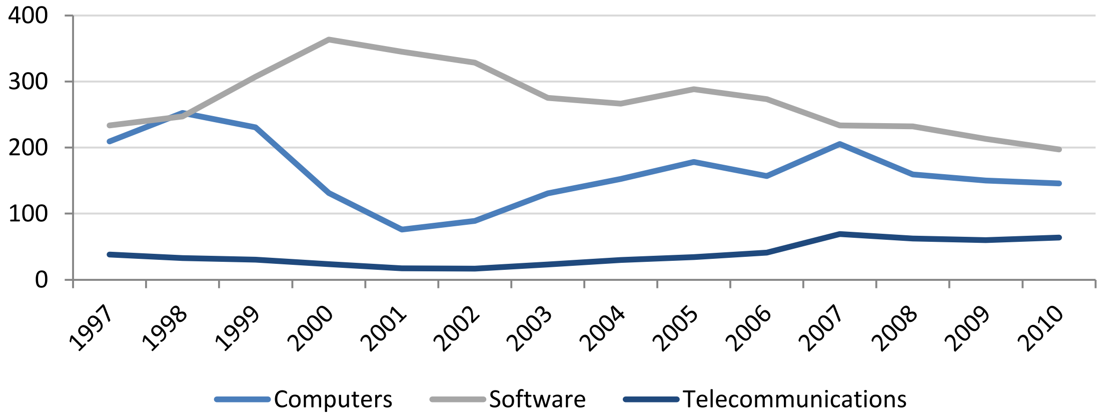
Source: Appendix Table 3h

Historically, capital intensity for computers and software in the air transportation sector have been consistently higher than the business sector, while capital intensity for telecommunications has been consistently lower (Chart 23). In terms of growth, however, capital intensity in air transportation relative to the business sector has declined in both computers and software between 1997 and 2010, exhibiting decreases of 0.6 percentage points and 0.4 percentage points, respectively. Telecommunications capital intensity has increased in the air transportation sector over this period, rising by 0.3 percentage points, from about 40 per cent of the business sector's telecommunications capital intensity to 64 percent.

In comparison to air transportation in the United States, computer and software capital intensity in Canadian air transportation is considerably higher, but for telecommunications it is substantially lower (Chart 24). Computer capital intensity in Canadian air transportation was 2.2 times that of its American counterpart in 2010, and software capital intensity was 2.8 times that of air transportation in the United States. Capital intensity in air transportation for each of these components outperforms the Canadian business sector for this indicator. In terms of telecommunications capital, however, air transportation in Canada compares unfavorably to its

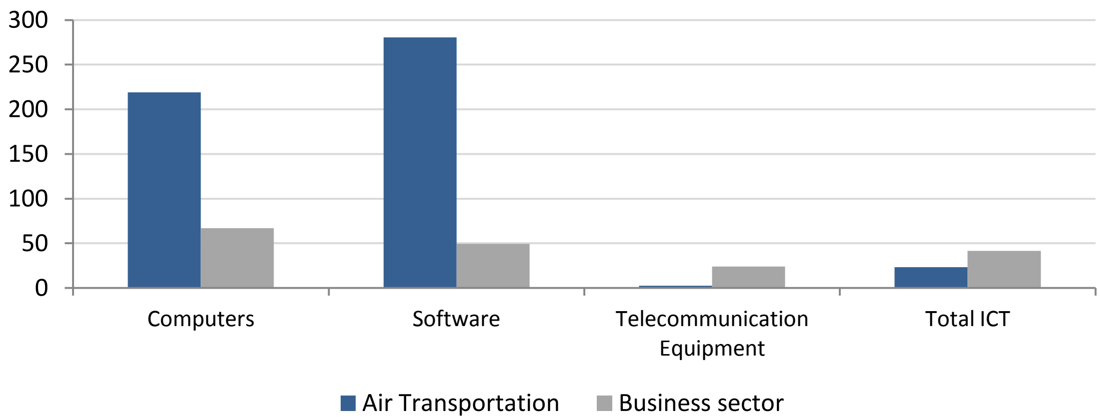
American counterpart, with a telecommunications capital intensity that is barely 3 per cent of the American figure.

Chart 23: ICT Capital Intensity (Nominal Capital Stock per Worker) Relative to the Business Sector (Business Sector=100), by Component, Air Transportation Canada, 1997-2010



Source: Calculated from Appendix Table 3h

Chart 24: ICT Capital Intensity (Nominal Capital Stock per Worker), PPP, Relative to the United States (US=100), Air Transportation and the Business Sector, Canada, 2010



Source: Appendix Table 9e

B. Rail Transportation

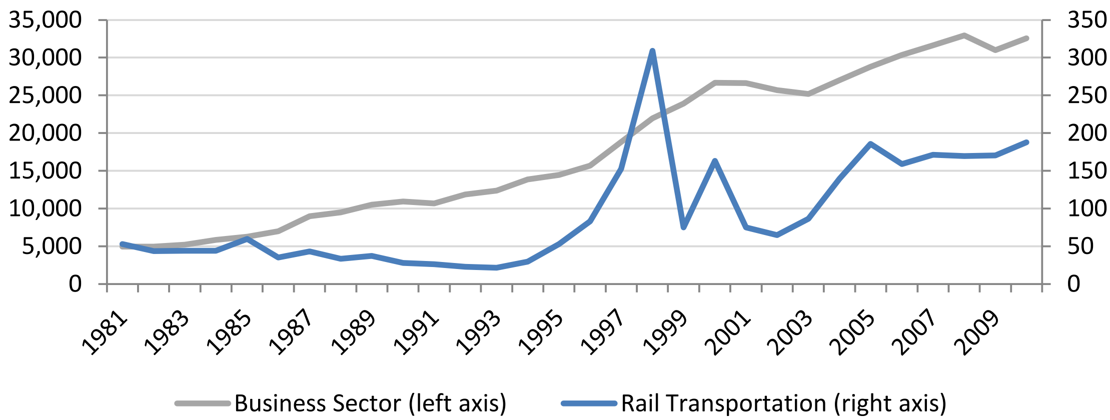
This subsection describes ICT investment and capital stock trends in Canadian rail transportation during the 1981-2010 period, comparing these trends to those observed in the Canadian business sector and to those seen in U.S. rail transportation. Several indicators are analyzed, including: current dollar ICT investment (total and by component), constant dollar ICT investment, current dollar ICT capital stock, and constant dollar ICT capital stock.

i. Current Dollar ICT Investment

This section outlines trends in ICT investment for the Canadian rail transportation sector, providing comparisons to the Canadian business sector and rail transportation in the United States. All figures in this section are expressed in current dollars.

Chart 25 depicts the time profiles of total ICT investment in Canadian rail transportation and the business sector. In 2010, total ICT investment in the rail transportation sector was $187.6 million, having increased from $53 million in 1981. ICT investment in rail transportation averaged annual growth of 4.5 per cent over this period, which was lower than that of the business sector, at 6.7 per cent. It should also be noted that over the 2000 to 2010 period, rail transportation averaged annual growth of 1.4 per cent, which also fell below that of the business sector, 2.0 per cent. There was a significant spike in ICT investment in the late 1990s, in which it nearly doubled in both 1997 and 1998. This was driven by significant increases in investment in both computers and software.

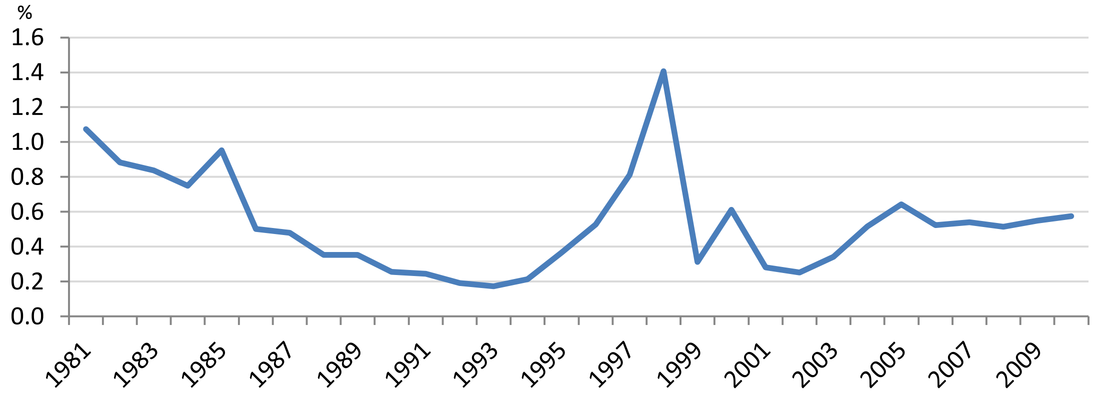
Chart 25: Total Nominal ICT Investment Rail Transportation and the Business Sector, Millions, Canada, 1981-2010



Source: Appendix Table 1a

As a share of total ICT investment in the business sector, rail transportation has comprised between 0.2 per cent and 1.4 per cent between 1981 and 2010 (Chart 26). Over the period, it exhibited a net change of 0.5 percentage points. In recent years, it has been relatively stagnant, showing no change between 2000 and 2010.

Chart 26: Nominal Investment, as a Share of Business Sector ICT Investment, Rail Transportation, Canada, 1981-2010

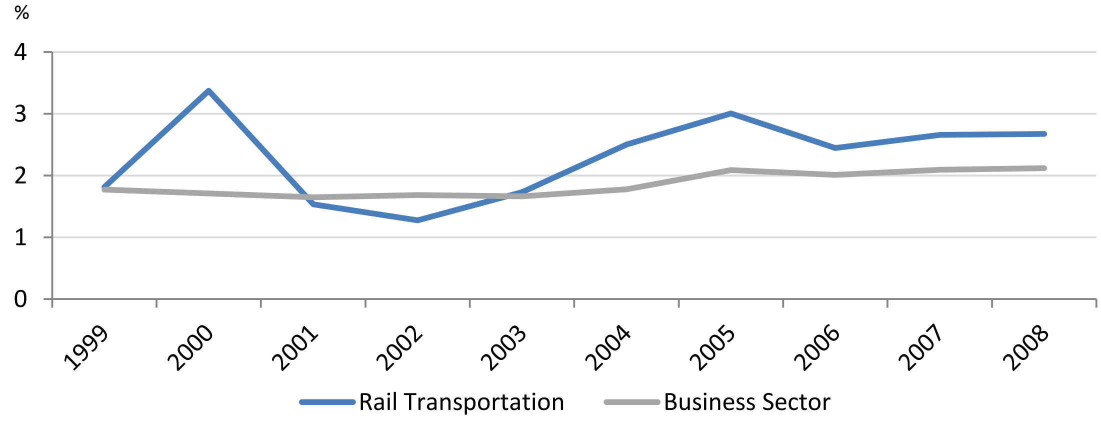


Source: Appendix Table 1f

ICT investment in rail transportation was relatively larger compared to value added than in the business sector in 2010, 2.7 per cent and 2.1 per cent, respectively (Chart 27). For the majority of the period 1981 to 2010, ICT investment has comprised a larger share of value added in the rail transportation sector than it has in the business sector. In recent years, this difference has been fairly consistent at about 0.5 percentage points. In terms of absolute change, ICT investment as a share of value added in rail transportation increased by 0.86 percentage points between 1999 and 2010, compared to an absolute change of only 0.35 percentage points in the business sector as a whole.

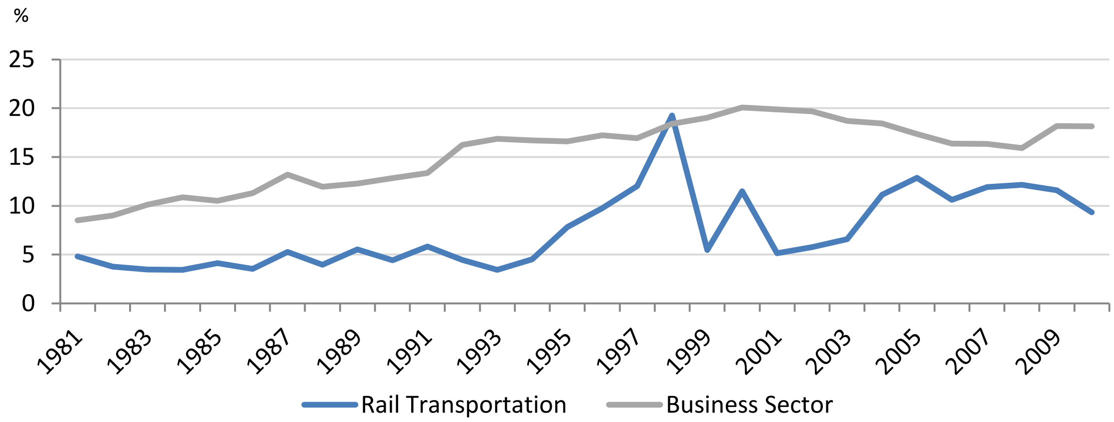
As a share of total investment, however, ICT investment in rail transportation was lower than in the business sector, comprising 9.3 per cent of total investment in 2010 (vs. 18.1 per cent in the business sector) (Chart 28). It is immediately noticeable that historically, ICT investment has comprised a larger share of total investment in the business sector than in the rail transportation sector. In recent years this difference has been approximately 10 percentage points. In terms of absolute change, the share of ICT investment in rail transportation increased by 4.5 percentage points between 1981 and 2010, while it increased by 9.6 percentage points in the business sector.

Chart 27: Total Nominal ICT Investment as a Share of Nominal Value-Added. Rail Transportation and the Business Sector, Canada, 1999-2008



Source: Appendix Table 1d

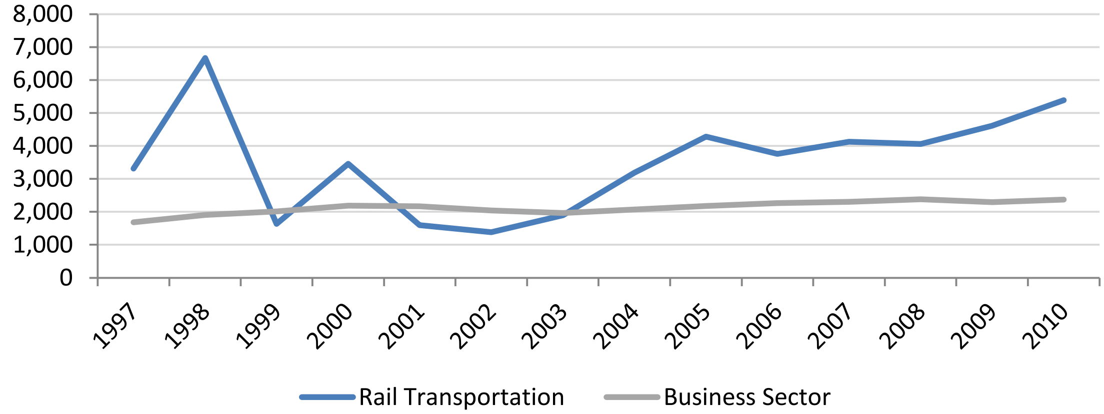
Chart 28: Nominal ICT Share of Sector's Total Non-Residential Fixed Investment, Rail Transportation and the Business Sector, Canada, 1981-2010



Source: Appendix Table 1e

ICT investment intensity was $5,384 per worker in the rail transportation sector in 2010. This was more than twice that of the business sector, $2,369 per worker (Chart 29). In terms of growth, the rail transportation sector averaged annual growth of 4.5 per cent between 2000 and 2010, whereas the business sector averaged 0.8 per cent growth annually over this period. It is also noteworthy that ICT investment intensity for rail transportation has risen drastically since 2008, while it has been relatively stagnant in the business sector.

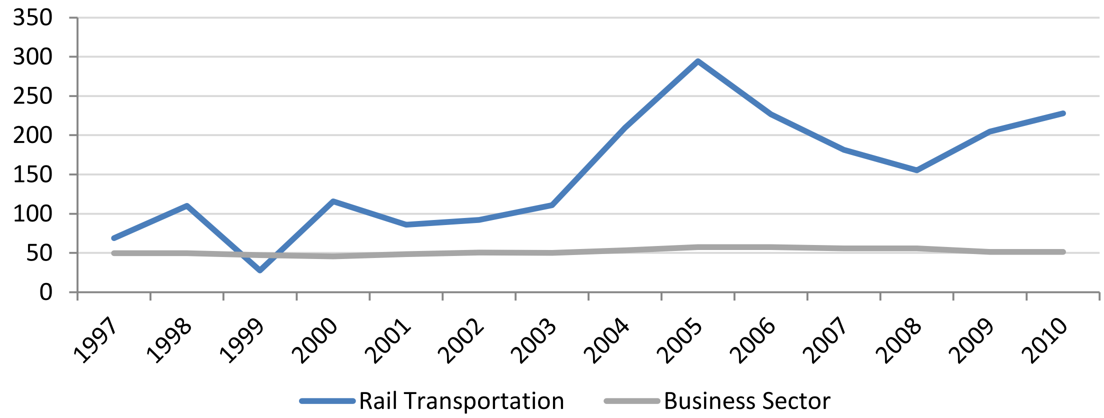
Chart 29: ICT Investment Intensity (Nominal Investment per Worker), Rail Transportation and the Business Sector, Canada, 1997-2010



Source: Appendix Table li

In comparison to rail transportation in the United States, Canadian rail transportation has been consistently higher in terms of ICT investment intensity (Chart 30). In 2010, ICT investment intensity in Canadian rail transportation was 2.3 times that of its American counterpart. Since 1997, this figure has increased by 159.0 percentage points. ICT intensity in the Canadian business sector has been approximately half of that of its American counterpart for this entire period.

Chart 30: ICT Investment Intensity Nominal Investment per Worker), PPP, Relative to the United States (US=100), Rail Transportation and the Business sector, Canada, 1997-2010



Source: Appendix Table 9a

Table 4 provides a summary of ICT investment indicators for Canadian rail transportation in comparison to the United States. For rail transportation, ICT investment in Canada grew at a rate of 4.5 per cent per year, outpacing its U.S. counterpart, which grew at a rate of 1.5 per cent per year. As a share of the sector's value added, ICT investment intensity was proportionately higher in Canadian rail transportation than in American rail transportation, 2.7 per cent versus 1.5 per cent. ICT investment in Canadian rail transportation also comprised a larger share of the sector's total investment than in American rail transportation, 9.3 per cent versus 3.2 per cent.

In 2010, Canada's ICT investment intensity in rail transportation was $4,684 per worker, almost twice that of the United States, $2,057 per worker. ICT capital intensity in Canadian rail transportation was 2.3 times that of the business sector. In the United States, ICT investment intensity in rail transportation was only 51 per cent of the business sector.

Table 4: ICT Investment, Rail Transportation, Canada-US Comparison, Levels, Growth, and Changes, 2010 or most recent year

	Levels		Growth or Absolute Change		
	Canada	US	Canada	US	Period
Investment, millions of domestic	187.6	442.0	4.5	1.5	1981-2010
Share of Rail Transportation's Value-Added	2.7	1.5	0.9	-3.2	1999-2008
Share of Business Sector ICT Investment	0.6	0.1	-0.5	-0.4	1981-2010
Share of Rail Transportation's Total Investment	9.3	3.2	4.5	-2.4	1981-2010
Investment Intensity (Absolute)	4,684	2,057	14.3	2.6	1990-2010
Investment Intensity (Relative to US), USD at PPP	198.1	100.0	158.7	100.0	1991-2010
Investment Intensity (Relative to Business Sector)	227.2	51.0	1.1	-91.0	1997-2010

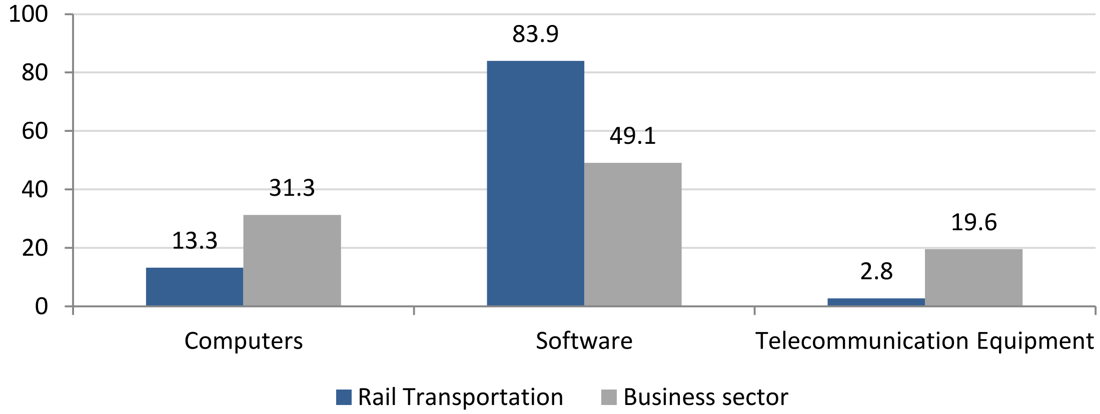
Notes: Investment in $millions. Growth in terms of average annual growth rates. 1981-2010 or longest period available. Changes for shares and relatives use absolute change.
Source: Appendix Tables 1a, 1d, 1f, 1i, 1j, 5a, 5d, 5f, 5i, 5j, 9a

ii. Current Dollar ICT Investment by Component

This section provides trend and cross-sectional analysis of ICT investment in terms of its components in the Canadian rail transportation sector, making comparisons to the Canadian business sector and rail transportation in the United States. All figures are reported in current dollars.

In 2010, the largest share of total ICT investment was attributable to software (83.9 per cent), followed by computers (13.3 per cent) and telecommunications equipment (2.4 per cent) (Chart 31). The relative importance of the three ICT components was the same for the business sector, with software comprising 61.2 per cent of total ICT investment, computers comprising 31.1 per cent of total ICT investment and telecommunications comprising 9.4 per cent of ICT investment. It is noticeable that the rail transportation sector is skewed considerably more toward software investment than the other components of ICT. This marks a significant difference from the business sector, in which computers and telecommunications account for larger shares of total ICT investment.

Chart 31: Nominal ICT Investment by Component, as a Share of Sector's Total ICT Investment, Rail Transportation and the Business Sector, Canada, 2010

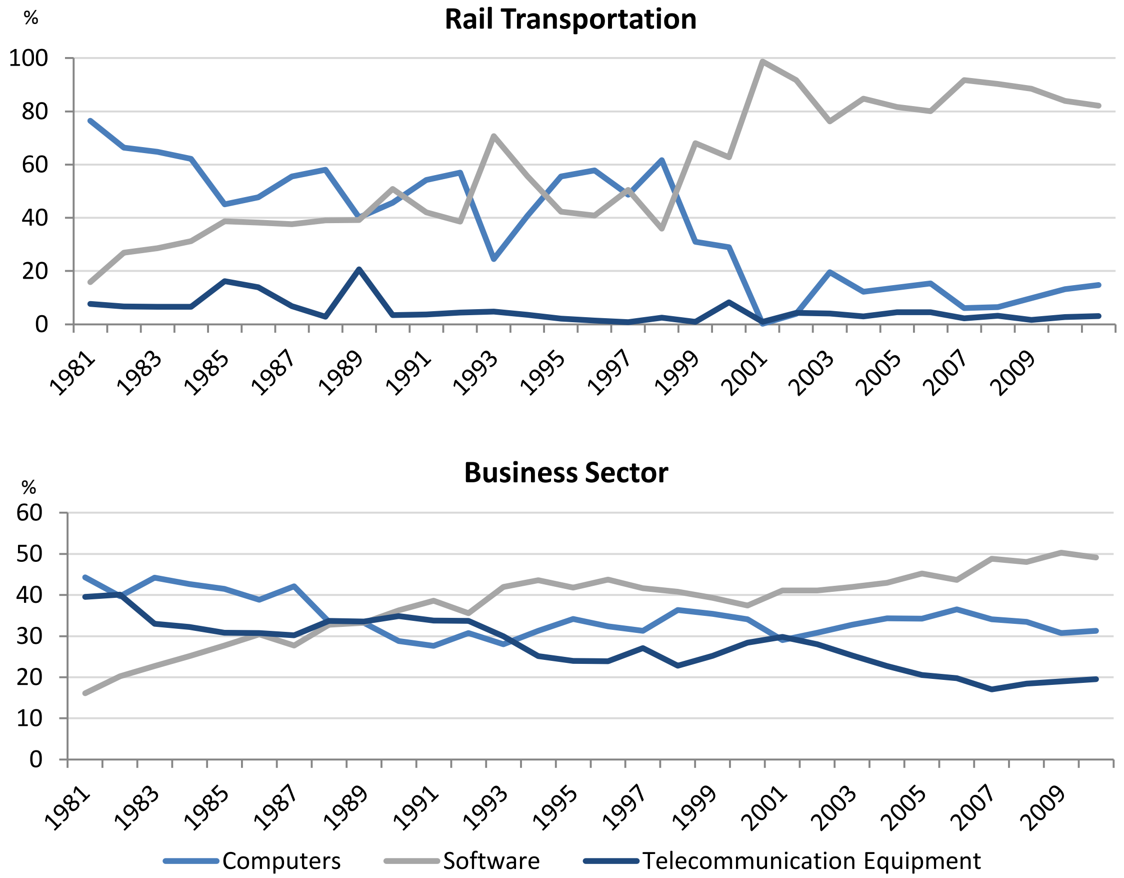


Source: Appendix Table 1g

Historically, software and computers have comprised the largest share of ICT investment in rail transportation (Chart 32). Between 1981 and 2010, the share of ICT investment attributable to computers in rail transportation fell by 63.2 percentage points while that of software has risen by 68.1 percentage points. In the business sector, the share of ICT investment comprised by computers fell by 13 percentage points over this period, while the share for software rose 33.0 percentage points. The telecommunications share of total ICT investment in rail transportation fell by 4.8 percentage points while it fell by 20.0 percentage points in the business sector.

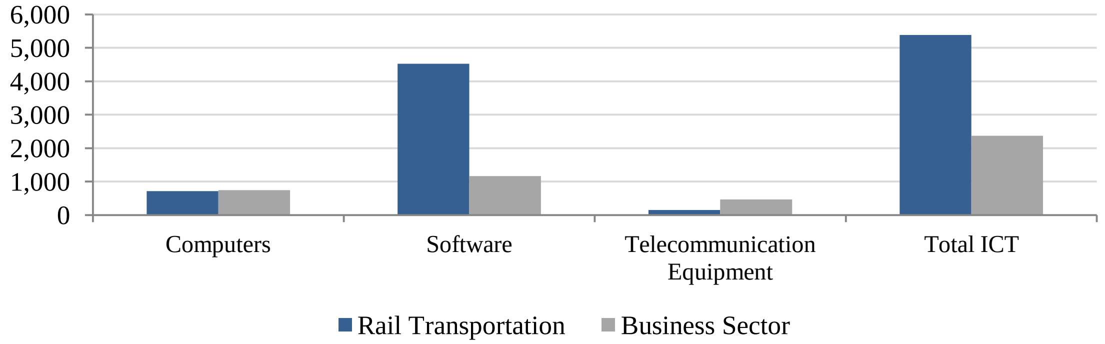
In 2010, computer investment intensity in rail transportation was $714 per worker, comparable to the business sector, in which it was $742 per worker (Chart 33). In the case of software, investment intensity in rail transportation was nearly four times higher than in the business sector, $4,520 per worker compared to $1,164 per worker. Telecommunications investment intensity in rail transportation was $150 per worker, less than half of telecommunications investment intensity in the business sector, $464 per worker.

Chart 32: Nominal ICT Investment by Component, as a Share of Sector's Total ICT Investment, Rail Transportation and the Business Sector, 1981-2010



Source: Appendix Table 1g

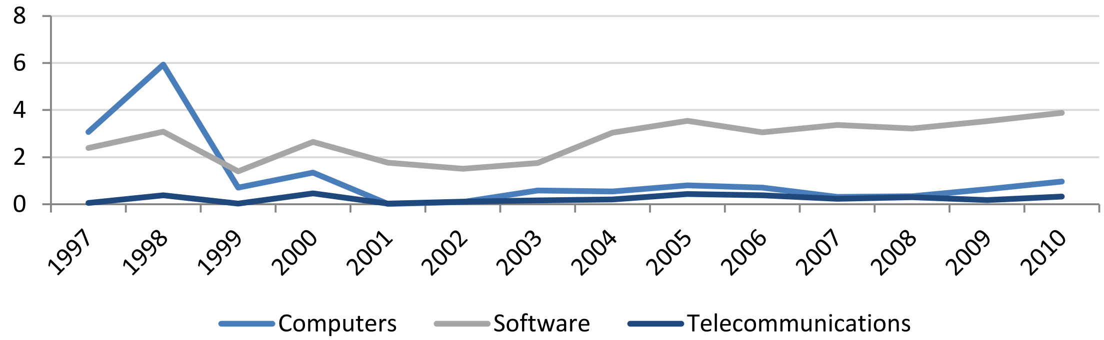
Chart 33: ICT Investment Intensity (Nominal Investment per Worker), Rail Transportation and the Business Sector, Canada, 2010



Source: Appendix Table 1i

Historically, software investment intensity in rail transportation has been consistently above that of the business sector. Between 1997 and 2010, software investment intensity has been between 1.5 and 3.9 times that of the business sector, with the largest differential being in 2010. Computer investment intensity for rail transportation was above that of the business sector prior to 1999. It has increased since 2008, reaching 96 per cent of the business sector in 2010. Telecommunications investment intensity has historically been much lower than that of the business sector. Between 1997 and 2010, it has remained at about one third of the business sector.

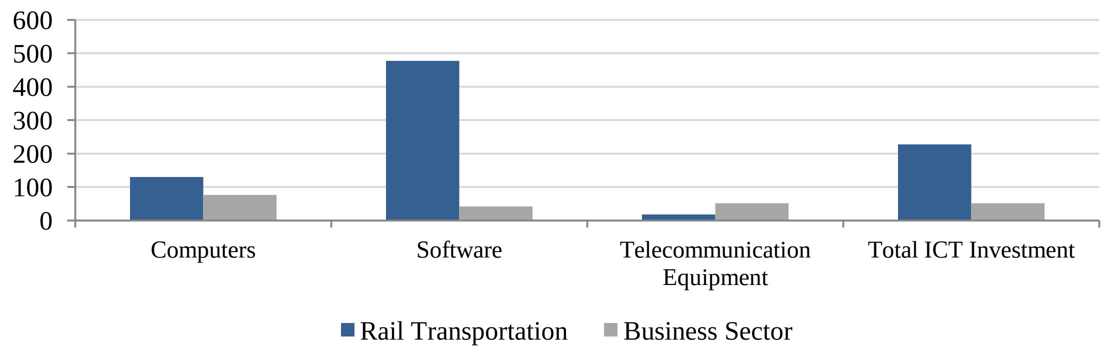
Chart 34: ICT Investment Intensity (Nominal Investment per Worker), Relative to the Business Sector, by Component, Air Transportation, Canada, 1997-2010



Source: Calculated from Appendix Table 1i

In comparison to the United States, Canadian rail transportation has higher investment intensity for two of three ICT components. Computer investment intensity in rail transportation was 1.3 times that of its American counterpart in 2010. For software, investment intensity in Canadian rail transportation was an impressive 4.8 times that of American rail transportation, which may reflect a discrepancy between the definitions used by the respective statistical agencies. Telecommunications investment intensity in Canadian rail transportation lagged behind, at only 17.3 per cent of the figure for rail transportation in America.

Chart 35: ICT Investment Intensity, (Nominal Investment per Worker), PPP, Relative to the United States, (US=100), Rail Transportation and the Business Sector



Source: Appendix Table 9a

iii. Constant Dollar Investment

Table 5 depicts growth rates for air transportation in Canada and the United States for total ICT investment as well as ICT components for a selection of indicators. In terms of total ICT investment, Canada's rail transportation grew faster than its American counterpart between 1981 and 2010, averaging an annual growth of 7.3 per cent (the American figure was 4.0 per cent per year). For the components of ICT, however, this was not the case, with Canadian rail transportation showing weaker growth than American rail transportation in each category.[6] This was most pronounced for computers. For total investment intensity, Canadian rail transportation grew faster than American rail transportation between 1981 and 2010, averaging annual growth of 8.1 per cent, compared to the American figure, 5.1 per cent.

Table 5: Growth Rates, Selected Investment Indicators, $2002, Rail Transportation, Canada and the United States

	Canada		United States	
	ICT Investment	ICT Investment Intensity	ICT Investment	ICT Investment Intensity
Total ICT Investment				
1981-1990	-6.3	-0.2	na	6.3
1990-2000	23.8	7.8	na	9.5
2000-2010	4.9	4.3	8.1	5.1
1981-2010	7.3	4.0	na	7.0
Computers				
1981-1990	4.4	35.8	na	44.7
1990-2000	33.9	32.1	na	34.2
2000-2010	4.6	11.5	7.8	12.3
1981-2010	13.8	25.6	na	29.2
Software				
1981-1990	6.5	32.8	na	41.5
1990-2000	24.4	17.5	na	19.4
2000-2010	6.0	-0.6	9.3	0.2
1981-2010	12.2	15.2	na	18.5
Telecommunications				
1981-1990	-16.8	-2.9	na	3.5
1990-2000	12.6	-1.4	na	0.2
2000-2010	-6.2	4.2	-3.3	4.9
1981-2010	-3.8	0.0	na	2.8

Source: Appendix Tables 2a, 2c, 2e, 6a, 6c, 6j

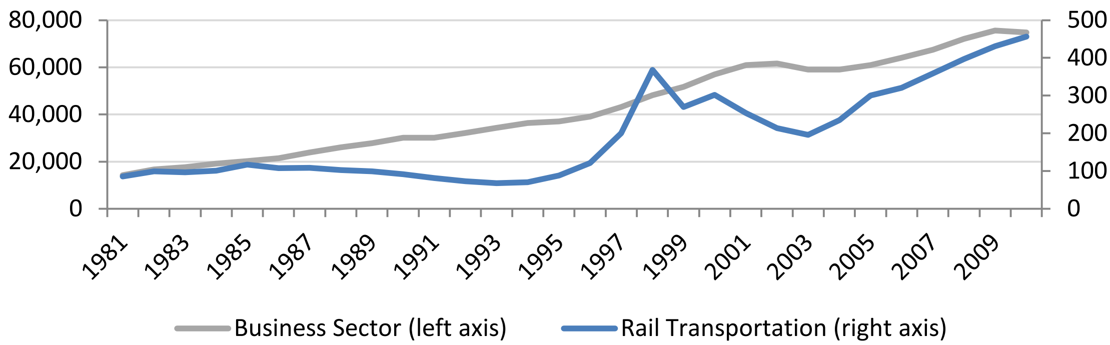
[6] Though this seems counterintuitive, it is the result of a mathematical regularity. The growth rates for components of ICT investment do not add to the growth rate of total ICT investment because each growth rate is calculated with a unique denominator, and hence the additive property does not hold.

iv. Current Dollar Capital Stock

This section outlines trends in the ICT capital stock for rail transportation in Canada, making comparisons to the Canadian business sector and rail transportation in the United States. All figures are expressed in current dollars.

In 2010, the ICT capital stock in Canadian rail transportation was $457 million, having increased from $85 million in 1981. Over this period the ICT capital stock for rail transportation averaged annual growth of 6.0 per cent, comparable to the business sector which grew at a rate of 5.9 per cent per year.

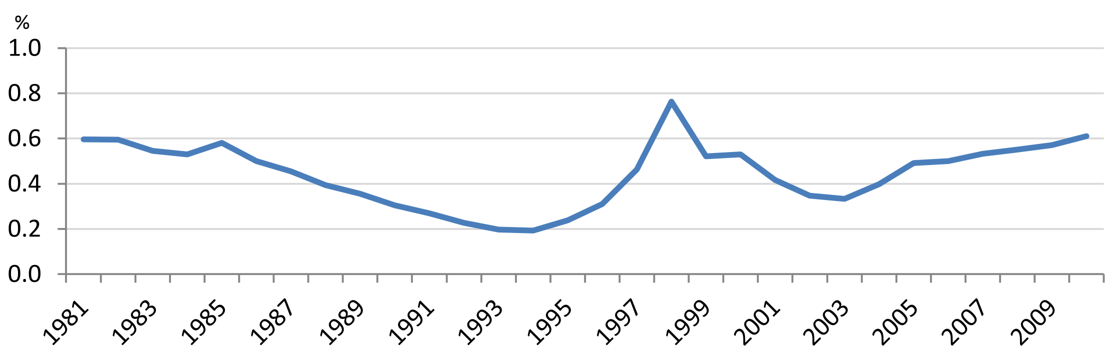
Chart 36: Total Nominal ICT Capital Stock, Rail Transportation and the Business Sector, Canada, 1981-2010



Source: Appendix Table 3a

As a share of the business sector's ICT capital stock, rail transportation comprised 0.61 per cent in 2010 (Chart 37). Despite significant fluctuations between 1981 and 2010, this figure has netted zero change over this period.

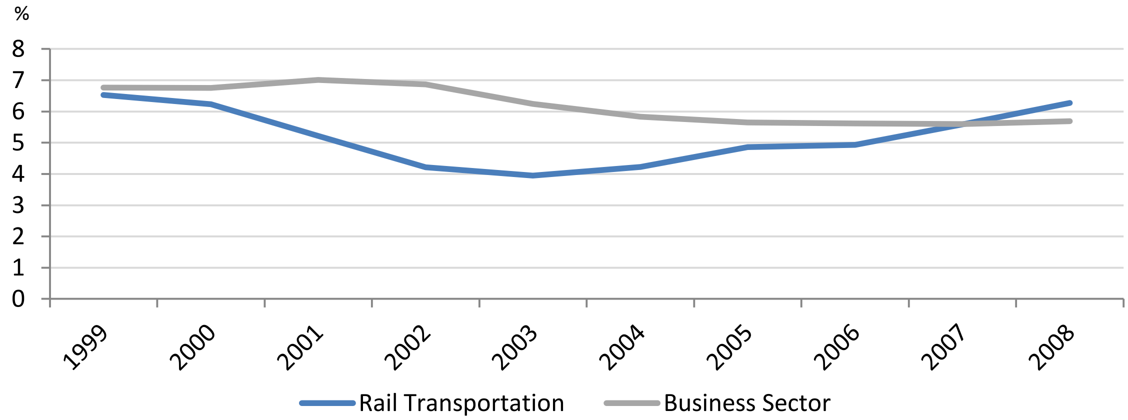
Chart 37: Nominal ICT Capital Stock, as a Share of the Business Sector, Rail Transportation, by Type of Capital, Canada, 1981-2010



Source: Appendix Table 3e

In comparison to the sector's value added, the ICT capital stock in rail transportation is proportionately larger than in the business sector (Chart 38). In 2008, the ICT capital stock in rail transportation was 6.7 per cent of value added, whereas it was 5.7 per cent in the business sector. Historically, this has not been the case, as the ICT capital stock in rail transportation as a share of value added only surpassed that of the business sector in 2008. In terms of relative importance historically, this indicator fell by 0.3 percentage points between 1999 and 2000 for rail transportation whereas it declined by 1.1 percentage points for the business sector.

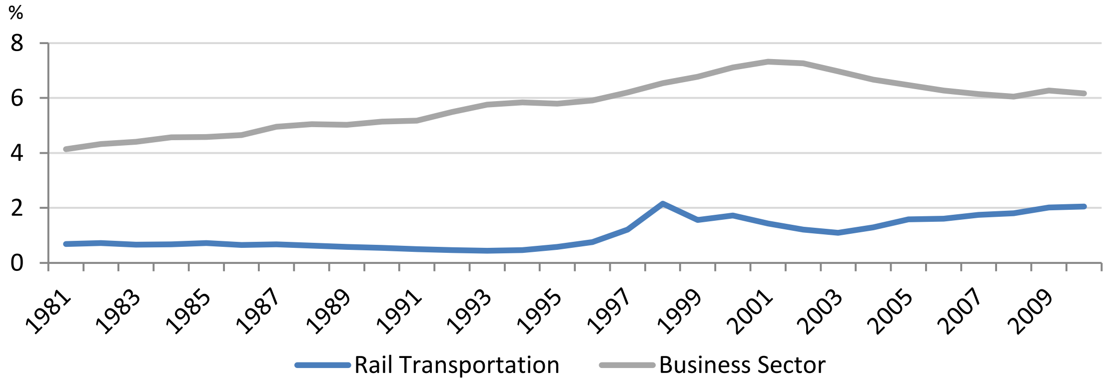
Chart 38: Total Nominal ICT Capital Stock as a Share of Nominal Value Added, Rail Transportation and the Business Sector, Canada, 1999-2008



Source: Appendix Table 3c

As a component of the sector's total non-residential fixed capital stock, ICT capital comprised 2.1 per cent for rail transportation in 2010, well below the business sector, for which the figure was 6.2 per cent (Chart 39). Such a difference may be explained by the rail transportation sector's considerable stock of structures, which accounts for a significant portion of total capital. This discrepancy has been persistent historically, with rail transportation being below the business sector for as long as data is available. Between 1981 and 2010, the share of total capital comprised by ICT capital in rail transportation increased by 1.4 percentage points, less than the business sector which netted a 2.0 percentage point increase. Between 2000 and 2010, however, rail transportation increase by 0.3 percentage points, whereas the business sector experienced a decline of 0.9 percentage points.

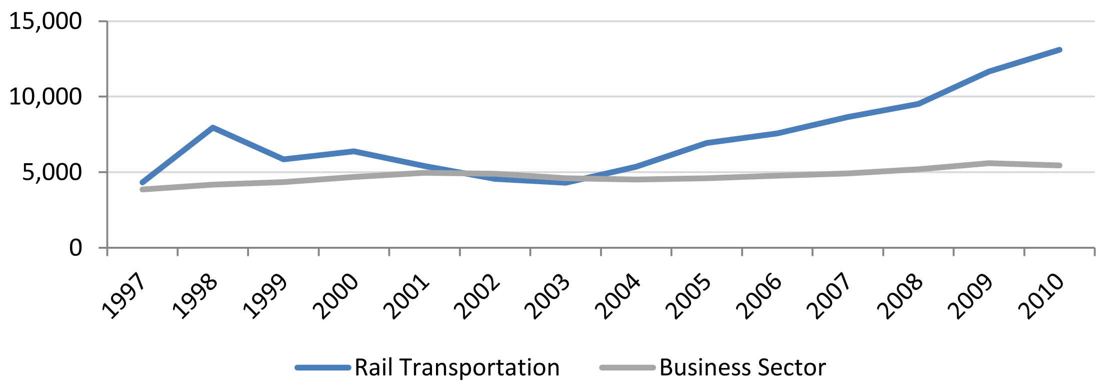
Chart 39: Nominal ICT Share of Sector's Total Non-Residential Fixed Capital Stock, Rail Transportation and the Business Sector, Canada, 1981-2010



Source: Appendix Table 3d

ICT capital intensity for rail transportation was $13,106 per worker in 2010, 2.4 times that of the business sector, which was $5,440 per worker (Chart 40). Historically, ICT capital intensity in rail transportation has been higher than in the business sector, having surged after 2004. In terms of growth, ICT capital intensity in rail transportation averaged annual growth of 8.9 per cent between 1997 and 2010, significantly higher than the 2.7 per cent per year seen in the business sector. In the shorter term, between 2003 and 2010, ICT capital intensity in rail transportation grew at an average rate of 17.2 per cent per year whereas the business sector grew at 2.7 per cent per year over this period.

Chart 40: ICT Capital Intensity (Nominal Capital Stock per Worker), Rail Transportation and the Business Sector, Canada, 1997-2010

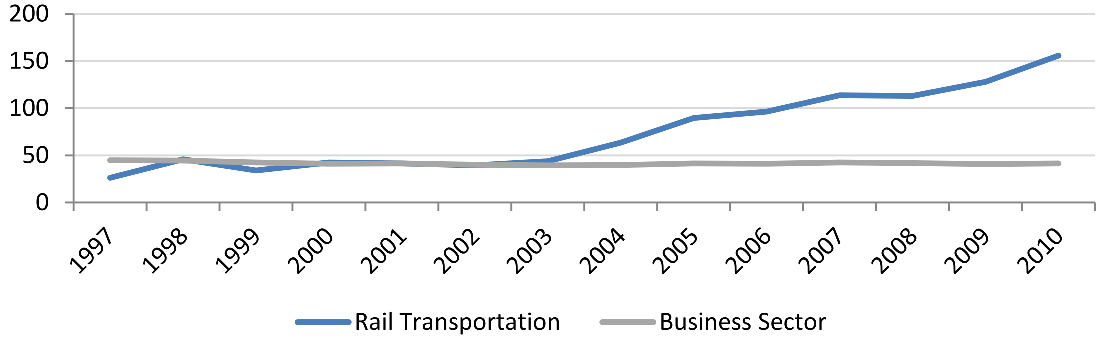


Source: Appendix Table 3h

ICT investment for rail transportation was 1.6 times that of its U.S. equivalent in 2010. Relative to the United States, ICT capital intensity for the Canadian business sector has been consistent between 1997 and 2010, sitting at approximately 40 per cent of that of its U.S.

counterpart. Prior to 2004, ICT capital intensity for rail transportation sat at approximately the same proportion, but exhibited significant growth through 2010.

Chart 41: ICT Capital Intensity (Nominal Capital Stock per Worker), PPP Relative to the United States (US=100), Rail Transportation and the Business Sector, 1997-2010



Source: Appendix Table 9e

Table 6 summarizes the 2010 levels for various ICT capital stock indicators, as well as growth rates and changes for the period 1981 to 2010 for rail transportation in Canada and the United States. The ICT capital stock in Canadian transportation grew at an average annual rate of 6.0 per cent between 1981 and 2010, faster than that of the United States, which grew at 1.3 per cent per year. In proportion to the sector's value added, ICT capital in Canadian rail transportation represented 6.3 per cent in 2010, compared to 2.5 per cent in the United States. As a share of the rail transportation sector's total capital stock, ICT capital comprised 2.0 per cent in Canada versus 0.4 per cent in the United States.

Capital intensity in Canadian rail transportation was $11,402 per worker in 2010, 1.4 times that of its United States counterpart, $7,324. The ICT capital stock of rail transportation was 2.4 times that of the business sector in 2010. For the United States this figure was 64 per cent. In terms of growth, the Canadian figure increased by 128.5 percentage points between 1981 and 2010, while the American figure declined by 4.4 percentage points.

Table 6: ICT Capital Stock, Rail Transportation, Canada-US Comparison, Levels, Growth, and Changes, 2010 or most recent year

	Levels		Growth or Absolute Change		
	Canada	US	Canada	US	Period
Capital Stock, millions domestic	484	1,574	6.0	1.3	1981-2010
Share of Rail Transportation's Value-Added	6.3	2.5	-0.3	-5.6	1999-2008
Share of Business Sector ICT Capital Stock	0.6	0.1	0.0	-0.4	1981-2010
Share of Rail Transportation's Total Investment	2.0	0.4	1.4	-0.1	1981-2010
Capital Intensity (Absolute), USD at PPP	11,402	7,324	8.9	-0.3	1990-2010
Capital Intensity (Relative to US), USD at PPP	135.4	100.0	129.6	na	1991-2010
Capital Intensity (Relative to Business Sector)	240.9	64.1	128.5	-4.4	1997-2010

Notes: Capital stock in $millions. Growth in terms of average annual growth rates. 1981-2010 or longest period available. Changes for shares and relatives use absolute change.

Source: Appendix Tables 3a, 3c, 3d, 3e, 3h, 3i, 7a, 7c, 7d, 7e, 7h, 7i, 9e

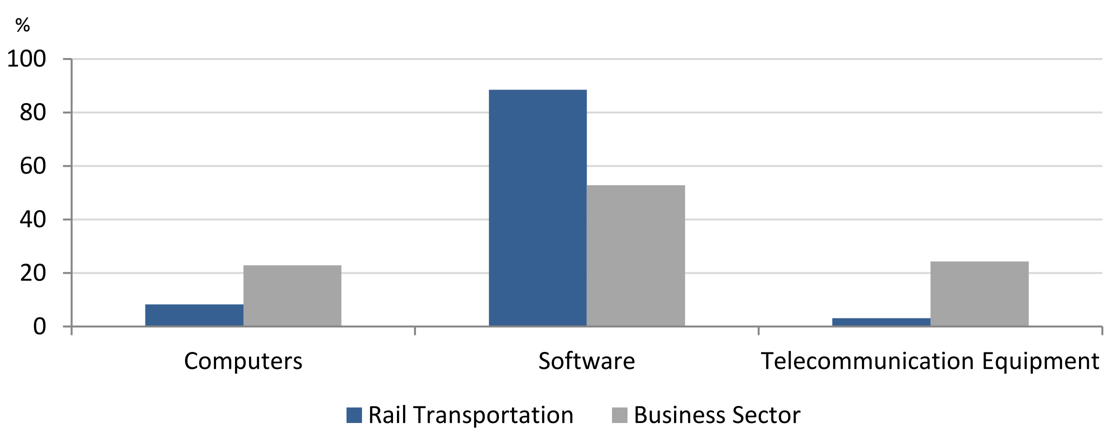
v. Current Dollar Capital Stock by Component

This section provides trend and cross-sectional analysis of the ICT capital stock in rail transportation in terms of the components of ICT. Comparisons are made to the Canadian business sector and rail transportation in the United States. All figures are expressed in current dollars.

In relative terms, a large majority of the ICT capital stock in rail transportation in 2010 was comprised by software, which accounted for 89.0 per cent of total ICT investment in the sector (Chart 42). This reflects the pattern seen for ICT investment in the sector. Computers and telecommunications equipment played a smaller role, accounting for 8.3 and 3.2 per cent, respectively. The relative importance of each ICT component was similar in the business sector, in which software also accounted for the majority of the ICT capital stock. It is notable that the share of software capital stock is disproportionately greater in rail transportation than it is in the business sector.

Software has been the largest component of the ICT capital stock in rail transportation historically, having grown significantly while computer and telecommunications capital has decreased (Chart 43). Between 1981 and 2010, the share of total ICT investment attributable to software increased by 71 percentage points. For computers and software, the shares for these components decreased by 58 percentage points and 13 percentage points over this same period. In the business sector, the share of software capital grew by 41 percentage points over this period and the share of telecommunications capital fell by 43 percentage points. The trend for computers differed between rail transportation and the business sector, as the share of total ICT capital comprised by computers in the business sector grew by 2.3 percentage points between 1981 and 2010.

Chart 42: Nominal ICT Capital Stock, as a Share of Sector's Total ICT Capital Stock, by Component, Rail Transportation and the Business Sector, Canada, 2010

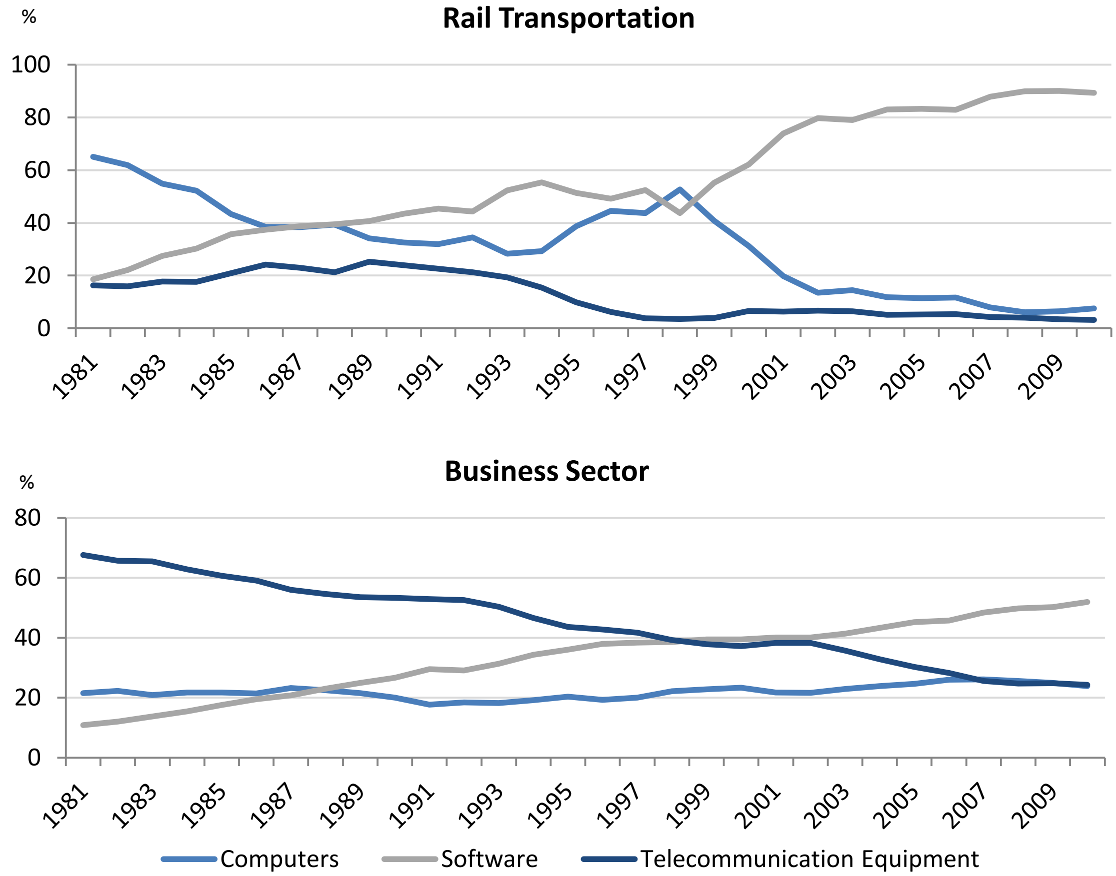


Source: Appendix Table 3f

As a share of the sector's total non-residential capital stock, computers and telecommunications equipment have declined between 1981 and 2010, while the share attributable to software has increased substantially (Chart 44). During this period, the share of total investment comprised by computers fell by 0.3 percentage points and the share for telecommunications fell by 0.1 percentage points. For software, the share has increased significantly, increasing by 1.7 percentage points between 1981 and 2010.

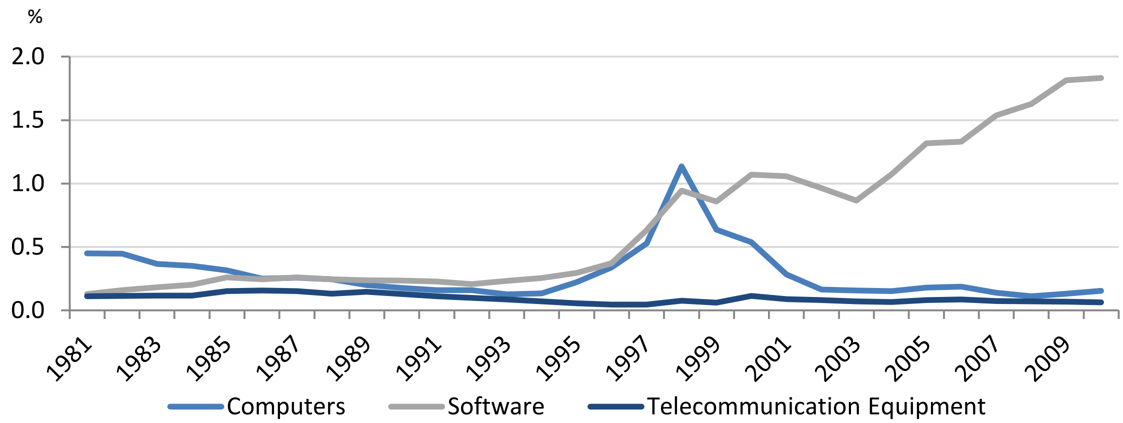
In 2010, ICT capital intensity for two of three ICT components was lower in rail transportation than in the business sector (Chart 45). For computers, capital intensity in rail transportation was $985 per worker in 2010, about 76 per cent of business sector computer capital intensity, which was $1,297 per worker. For telecommunications, this figure was $414 per worker, less than half of that of the business sector, which was $1,319 per worker. For software, capital intensity in rail transportation was 4.2 times that of the business sector, $11,707 per worker versus $2,823 per worker.

Chart 43: Nominal ICT Capital Stock by Component, as a Share of the Sector's Total ICT Capital Stock, Rail Transportation and the Business Sector, Canada, 1981-2010



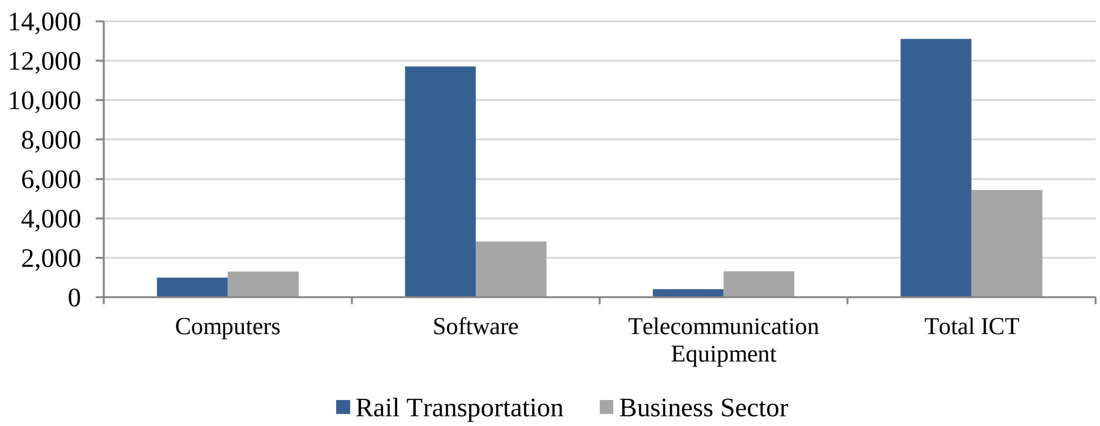
Source: Appendix Table 3f

Chart 44: Nominal ICT Capital Stock, as a Share of Sector's Total Non-Residential Fixed Capital Stock, by Component, Rail Transportation, Canada, 1981-2010



Source: Appendix Table 3d

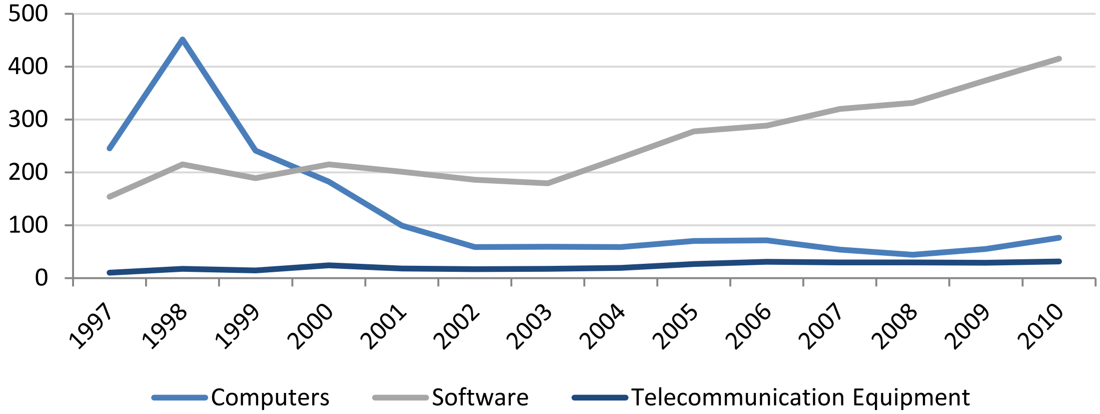
Chart 45: ICT Capital Intensity (Nominal Capital Stock per Worker) Rail Transportation and the Business Sector, by Component, Rail Transportation, Canada, 2010



Source: Appendix Table 3h

Historically, ICT capital intensity in rail transportation relative to the business sector has fallen for computers between 1997 and 2010, while it has increased for software and telecommunications (Chart 46). Over this period, capital intensity relative to the business sector for computers has decreased by 170 percentage points. For software and telecommunications, it has risen by 261 percentage points, respectively. Prior to 2001, capital intensity for computers was proportionately higher than for the business sector.

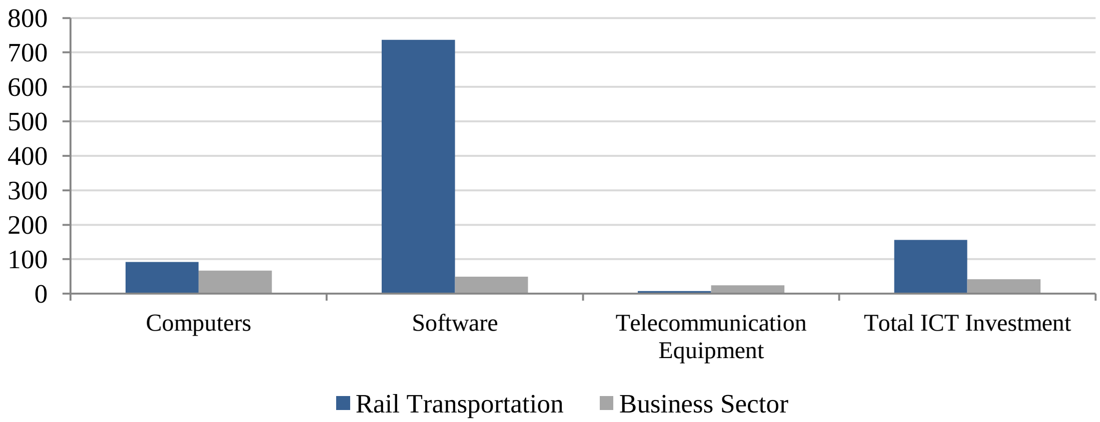
Chart 46: ICT Capital Intensity (Nominal Capital Stock per Worker) Relative to the Business Sector (Business Sector=100), by Component, Rail Transportation, Canada, 1997-2010



Source: Calculated from Appendix Table 3h

Relative to the United States, capital intensity for only one of the three ICT components in rail transportation compares favorably to its American counterpart, but two compare to the United States better than the business sector as a whole. Software capital intensity in rail transportation was 7.4 times higher than its American counterpart, while computer and telecommunications capital intensities were 92 per cent and 7 per cent. Only telecommunications in rail transportation was a relatively smaller share of its American counterpart than the business sector.[7]

Chart 47: ICT Capital Intensity (Nominal Capital Stock per Worker), PPP, Relative to the United States (US=100), Rail Transportation and the Business Sector, Canada, 1997-2010



Source: Appendix Table 9e

[7] For telecommunications, ICT capital intensity is substantially low compared to the U.S. figure. This may reflect different definitions of telecommunications being employed by the BEA and Statistics Canada.

C. Summary

i. Air transport

Most ICT indicators in this report suggest the air and rail transportation subsectors in Canada compare favorably to the business sector. It is crucial to recognize, however that the composition of ICT capital and total capital stock in these sectors differs from that of the Canadian business sector.

Nominal ICT investment in air transportation grew at a slower pace than in the business sector between 1981 and 2010 (5.9 per cent per year versus 6.7 per cent per year). In spite of this, ICT investment in air transportation as a share of value added remains proportionately larger than in the business sector, a situation that has persisted for over a decade. As a component of the sector's total investment, ICT investment has traditionally been low in air transportation in comparison to the business sector, but substantial growth in recent years has brought it to its highest level since 1986. ICT capital as a share of the sector's total capital stock has similarly increased, having kept pace with the business sector between 1981 and 2010.

ICT investment intensity in the air transportation sector has historically been higher than that of the business sector and remains so, despite declining in recent years from its historical peak in 2004.

In terms of the relative importance of the three ICT components, there are noticeable differences between air transportation and the business sector. Telecommunications comprises a much larger share of total ICT investment in air transportation than in the business sector as does software.

Historically, there have been similar trends in air transportation and the business sector in terms of the composition of ICT investment, with software becoming a more important component and computers becoming a less important component between 1981 and 2010.

In 2010, both investment and capital intensity in air transportation were higher for computers, software and total ICT than in the business sector. Telecommunications investment intensity was slightly less in air transportation than in the business sector. Since 1981, investment intensity relative to the business sector has declined for each component of ICT.

ii. Rail transport

ICT investment in rail transportation grew slower than in the business sector between 1981 and 2010. ICT capital stock growth in rail transportation did keep pace with the business sector between 1981 and 2010, with both averaging annual growth rates of about 6 per cent.

ICT investment in rail transportation comprised less than 1 per cent of business sector ICT investment in 2010, having fallen since 1981. In proportion to the sector's value added, ICT investment is relatively large in rail transportation compared to the business sector. Though the ICT capital stock in rail transportation has traditionally been small relative to the sector's value added in comparison to the business sector, the most recent data demonstrates that this trend has recently reversed. For the rail transportation sector, the ICT share of total capital has historically been lower than in the business sector, with a difference between shares being approximately 4 percentage points on average between 1981 and 2010.

ICT investment intensity in rail transportation in 2010 was twice as high as the business sector, having grown significantly since the early 2000s.

In terms of composition, software investment represents a larger share of total ICT investment in rail transportation than in the business sector, while computers and telecommunications account for much smaller shares of total ICT investment than in the business sector as a whole. Historically, the role of software in rail transportation grew substantially between 1981 and 2010, outpacing the business sector. Similarly, the importance of computers in rail transportation fell over this period significantly more than it did in the business sector. Telecommunications has waned in relative importance in both sectors, with rail transportation seeing a smaller decline than in the business sector.

ICT investment intensity for software was substantially higher in rail transportation than in the business sector in 2010, whereas it was significantly lower for telecommunications and comparable for computers. Historically, ICT investment intensity for software increased relative to the business sector between 1981 and 2010, whereas it declined for computers and remained relatively stagnant for telecommunications.

iii. Comparisons with the United States

Of the ICT indicators used in this report, some are particularly well-suited to making a comprehensive assessment of ICT usage, particularly for making comparisons between ICT performance in the air and rail transportation sectors in Canada and the United States. These seven indicators are:

- growth rates of ICT investment and ICT capital stock (nominal);
- growth rates of ICT investment and ICT capital stock (real);
- growth rates of ICT investment and ICT capital intensities (nominal);
- growth rates of ICT investment and ICT capital intensities (real);
- levels of ICT investment and ICT capital intensities (nominal);
- the share of the sector's total investment and capital stock comprised by ICT (nominal);
- the relative proportion of the sector's value added represented by ICT investment and ICT capital stock (nominal).

Exhibit 2 highlights these indicators for the air transportation subsector for Canada and the United States. The Canadian air transportation sector compares favorably to its American counterpart, with six of seven indicators for investment performing better in Canada than in the United States either in 2010 for levels or between 2000 and 2010 for growth rates. Only the share of the air transportation sector's total investment comprised by ICT investment was lower than that of the United States.

For ICT capital stock, Canada outperformed the United States in four of seven indicators, all of which are growth rates. This faster performance for growth compared to levels lead to an increase in the relative ICT investment intensity of Canadian air transportation, though the sector still lagged behind that of the United States in this indicator in 2010. Additionally, ICT capital stock is smaller in proportion to the air transportation sector's total capital stock and value added in Canada than in the United States.

Exhibit 3 provides a similar comparison of growth rates and levels for key indicators of ICT investment and capital stock in rail transportation. For rail transportation, Canada enjoys a superior performance relative to the United States for all indicators, both for growth and levels, investment and capital stock.

Rail transportation ICT investment in Canada grew faster than it did in the United States between 2000 and 2010. The same is true for ICT capital stock. In 2010, both ICT investment and ICT capital stock were proportionately larger compared to the rail transportation sector's total investment, capital stock and value added in Canada than in the United States. ICT investment and capital stock per worker in Canadian rail transportation were also larger than that of its American counterpart, suggesting ICT use is more prominent in Canada than the United States in this sector.

Exhibit 2: A Canada-U.S. Comparison of ICT Investment and Capital Stock in Air Transportation, Selected Indicators

ICT Investment		ICT Capital Stock	
Canada Outperforms US	US Outperforms Canada	Canada Outperforms US	US Outperforms Canada
Growth (2000-2010)			
• Nominal ICT Investment growth • Real ICT Investment growth • Nominal ICT Investment per worker growth • Real ICT Investment per worker growth		• Nominal ICT Capital Stock growth • Real ICT Capital Stock growth • Nominal Capital Stock per worker growth • Real ICT Capital Stock per worker growth	
Levels (2010)			
• Nominal ICT Investment as a Share of Value-Added • Nominal ICT Investment per Worker	• Nominal ICT Investment as a Share of Sector's Total Investment		• Nominal ICT Capital Stock as a Share of Value-Added • Nominal ICT Capital Stock as a Share of Sector's Total Capital Stock, • Nominal ICT Capital Stock per Worker

Source: Appendix Tables 1a, 1d, 1e, 1i, 2a, 2d, 3a, 3c, 3d, 3h, 4a, 4d, 5a, 5d, 5e, 5i, 6a, 6d, 7a, 7c, 7d, 7h, 8a, 8d

Exhibit 3: A Canada-US Comparison of ICT Investment and Capital Stock in Rail Transportation, Selected indicators

ICT Investment		ICT Capital Stock	
Canada Outperforms US	US Outperforms Canada	Canada Outperforms US	US Outperforms Canada
Growth (2000-2010)			
• Nominal ICT Investment growth • Real ICT Investment growth • Nominal ICT Investment per worker growth • Real ICT Investment per worker growth		• Nominal ICT Capital Stock growth • Real ICT Capital Stock growth • Nominal ICT Capital Stock per worker growth • Real ICT Capital Stock per worker growth	
Levels (2010)			
• Nominal ICT Investment as a Share of Value-Added • Nominal ICT Investment as a Share of Sector's Total • Nominal ICT Investment per Worker		• Nominal ICT Capital Stock as a Share of Value-Added • Nominal ICT Capital Stock as a Share of Sector's Total Capital Stock • Nominal ICT Capital Stock per Worker	

Source: Appendix Tables 1a, 1d, 1e, 1i, 2a, 2d, 3a, 3c, 3d, 3h, 4a, 4d, 5a, 5d, 5e, 5i, 6a, 6d, 7a, 7c, 7d, 7h, 8a, 8d

IV. Air and Rail Transportation Productivity

This section of the report provides a detailed examination of labour and multifactor productivity trends in Canadian air and rail transportation during the 1997-2010 period, with the productivity performance of the business sector serving as a benchmark. Before analyzing the evolution of air and rail transportation productivity in recent years, it is important to look at the underlying data used to construct these estimates, namely GDP (at basic prices) and hours worked (capital stock data were analyzed in the previous section).

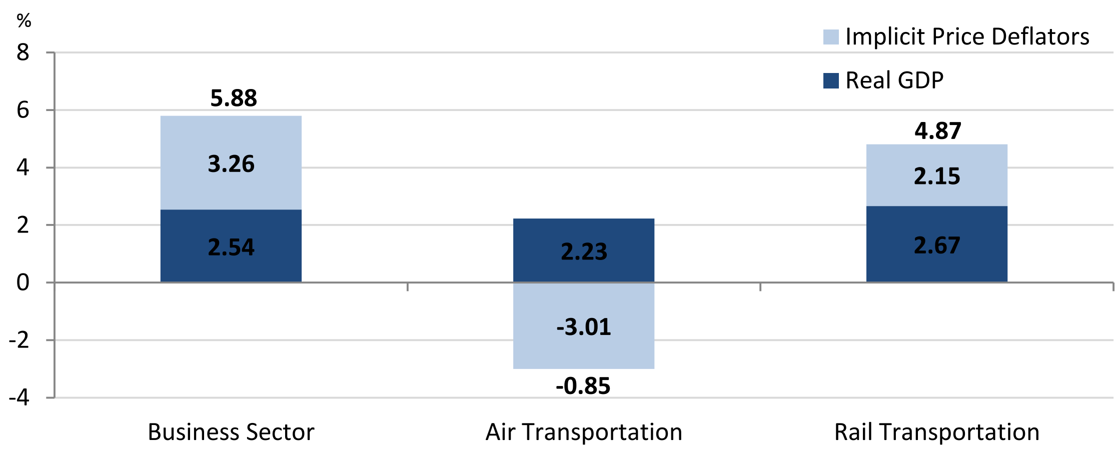
A. GDP

In this subsection, we look at nominal GDP, real GDP, and implicit price deflator estimates for Canadian air and rail transportation during the 1999-2008 period (real GDP estimates are available for the 1997-2010 period).

i. Nominal GDP

Nominal GDP in air transportation declined at a compound annual rate of 0.85 per cent per year during the 1999-2008 period, from $4,934 million in 1999 to $4,571 million in 2008. Meanwhile, nominal GDP in rail transportation grew 4.87 per cent per year, from $4,127 million to $6,331 million – a robust growth rate when compared to that of air transportation, but still below the growth rate observed in the Canadian business sector over the same period, 5.88 per cent per year (Chart 48).

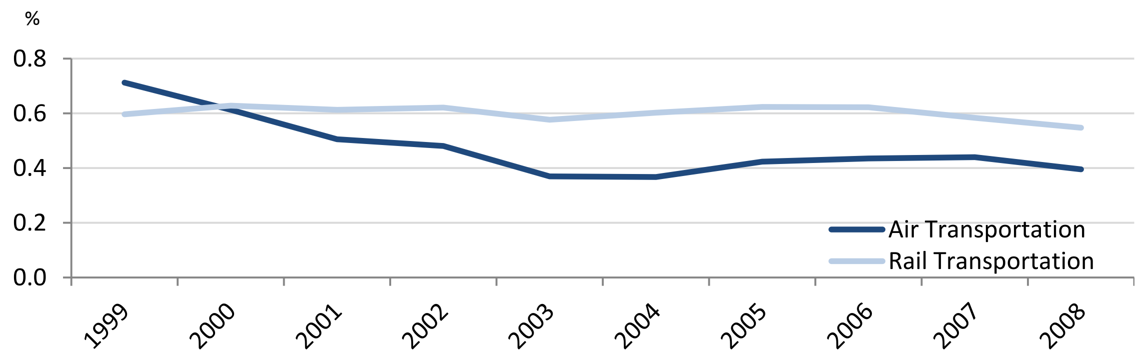
Chart 48: Nominal GDP Growth Breakdown in Air and Rail Transportation, Canada, 1999-2008 (Compound Annual Growth Rates)



Note: Contributions do not sum to total growth rates due to rounding.
Source: CSLS calculations based on Statistics Canada data: 1) Nominal GDP from the Input-Output Structure of the Canadian Economy at Current Prices (CANSIM Table 379-0023); 2) Real GDP from GDP by Industry (monthly) (CANSIM Table 379-0027).

Given the below average growth in both air and rail transportation, their importance as a share of business sector GDP declined, from 0.71 per cent to 0.40 per cent in the case of air transportation and 0.60 per cent to 0.55 per cent in the case of rail transportation (Chart 49).

Chart 49: Nominal GDP in Air and Rail Transportation as a Share of Business Sector GDP, Canada, 1999-2008

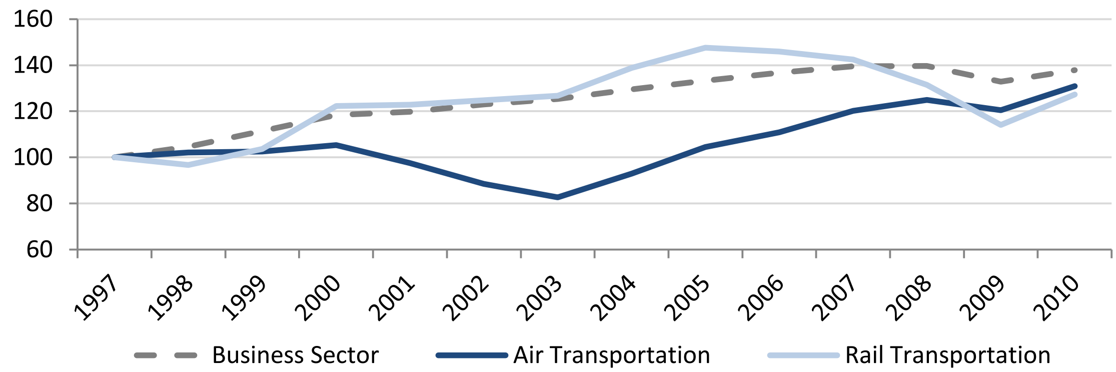


Source: CSLS calculations based on Statistics Canada data, Real GDP from GDP by Industry (monthly) (CANSIM Table 379-0027).

ii. Real GDP

Real GDP in air transportation increased at a compound annual rate of 2.09 per cent during the 1997-2010 period, slightly higher than real GDP growth in rail transportation, 1.88 per cent, but below the average growth observed in the business sector as a whole (2.50 per cent) (Table 7, Chart 50). During the period, real GDP in air transportation increased from $4,433 million (chained 2002 dollars) in 1997 to $5,802 million in 2010, while real GDP in rail transportation went from $4,066 million to $5,178 million.

Chart 50: Real GDP Growth in Air and Rail Transportation, Canada, 1997-2010 (1997=100)



Source: CSLS calculations based on Statistics Canada data, Real GDP from GDP by Industry (monthly) (CANSIM Table 379-0027).

Table 7: Real GDP in Air and Rail Transportation, Canada, 1997-2010

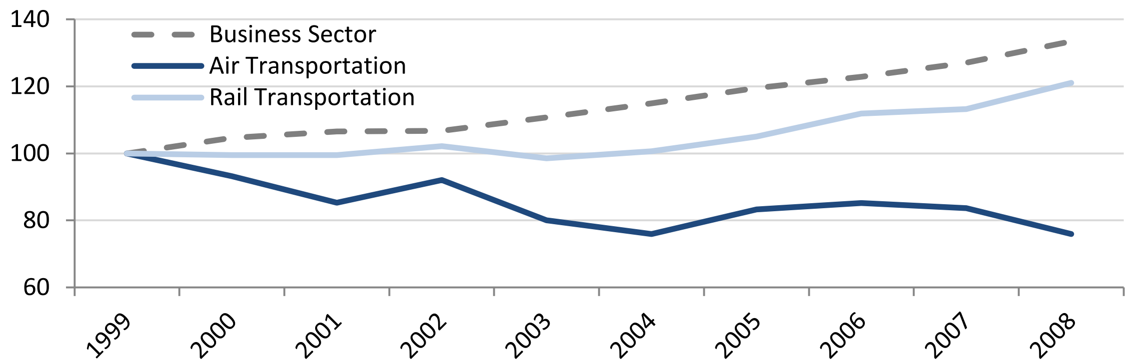
	1997-2010	1997-2000	2000-2010
	(compound Annual Growth Rates, per cent)		
Business Sector	2.50	5.80	1.53
Air Transportation	2.09	1.75	2.19
Rail Transportation	1.88	6.92	0.41
	1997	2000	2010
	(millions, chained 2002 dollars)		
Business Sector	662,924	785,154	913,621
Air Transportation	4,433	4,670	5,802
Rail Transportation	4,066	4,970	5,178

Source: Statistics Canada data, Real GDP from GDP by Industry (monthly) (CANSIM Table 379-0027).

iii. Implicit Price Deflators

While business sector prices increased at a rate of 3.26 per cent per year during the 1999-2008 period, the implicit price deflator for air transportation declined sharply, at a rate of 3.01 per cent per year, and rail transportation prices increased only 2.15 per cent per year (Chart 51).

Chart 51: Implicit Price Deflators for Air and Rail Transportation, Canada, 1999-2008 (1999=100)



Source: CSLS calculations based on Statistics Canada data.

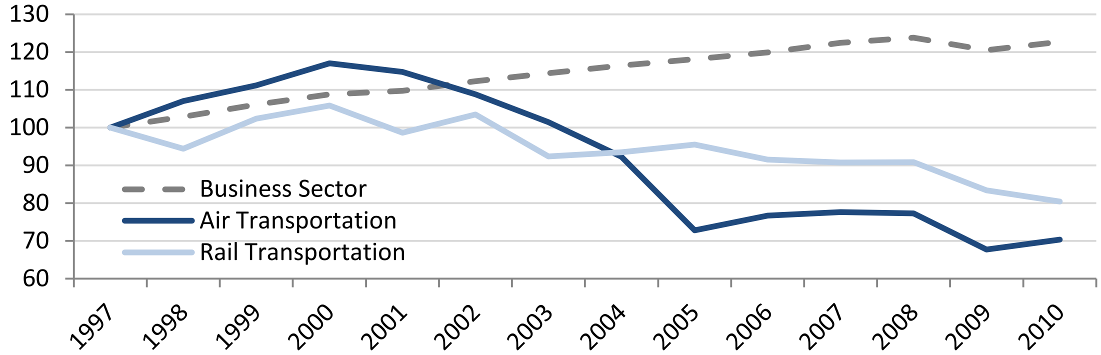
B. Labour Input

In this section, we analyze labour input trends in Canadian air and rail transportation, and compare them to trends observed at the business sector level. We start our discussion by looking at the evolution of employment in air and rail transportation during the 1997-2010 period. Next, we look at average weekly hours worked, total hours worked, and labour compensation as a share of nominal GDP.

i. Number of Jobs

In 2010, the air transportation subsector employed 42 thousand people, 29.6 per cent less than the number observed in 1997, 60 thousand (Chart 52). The loss of jobs in air transportation happened primarily between 2001 and 2005. The rail transportation subsector also shed a considerable numbers of jobs in the period and went from 47 thousand people in 1997 to 38 thousand in 2010, a decline of 19.6 per cent. During the period, business sector employment rose 22.7 per cent, from 11.2 million to 13.7 million.

Chart 52: Number of Jobs in Air and Rail Transportation, Canada, 1997-2010 (1999=100.0)

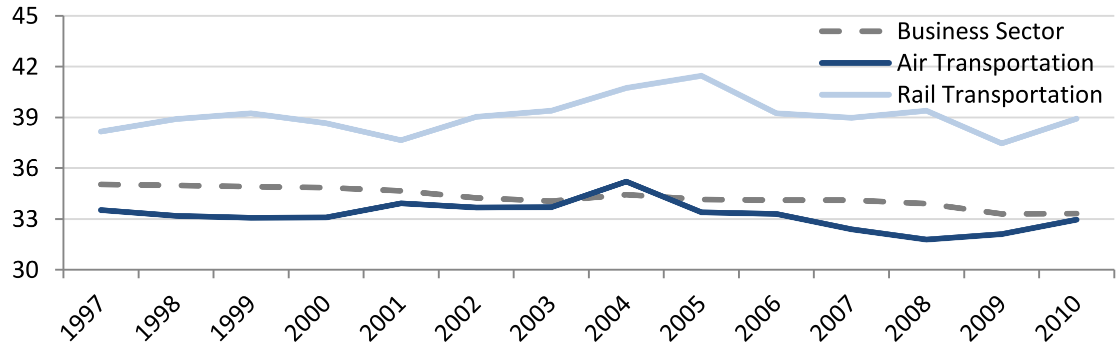


Source: CSLS calculations based on Statistics Canada, Canadian Productivity Accounts (CANSIM Table 383-0010).

ii. Average Weekly Hours Worked

The average work week in rail transportation was significantly longer than that of air transportation throughout the entire 1997-2010 period (Chart 53). In rail transportation, the duration of the work week increased from 38.2 hours in 1997 to 38.9 hours in 2010, while in air transportation it decreased slightly from 33.5 hours in 1997 to 33.0 hours in 2010. Looking at the business sector as a whole, there was a reduction in the duration of the work week, from 35.0 hours in 1997 to 33.3 hours in 2010.

Chart 53: Average Weekly Hours Worked per Worker in Air and Rail transportation, Canada, 1997-2010

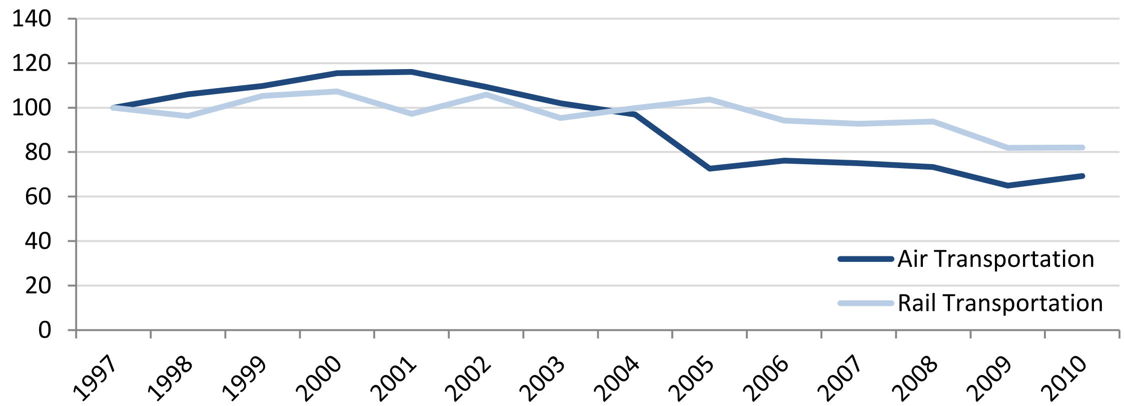


Source: CSLS calculations based on Statistics Canada, Canadian Productivity Accounts (CANSIM Table 383-0010).

iii. Hours Worked

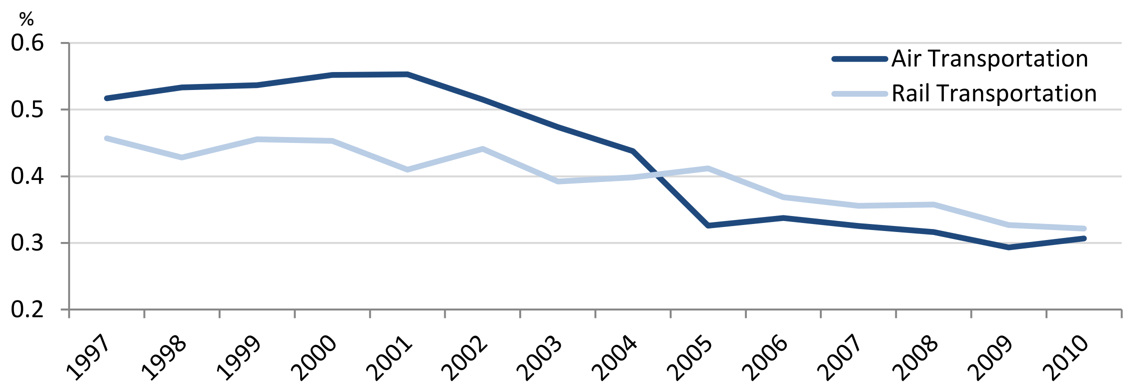
Total hours worked in the air transportation subsector declined 2.79 per cent per year during the 1997-2010 period, from 105 million in 1997 to 73 million in 2010 (Chart 54). The decline was particularly marked during the 2001-2005 period. Rail transportation also saw a significant drop of 1.51 per cent per year in total hours worked, from 93 million to 76 million. During the 1997-2010 period, since hours worked in the business sector actually increased (1.19 per cent per year), there was a marked drop in the importance of air and rail transportation as a share of total hours worked in the business sector (Chart 55).

Chart 54: Hours Worked in Air and Rail Transportation, Canada, 1997-2010 (1997=100.0)



Source: CSLS calculations based on Statistics Canada, Canadian Productivity Accounts (CANSIM Table 383-0010).

Chart 55: Hours Worked in Air and Rail Transportation as a Share of the Business Sector, Canada, 1997-2010



Source: CSLS calculations based on Statistics Canada, Canadian Productivity Accounts (CANSIM Table 383-0010).

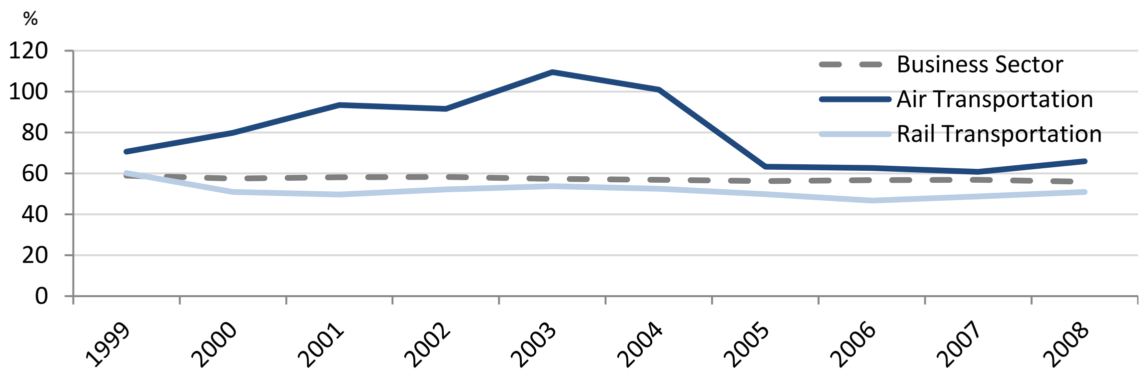
iv. Labour Compensation Share

Another important issue related to the use of labour input has to do with how much of nominal GDP goes to labour compensation (as opposed to capital compensation). The labour compensation share of rail transportation declined from 60.1 per cent in 1999 to 50.9 per cent in 2008.

Overall, the fluctuations seen in the labour compensation share of rail transportation were minor when compared to those observed in air transportation. From 1999 to 2003, the labour compensation share in air transportation increased dramatically, from 70.6 per cent to 109.4 per cent. In 2004, although the subsector's labour compensation was still above 100.0 per cent, it started to drop until it reached 65.9 per cent in 2008. The labour compensation shares above 100.0 per cent in 2003 and 2004 imply that the air transportation sector as a whole had negative capital compensation during the period.

Throughout the entire period, the labour compensation share of the business sector declined consistently, from 58.8 per cent in 1999 to 55.9 per cent in 2008. The labour compensation share of rail transportation remained below that of the business sector for most of the period (with the exception of 1999), while the opposite is true for air transportation.

Chart 56: Labour Compensation as a Share of Nominal GDP in Air and Rail Transportation, Canada, 1997-2010



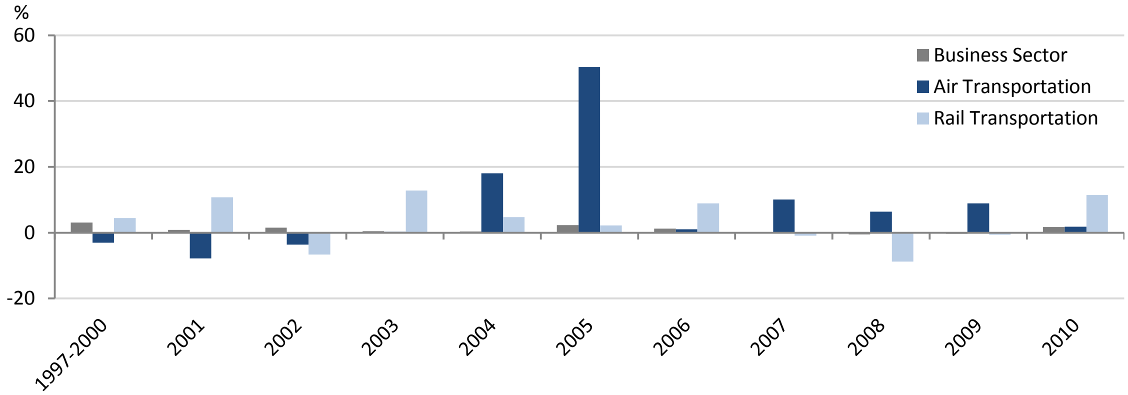
Source: CSLS calculations based on Statistics Canada, Canadian Productivity Accounts (CANSIM Table 383-0010).

C. Labour Productivity

Labour productivity, defined here as real GDP per hour worked, grew at very robust rates in both air transportation (5.02 per cent per year) and rail transportation (3.44 per cent per year) during the 1997-2010 period. Meanwhile, business sector productivity increased at the very modest pace of 1.29 per cent per year.

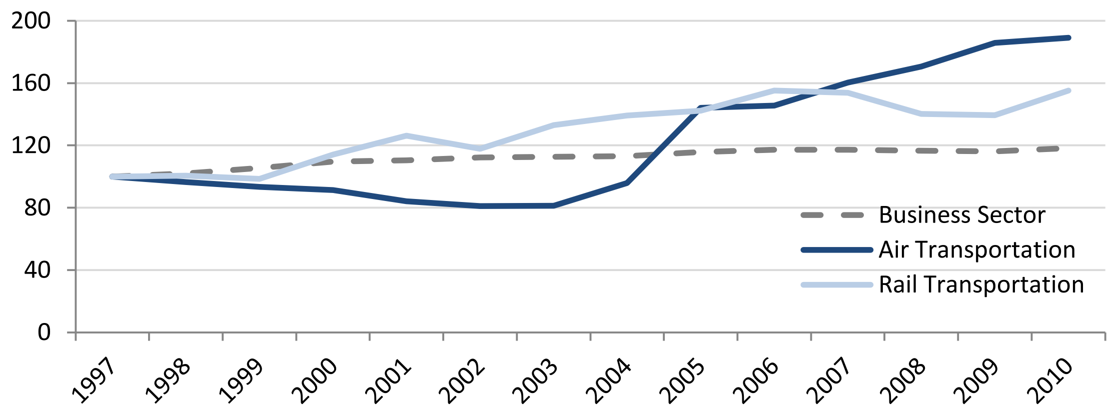
It is interesting to note that, while productivity gains in rail transportation were somewhat concentrated in the pre-2006 period, productivity gains in air transportation were concentrated in the post-2003 period, especially in 2004 and 2005, when productivity in the subsector increased 18.1 per cent and 50.3 per cent, respectively (Chart 57, Chart 58).

Chart 57: Labour Productivity Growth in Air and Rail Transportation, Canada, 1997-2010



Source: CSLS calculations based on Statistics Canada: 1) Real GDP from GDP by Industry (monthly) (CANSIM Table 379-0027); 2) Hours worked from the Canadian Productivity Accounts (CANSIM Table 383-0010).

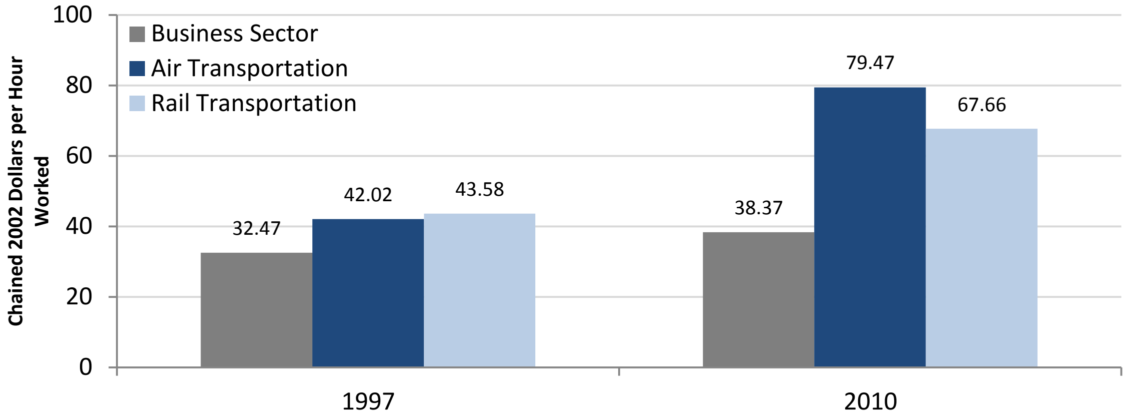
Chart 58: Labour Productivity Growth in Air and Rail Transportation, Canada, 1997-2010 (Index, 1997=100.0)



Source: CSLS calculations based on Statistics Canada: 1) Real GDP from GDP by Industry (monthly) (CANSIM Table 379-0027); 2) Hours worked from the Canadian Productivity Accounts (CANSIM Table 383-0010).

Both air and rail transportation had labour productivity levels above that of the business sector during the entire period. Due to the rapid productivity growth in the two transportation subsectors, however, the level difference with the business sector has increased substantially over the years. In 1997, labour productivity levels in air and rail transportation were $42.02 (chained 2002 dollars) per hour and $43.58 per hour (respectively), while the business sector labour productivity level was $32.47 per hour. By 2010, labour productivity in air and rail transportation had risen to $79.47 (chained 2002 per hour) per hour and $67.66 per hour (respectively), with business sector labour productivity at $38.37 per hour.

Chart 59: Labour Productivity Levels in Air and Rail Transportation, Canada, 1997 and 2010 (chained 2002 dollars per hour worked)



Source: CSLS calculations based on Statistics Canada: 1) Real GDP from GDP by Industry (monthly) (CANSIM Table 379-0027); 2) Hours worked from the Canadian Productivity Accounts (CANSIM Table 383-0010).

Table 8 summarizes the main points previously discussed regarding labour productivity growth rates and levels in Canadian air and rail transportation. In addition, this table provides relative labour productivity levels, i.e. air and rail productivity levels as a per cent of the business sector level.

Table 8: Labour Productivity in Air and Rail Transportation, Canada, 1997-2010

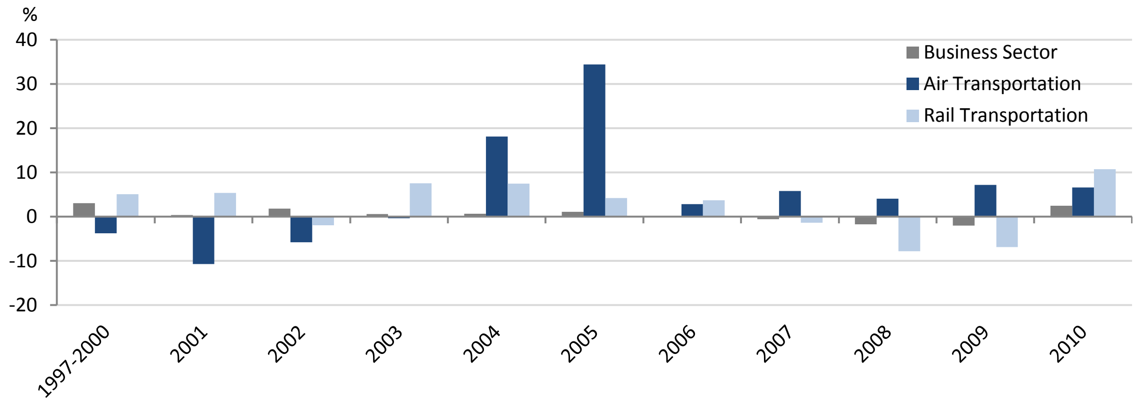
	1997-2010	1997-2000	2000-2010
	(compound annual growth rates, per cent)		
Business Sector	1.29	3.07	0.76
Air Transportation	5.02	-3.02	7.56
Rail Transportation	3.44	4.47	3.14
	1997	2000	2010
	(chained 2002 dollars per hour worked)		
Business Sector	32.47	35.55	38.37
Air Transportation	42.02	38.33	79.47
Rail Transportation	43.58	49.69	67.66
	1997	2000	2010
	(as a per cent of the Business Sector)		
Business Sector	100.0	100.0	100.0
Air Transportation	129.4	107.8	207.1
Rail Transportation	134.2	139.7	176.3

Source: CSLS calculations based on Statistics Canada: 1) Real GDP from GDP by Industry (monthly) (CANSIM Table 379-0027); 2) Hours worked from the Canadian Productivity Accounts (CANSIM Table 383-0010).

D. Multifactor Productivity

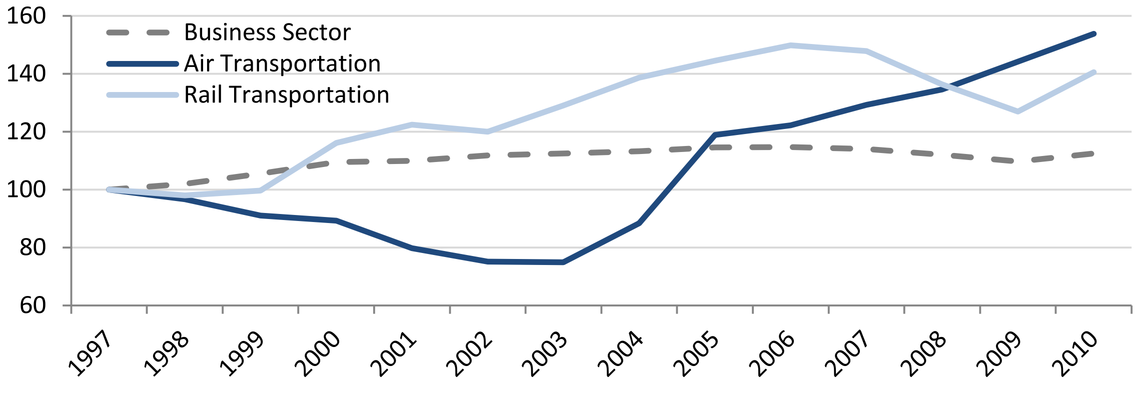
Multifactor productivity[8] growth in both air and rail transportation was well above that of the Canadian business sector during the 1997-2010 period. MFP in air transportation increased 3.40 per cent per year, while in rail transportation it increased 2.68 per cent per year. Meanwhile, business sector MFP rose only 0.93 per cent per year. Much like the trends observed in labour productivity, MFP growth was concentrated in the post-2003 period for air transportation and in the pre-2006 period for rail transportation (Chart 60, Chart 61).

Chart 60: Multifactor Productivity Growth in Air and Rail Transportation, Canada, 1997-2010



Source: CSLS calculations based on Statistics Canada data.

Chart 61: Multifactor Productivity Growth in Air and Rail Transportation, Canada, 1997-2010 (Index, 1997=100.0)



Source: CSLS calculations based on Statistics Canada data.

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[8] The MFP estimates presented here were calculated by the CSLS (no official estimates for air and rail transportation were available from Statistics Canada). The CSLS MFP estimates differ from Statistics Canada's in that they embody changes in both labour quality and capital composition. As a consequence, CSLS estimates tend to yield growth rates substantially higher than that of the official estimates. Although official MFP estimates for the business sector are available, the CSLS ones are used in this report for consistency. According to Statistics Canada's estimates, MFP growth in the business sector was zero during the 1997-2010 period.

V. Measuring the Impact of ICT on Productivity: Methodology Overview and Literature Review

Twenty five years ago, Robert Solow remarked that "you can see the computer age everywhere but in the productivity statistics" (Solow, 1987). Since then, several different techniques and methodologies, with varying degrees of complexity, have been developed in an effort to understand and quantify the links between ICT and productivity growth. This section of the report provides an overview of these methodologies, their limitations, and estimation results. It should be noted, however, that we do not provide an exhaustive literature review of the topic.[9] Rather, the focus of the section is on the main findings of the more recent literature.

Studies that analyze the links between ICT and productivity growth can generally be divided into three groups:

- Growth accounting studies;
- Econometric studies;
- Case studies.

Readers should bear in mind that, *stricto sensu*, this breakdown is artificial. Growth accounting studies often use econometrics techniques in a supporting role. Econometric studies, on the other hand, frequently rely on basic assumptions of the neo-classical growth accounting and use growth accounting results as a starting point. Both types of studies can make use of case studies to emphasize a particular issue. This categorization can, however, help us develop a good understanding of the main findings in the literature by emphasizing certain commonalities in the studies.

While case studies refer to the impact of ICT investment in the production process of a particular firm or industry, growth accounting studies generally refer to the aggregate economy level (either business sector or total economy) or to the industry level. Although econometric studies can also refer to the aggregate economy level, they tend to deal with the productivity impact of ICT either at the firm level or at the industry level.

This section of the report is divided into three subsections. First, we discuss the main aspects of growth accounting studies, describing the basic neoclassical framework and

[9] For a reasonably recent and very technical literature review, see Draca *et al.* (2006). For non-technical literature reviews, refer to Sharpe (2006) and Cavusoglu *et al.* (2011). OECD (2004) provides a thorough discussion of the various (theoretical) channels through which ICT can impact the economy, along with a discussion of how to measure the ICT contribution to economic growth and the evidence up to that point.

highlighting estimation results for Canada, the United States, and Europe. Next, econometric studies are analyzed. Two common types of econometric models used to estimate the impact of ICT on productivity are described, and the main conclusions of the literature discussed. Finally, selected case studies are reviewed. Throughout the section, we emphasize the different theoretical and empirical links between ICT and productivity. Furthermore, whenever possible, we examine studies that look into how ICT impacts productivity in air and rail transportation.

A. Growth Accounting Studies

In this subsection, we analyze how growth accounting studies measure the link between ICT and productivity growth. We start with an exposition of the basic neo-classical growth accounting framework. This is followed by a review of the main conclusions of the growth accounting literature. Finally, we look into the limitations of the growth accounting methodology.

i. Basic Framework

The standard neo-classical framework assumes a production function F(.) which combines inputs and transforms them into output (Y). In a value-added framework,[10] inputs generally include labour (L), non-ICT capital (K), and ICT capital (C), such that:

$$Y_t = A_t F(L_t, K_t, C_t) \tag{1}$$

where A represents multifactor productivity.

A common functional form used in growth accounting exercises is the Cobb-Douglas form, such that the above expression becomes:

$$Y_t = A_t L_t^{\alpha} K_t^{\beta} C_t^{\gamma} \tag{2}$$

where the coefficients α, β and γ indicate the output elasticity with respect to labour, non-ICT capital, and ICT capital (respectively). [11]

[10] Our focus in this subsection is on value-added labour productivity instead of gross-output labour productivity. The former tends to be the preferred productivity measure when discussing the aggregate economy or when conducting inter-industry comparisons because it avoids the double-counting of output. The labour productivity decomposition shown in this section can be extended without loss of generality to the gross-output case by adding one more input, materials (M), to the production function (see Draca *et al.*, 2006).

[11] The output elasticity with respect to a certain input measures the per cent change in output given a one percent change in that particular input. In other words: how much does output increase if we increase the use of a particular input by one per cent? Intuitively, the coefficients α, β, and γ reflect the importance of each input in the production process.

Since labour productivity is output per unit of labour input, we divide both sides of (2) by *L*:

$$\frac{Y_t}{L_t} = \frac{A_t L_t^{\alpha} K_t^{\beta} C_t^{\gamma}}{L_t} \tag{3}$$

Assuming constant returns to scale (such that $\alpha + \beta + \gamma = 1$) and taking the natural logarithms of both sides of equation (3), we have that:

$$lp_t = (y_t - l_t) = a_t + \beta(k_t - l_t) + \gamma(c_t - l_t) \tag{4}$$

where lower case letters denote the natural logarithm of the original variable (e.g. $y = lnY$) and lp_t denotes the natural logarithm of labour productivity.

Thus, labour productivity growth from period *t-1* to period *t* will be:

$$\Delta lp = \Delta(y - l) = \Delta a + \beta\Delta(k - l) + \gamma\Delta(c - l) \tag{5}$$

where Δ indicates the change in the variables between periods *t* and *t-1*.

Equation (5) decomposes labour productivity growth into three components: 1) multifactor productivity growth, 2) non-ICT capital growth that exceeds labour input growth (weighted by the coefficient β); and 3) ICT capital growth that exceeds labour input growth (weighted by the coefficient γ). It is clear, therefore, that what matters for productivity growth is not capital stock growth *per se* (be it non-ICT or ICT), but capital stock growth in excess of labour input growth. In other words, what matters for productivity growth is *capital intensity* growth (defined here as capital per unit of labour input). Increased capital intensity indicates *capital deepening*, i.e. workers have more capital to work with.

If we assume, additionally, that factor and product markets are perfectly competitive, the coefficients α, β, and γ become equal to the (nominal) compensation shares of labour, non-ICT capital, and ICT capital (respectively) in output. The compensation share of ICT capital, for instance, is the user cost[12] of ICT capital multiplied by the quantity of ICT capital and divided by nominal output.[13] In this case, ICT would contribute to labour productivity through increased

[12] Just as wages are the price of labour, the user cost of capital (also known as rental price of capital) is the price of capital services. It can be seen as an "implicit rent that capital good owners 'pay' themselves" (OECD, 2001:52). Under perfect competition, user costs reflect the marginal productivity of different capital assets.

[13] Analogously, the compensation share of non-ICT capital is the user cost of non-ICT capital multiplied by the quantity of non-ICT capital and divided by nominal output, while the compensation share of labour is the average wage rate multiplied by the quantity of labour input and divided by nominal output.

ICT capital intensity, and the magnitude of the contribution would be equal to the compensation share of ICT capital times the growth rate differential between ICT capital and labour input.

At the aggregate economy level, the share of MFP growth driven by ICT-producing sectors is also part of the overall contribution of ICT to aggregate labour productivity growth (Jorgenson *et al.*, 2008). This component reflects, in large part, the rapid rate of technological progress experienced by ICT-producing sectors in the last decades, during which the quality of ICT equipment rose drastically, at the same time as relative prices fell.[14]

Alternatively, the contribution of ICT to labour productivity can also be approached from an industry perspective, looking at the role of various industries in driving aggregate productivity growth, with a special focus on ICT-producing industries. This approach – seen, for instance, in Someshwar and Tang (2001) and Van Ark *et al.* (2003) – complements the traditional growth accounting framework that decomposes labour productivity growth into the contributions of ICT capital intensity, non-ICT capital intensity, and MFP.

ii. Main Results in the Growth Accounting Literature

Overall, the growth accounting literature seems to point to the following macro results:

United States

ICT played a major role in the acceleration of labour productivity growth in the United States in the post-1995 period, especially in the 1995-2000 period (see Oliner and Sichel, 2002,[15] Jorgenson *et al.*, 2008, and Basu and Fernald, 2008). According to Jorgenson *et al.*, U.S. labour productivity grew at an average annual rate of 1.49 per cent per year during the 1973-1995 period, 0.65 percentage points (43 per cent of total growth) of which can be attributed to ICT (Table 9).[16] In the 1995-2000 period, labour productivity growth rose to 2.70 per cent per year, with the contribution of ICT increasing to 1.59 percentage points (59 per cent of total growth). Of the total ICT contribution, 1.01 percentage points were due to increased ICT capital intensity. An important reason for the increase in ICT capital intensity was the fall in ICT (relative) prices, which induced firms to substitute ICT capital for other inputs. During the 2000-2006 period, U.S. labour productivity growth dropped to 2.50 per cent per year, with the contribution of ICT to productivity (0.96 percentage points or 38 per cent of total productivity growth) declining considerably after the burst of the dot-com bubble. As Jorgenson *et al.* (2008:14) note, however:

[14] The dramatic improvement in ICT equipment technology has been epitomized by Moore's Law, which states that the number of transistors in a minimum cost integrated circuit board doubles every 18 months (Brynjolfsson and McAfee, 2011).

[15] The original Oliner and Sichel (2002) paper has labour productivity estimates up to (and including) 2001. Updated estimates by Oliner and Sichel, with data up to (and including) 2005, can be found in Gordon (2006).

[16] In Jorgenson *et al.* (2008), the total contribution of ICT to labour productivity growth takes into account not only ICT capital deepening, but also MFP growth in ICT-producing sectors.

> (…) information technology remains a substantial source of growth, even in the post-2000 period. Information technology investment is less than 5 percent of aggregate output, but (…) has accounted for one-third of the labor productivity growth since 2000. The declining contribution of information technology reflects a return to more sustainable growth rates after the information technology investment boom of the late 1990s.

The post-1995 period saw a substantial increase in MFP growth of non-ICT producing industries in the United States (Corrado *et al.*, 2006, and Bosworth and Triplett, 2007). MFP growth was particularly pronounced in industries that use ICT intensively, such as retail trade, wholesale trade, and finance (Basu *et al.*, 2008). Did ICT investment in these industries have anything to do with rising MFP growth? If so, what were the transmission mechanisms (this issue is further discussed in the next subsection)?

Table 9: Sources of Productivity Growth in the United States, 1973-2006 (average annual growth rates)

	1973-1995	1995-2000	2000-2006
Private Output	**3.08**	**4.77**	**3.01**
Hours Worked	1.59	2.07	0.51
Average Labour Productivity	1.49	2.70	2.50
Contribution of Capital Deepening	**0.85**	**1.51**	**1.26**
Information Technology	0.40	1.01	0.58
Non-Information Technology	0.45	0.49	0.69
Contribution of Labour Quality	**0.25**	**0.19**	**0.31**
Multifactor Productivity	**0.39**	**1.00**	**0.92**
Information Technology	0.25	0.58	0.38
Non-Information Technology	0.14	0.42	0.54
Share Attributed to Information Technology	**0.43**	**0.59**	**0.38**

Source: Jorgenson *et al.* (2008).

Europe

Labour productivity growth did not, however, accelerate in Europe after 1995. In fact, it slowed down in the EU-15 from 2.3 per cent per year during the 1987-1995 period to 1.8 per cent per year in the 1995-2000 period and 1.1 per cent per year in the 2000-2004 period (van Ark and Inklaar, 2005). Inklaar *et al.* (2005), Timmer and van Ark (2005), van Ark and Inklaar (2005), and Inklaar *et al.* (2008) investigate whether ICT had an important role in this productivity slowdown.

As was the case in the United States, the contribution of ICT capital deepening and ICT-production MFP also increased during the 1995-2000 period (from a total of 0.6 percentage points in the 1987-1995 period to 1.0 percentage point in the 1995-2000 period) (van Ark and Inklaar, 2005) (Table 10). This increase, however, was much less substantial than that of the U.S.

economy (partly due to lower ICT capital intensity levels in Europe), and not enough to offset the declining contribution of non-ICT capital deepening and non-ICT production MFP to aggregate productivity growth. In the 2000s, the contribution of ICT capital deepening and ICT-production MFP dropped markedly (to a total of 0.5 percentage points). This was also accompanied by a decline in non-ICT production MFP growth (from 0.4 percentage points in the 1995-2000 period to 0.0 percentage points in the post-2000 period). Van Ark and Inklaar suggest that the significant contribution of ICT to European labour productivity growth during the 1995-2000 period was caused by "hard savings" related to the use of ICT equipment. In contrast, the decline in the contribution of ICT to aggregate productivity post-2000 might reflect the difficulty of European firms in taking advantage of "soft savings" associated with ICT. [17]

Table 10: Sources of Productivity Growth in the EU-15, 1987-2004 (average annual growth rates)

	1987-1995	1995-2000	2000-2004
Aggregate Labour Productivity Growth	**2.3**	**1.8**	**1.1**
Contribution of Capital Deepening	**1.2**	**1.0**	**0.8**
ICT Capital Deepening	0.4	0.6	0.3
Non-ICT Capital Deepening	0.8	0.4	0.5
Multifactor Productivity	**1.1**	**0.8**	**0.2**
ICT-Production MFP	0.2	0.4	0.2
Non-ICT Production MFP	0.9	0.4	0.0
Share Attributed to ICT	**0.26**	**0.56**	**0.45**

Source: Van Ark and Inklaar (2008).

Inklaar *et al.* (2005) note that, in contrast with the United States, aggregate MFP growth in Europe did not accelerate significantly in the post-1995 period. The main reason behind this divergence was that MFP growth in Europe's ICT-using industries remained at its pre-1995 levels, while U.S. ICT-using industries experienced a major boost in MFP growth.

Inklaar *et al.* (2005) and Timmer and van Ark (2005) note that ICT alone cannot be seen as the main explanation of the growing U.S.-Europe productivity gap, highlighting the importance of institutional factors.

[17] The difference between "hard savings" and "soft savings" can be better understood with an example: "(…) in the retail industry, ICT investment had an immediate impact on productivity growth through hard savings. For example, the introduction of barcode scanning allowed for more efficient check-out systems without much further investment. However, the same barcode technology has enabled a reorganization of the supply chain and the introduction of new shopping concepts. These soft savings do not only require heavy investment in ICT, but also in newer complementary technologies (…) and organizational change (new shopping concepts, adjustment in the logistic chain of supplying the shops more frequently, etc.)" (Van Ark and Inklaar, 2005:15-16).

Canada

Much like in Europe, ICT use in Canada failed to generate the exceptional gains observed in the United States (Sharpe, 2006, and Dion, 2007). Dion (2007), using Statistics Canada data, shows that, from 1974 to 1997, ICT capital deepening accounted for 0.4 percentage points of the average annual labour productivity growth of 1.4 per cent per year observed in the Canadian economy. During the 1997-2000 period, productivity growth more than doubled, reaching 3.0 per cent per year, while the contribution of ICT capital increased to 0.7 percentage points, less than double of its original value. Labour productivity growth in Canada plummeted in the post-2000 period (1.0 per cent per year during the 2000-2005 period), largely because of a substantial decline in MFP growth, although the contribution of ICT capital deepening also went down, to 0.3 percentage points.

Table 11: Sources of Productivity Growth in Canada, 1987-2004 (average annual growth rates)

	1974-1996	1996-2000	2000-2005
Labour Productivity	**1.4**	**3.0**	**1.0**
Contribution of Capital Deepening	**1.1**	**1.0**	**0.7**
ICT Capital Deepening	0.4	0.7	0.3
Non-ICT Capital Deepening	0.7	0.4	0.4
Labour Quality	0.4	0.4	0.4
Multifactor Productivity	**0.0**	**1.6**	**-0.1**
Share Attributed to ICT	**0.29**	**0.23**	**0.30**

Note: Unlike Jorgenson *et al.* (2008) and Van Ark and Inklaar (2005), Dion (2007) does not include in the total contribution of ICT the share of MFP growth directly associated to ICT-producing industries.
Source: Dion (2007).

Air and Rail Transportation

There are several studies that analyze productivity trends in air transportation and, to a lesser degree, rail transportation using a growth accounting framework. Most of these studies, however, just look at the overall contribution of capital deepening to labour productivity growth, not making a distinction between ICT capital deepening and non-ICT capital deepening.

Apostolides*(2003, 2004), Duke and Torres*(2005) and Gu and Lafrance (2008) look at labour productivity and MFP trends in the U.S. air transportation sector from the 1970s to the early 2000s. Using a gross output approach, Apostolides*(2004) and Duke and Torres*(2005) find that labour productivity in U.S. air transportation rose substantially in the 1990-1995 period, from 1.6 per cent per year during the 1979-1990 period to 4.1 per cent per year (Table 12). This was due to a significant boost in both MFP growth and intermediate inputs growth, which accounted for 90 per cent of labour productivity growth in the period. Capital stock (including both ICT and non-ICT) accounted for the remaining 10 per cent of labour productivity growth.

During the 1995-2000 period, labour productivity growth in air transportation fell to 0.6 per cent per year, mainly because of the strong negative contribution of intermediate inputs growth, with MFP still growing at a robust pace. The contribution of capital stock growth to overall productivity growth during that period was nil.

Table 12: Sources of Gross Output Productivity Growth in U.S. Air Transportation, 1987-2004 (average annual growth rates)

	1972-2001	1973-1979	1979-1990	1990-1995	1995-2000
Air Transportation					
Labour Productivity Growth	2.5	5.6	1.6	4.1	0.6
Contribution of Capital Deepening	0.2	0.2	0.2	0.4	0.0
Contribution of Intermediate Purchases	0.3	0.3	0.6	1.6	1.7
Multifactor Productivity	2.0	5.1	0.8	2.1	-1.1

Source: Duke and Torres*(2005).

An important limitation in the analyses conducted by Apostolides*(2004) and Duke and Torres*(2005) is that the capital measure they use is not quality adjusted. Thus, improvements in capital stock quality show up as MFP growth, not capital deepening. In other words, the contribution of capital to productivity growth in air transportation would be significantly understated. Apostolides* recognizes this, listing the increased use of computer technology as a factor influencing MFP growth (although no attempt is made to measure the exact contribution of this factor).

Using a value added framework, Gu and Lafrance (2005) decompose labour productivity growth into MFP growth and total capital intensity growth, comparing the performance of air transportation in Canada with that of the United States during the 1977-2003 period (Table 13). With respect to the productivity of U.S. air transportation, their findings are somewhat similar to the aforementioned studies, with labour productivity growth increasing from 1.4 per cent per year during the 1977-1990 period to 7.9 per cent per year in the 1990-2003 period. Again, most (70 per cent) of this gain was due to the increase in MFP growth. The performance of Canadian air transportation was very different from that of the United States, with labour productivity declining substantially between the two periods, from 3.1 per cent per year between 1977 and 1990 to -2.6 per cent per year between 1990 and 2003. This decline was accounted for entirely by MFP growth.

Gu and Lafrance (2005) also look into the productivity performance of Canadian and U.S. rail transportation noting robust growth rates throughout the entire 1977-2003 period (6.2 per cent per year in Canada vs. 6.1 per cent per year in the United States) (Table 13). In both countries, MFP growth accounted for approximately 80 per cent of total labour productivity growth in the rail transportation sector. Apostolides*(2003, 2004), using a gross output approach, finds similar results for the U.S. rail transportation subsectors.

Table 13: Sources of Productivity Growth in Air and Rail Transportation, Canada-U.S. Comparison, 1987-2004 (average annual growth rates)

	Canada			United States		
	1977-2003	1977-1990	1990-2003	1977-2003	1977-1990	1990-2003
Air Transportation						
Labour Productivity Growth	0.2	3.1	-2.6	4.6	1.4	7.9
Contribution of Capital Deepening	0.8	0.8	0.8	0.6	-0.4	1.6
Multifactor Productivity	-0.6	2.3	-3.4	4.0	1.8	6.3
Rail Transportation						
Labour Productivity Growth	6.2	5.7	6.8	6.1	7.8	4.3
Contribution of Capital Deepening	1.1	1.4	0.8	1.1	1.9	0.4
Multifactor Productivity	5.1	4.3	6.0	4.9	6.0	3.9

Source: Gu and Lafrance (2005).

Overall, the studies discussed above recognize the role of ICT in promoting productivity growth in air and rail transportation (Apostonides*2003, 2004). However, as mentioned previously, very few attempts are made to actually measure its contribution using a growth accounting framework.

Exhibit 4 lists some of the main growth accounting studies in the literature.

Exhibit 4: Review of Growth Accounting Literature

Canada	United States	Other
- *Dion (2007)* Aggregation: Country and firm-level Time Period: 1974-2006 Key Results: 1) The differential between Canadian and U.S. productivity growth rates in the past decade is largely unexplained; 2) Canada appears to have taken less advantage of ICT than the U.S. and has achieved fewer efficiency gains in the production of services and non-ICT goods; 3) Additional potential contributors to low productivity growth in Canada include stable capital deepening, high resource prices driving the exploitation of marginal reserves and a lack of demand for innovation. - *Sharpe (2006)* Aggregation: Country and industry-level Time Period: 1980-2005 Key Results: 1) ICT has been the driving force behind the acceleration of productivity growth in Canada since 1996; 2) The potential of ICT as a driver of productivity has not been fully exploited. 3) There will be significant contributions to productivity growth in coming years. - Other papers: Baldwin *et al.* (2002), Khan and Santos (2002), Dachraoui *et al.* (2003), and Harchaoui *et al.* (2004).	- *Jorgenson et al. (2008)* Aggregation: Country Time Period: 1959-2006 Key Results: 1) The emergence of ICT drove the acceleration of labour productivity that began in the 1990s, while capital deepening and total factor productivity growth outside of ICT increased in relative importance after 2000; 2) Stability of productivity outlooks implies that substantial portion of large productivity gains between 2002 and 2004 can be attributed to transitory factors, as might the more recent slowdown. - *Basu et al. (2008)* Aggregation: Industry-level Time Period: 1987-2004 Key Results: 1) in ICT-using sectors, TFP growth rose in the 1990s and fell in the 2000s, as more resources are devoted to reorganization and learning; 2) TFP accelerations in the early 2000s are positively correlated with ICT capital growth in the 1990s but after controlling for past ICT investment, TFP growth is negatively correlated with ICT investment in the 2000s - *Bosworth and Triplett (2007)* Aggregation: Industry-level Time Period: 1987-2005 Key Results: The contribution of MFP to U.S. labour productivity growth exceeded the contribution of ICT. - *Corrado et al. (2006)* Aggregation: Country, sector and industry-level Time Period: 1987-2004 Key Results: 1) U.S. productivity acceleration in the late 1990s was not solely concentrated amongst producers of high-technology equipment and software, and that a surge in innovations in the retail and wholesale trade sector also contributed to economic growth - *Oliner and Sichel (2002)+2006 Update* Aggregation: Country Time Period: 1974-2001 Key Results: 1) Earlier results on contribution of IT using and producing sectors still valid despite the dot.com bubble; 2) Model projections of 2.00-2.75 per cent labour productivity growth/year over the next decade.	- Inklaar *et al. (2008)* Country/Region: US, Europe Aggregation: Country and industry-level Time Period: 1980-2004 Key Results: 1) Increased investment in ICT and growth in human capital contributed substantially to labor productivity across all European countries and the US; 2) Authors find no evidence of an externality driven relationship between efficiency changes and growth of ICT use. - Van Ark *et al. (2005)* Country/Region: US, Europe Aggregation: Country and industry-level Time Period: 1980-2004 Key Results: 1) the slower contribution of ICT to labour productivity growth in Europe compared to the U.S. persisted into the early part of the 21st century, which may be related to more productive use of ICT in the US; 2) The authors find no support for significant TFP spillovers from ICT investment, in the U.S. or Europe. - *Van Ark and Inklaar (2005)* Country/Region: US, France, Germany, Netherlands, UK Aggregation: Country and industry-level Time Period: 1987-2004 Key Results: 1) Lower IT-contribution to EU growth has continued through early 2000s; 2) US-EU differential increased following strong labour productivity gains in U.S. market services.; 3) No evidence of IT spillovers to MFP; 4) Hypothesis of U-shaped IT returns pattern: initial ' hard savings' followed by experimentation period then ' soft savings' as capital complementarities develop.. - Other papers: Inklaar *et al.* (2005).

Source: Draca *et al.* (2006) and CSLS.

iii. Limitations and Criticisms

The basic growth accounting framework delineated above can be very useful as a workhorse model to quantify the impact of ICT capital on productivity. However, it has a number of important limitations that need to be understood so that the model's conclusions can be accurately assessed.

First, although it is tempting to interpret the model's results in terms of causality, the neoclassical growth accounting framework is a *descriptive* model. In this sense, the terms in the right-hand side of equation (5) (ICT capital intensity, non-ICT capital intensity, and multifactor productivity) should be interpreted as the *proximate determinants* of productivity growth, not as the causes of productivity growth.

Second, the assumptions of a Cobb-Douglas functional form, constant returns to scale, and perfect competition can be quite strong (and untested) assumptions, which, in the end, have a decisive impact on the estimated contribution of ICT to productivity growth. If, for instance, the perfect competition assumption does not hold, then the contribution of ICT capital to productivity is not equal to ICT capital intensity growth weighted by the compensation share of ICT in total output. While it is reasonable to believe that the standard assumptions lead to a fairly accurate picture of the contribution of different factors to productivity growth at the aggregate economy level, it is very hard to make the same argument for the transportation sector, where perfect competition (for example) tends to be a very poor description of reality. It should be noted that several econometric techniques (discussed in the next subsection) allow for these basic assumptions to be relaxed, using different functional forms, assuming no *a priori* returns to scale, and taking into account different market structures.

Third, the impact of ICT on labour productivity growth may not occur in the same period in which investment takes place due to lags (see, for instance, Shinjo and Xingyuan, 2004). Using U.S. firm-level data, Brynjolfsson and Hytt (2003) find that long-term returns (three to seven years) to computer investment are two to five times higher than short-term returns (which are consistent with the expected "normal returns" to investment). What could explain the existence of these relatively long lags?

The main reason identified by the literature so far is that ICT appears to be a general purpose technology (GPT) (Basu *et al.*, 2003, and Basu *et al.*, 2008). GPTs are technologies that fundamentally change the production process of firms that make use of them. Historical examples of GPTs include railroads, the steam engine, etc. As a GPT, ICT could affect aggregate productivity growth through alternative channels (other than increased ICT capital intensity or, at the aggregate economy level, MFP growth of ICT-producing industries):

- For the full benefits of ICT to materialize, firms have to reorganize their production process, which involves the accumulation of a stock of intangible organizational capital. More formally, there is a complementarity between ICT and organizational capital. This complementarity provides a persuasive explanation for the long lags observed between ICT investment and its full effect on productivity, and is supported by firm-level evidence (Bresnahan *et al.*, 2002). The accumulation of organizational capital is a slow process. Initially, firms have to divert resources from production (which might even have a negative effect on contemporaneous productivity growth). Only when enough organizational capital is accumulated will the effects of ICT on productivity be felt, hence the lags. The complementarity between ICT and organizational capital also provides a possible channel (other than ICT capital deepening) through which ICT could affect productivity gains of non-ICT producing industries. Note that the accumulation of intangible organizational capital would show up in growth accounting exercises as MFP growth. In fact, Basu *et al.* (2008) find that it explains why MFP growth of ICT-using industries in the United States rose in the post-1995 period.[18]

- ICT could also affect productivity growth through spillover effects, i.e. ICT investment by one firm might affect investment decisions and productivity of other firms. Two possible channels that could lead ICT investment to have spillover effects are: 1) Firms could learn from the innovation efforts of other ICT-adopting firms; 2) The possible existence of network effects might cause ICT to be more effective when its use is more widespread in a certain region or industry.

The effects described above can be estimated econometrically, but the difficulty in ascertaining the accuracy of these estimates provides a rationale for case studies, where the impact of specific ICT technologies can be directly linked to physical productivity gains.

Finally, it is also important to keep in mind that the growth accounting framework described here looks at a static, long-run equilibrium picture, and therefore does not take into account possible adjustment costs associated with ICT adoption (Draca *et al.*, 2006:8).

B. Econometric Studies

In this subsection, we first look at how econometrics is used to measure the impact of ICT on productivity. Next, we describe the overall conclusions of the literature and provide a summary of important studies.

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[18] As Basu *et al.* (2008:2) note, however, "From the perspective of the firm, the [complementarity between ICT and organizational capital] story is essentially one of neoclassical capital accumulation. If growth accounting could include intangible capital as an input to production then it would show no technical change in ICT-using industries".

i. Econometric Approaches Used to Measure the Contribution of ICT to Productivity Growth

The two main econometric approaches used in the literature to measure the contribution of ICT to productivity growth are: 1) the MFP-based approach; 2) and production function estimation.[19]

a. MFP-Based Approaches

A common starting point of this approach is the standard Cobb-Douglas production function shown in equation (2). Taking the natural logarithm of both sides and rearranging the equation so that multifactor productivity (a_t) is on the left-hand side, we have that:

$$a_t = y_t - \alpha l_t - \beta k_t - \gamma c_t \tag{6}$$

Thus, multifactor productivity growth between period *t*-1 and period *t* will be:

$$\Delta a = \Delta y - \alpha \Delta l - \beta \Delta k - \gamma \Delta c \tag{7}$$

If ICT capital has "normal returns", then its contribution to output growth will be equal to its weighted growth rate ($\gamma \Delta c$), where the weight γ is the nominal compensation share of ICT capital in total output. In this case, ICT capital growth and multifactor productivity growth will be uncorrelated. If, on the other hand, ICT yields "excess returns", then ICT capital growth will be correlated to multifactor productivity growth. Hence, our objective is to estimate the equation below:

$$\Delta a = \alpha + \beta \Delta c + \varepsilon \tag{8}$$

where α and β are the parameters being estimated and ε is the error term. The hypothesis being tested is whether ICT capital has normal returns:

H_0: $\beta_1 = 0$ (ICT capital exhibits "normal returns")
H_1: $\beta_1 \neq 0$ (ICT capital does not exhibit "normal returns")

---

[19] There is a wide range of studies that use non-parametric estimation techniques such as data envelopment analysis (DEA) to calculate firm-level or industry-level MFP growth for air and rail transportation (see, for example, Fung *et al.*, 2008, Barros and Assaf, 2009, and Barros *et al.*, 2011). With the help of the Malmquist index (usually), several of these papers decompose MFP growth into two components: 1) technical change (innovation); and 2) efficiency change (catching up). The problem here is that no attempt is made to differentiate between productivity changes driven by ICT capital and productivity changes driven by other factors. Since this report is interested specifically on the link between ICT and productivity, the use of the DEA methodology and the Malmquist index is not discussed here.

This approach is adopted, for instance, by Brynjolffson and Hitt (2003), van Ark and Inklaar (2005), and Basu *et al.* (2008). To take into account the fact that the effect of ICT on productivity is lagged, equation (8) can be altered to include long differences (instead of one year differences) and lagged terms.

An important limitation of this approach is that it does not correct for endogeneity bias. In economics, endogeneity happens when an explanatory variable (on the right-hand side of the equation) has a correlation with the error term. This might be caused by several reasons, including: measurement errors, omitted variables, simultaneity, etc. In this particular case, there is a simultaneity problem. On the one hand, productivity depends on how inputs are combined to generate output. On the other hand, the optimal quantity of inputs chosen by firms might be affected by productivity shocks. Thus, the way firms use inputs affect productivity, but productivity also affects input use.

Equation (8) solves the endogeneity problem for labour and non-ICT capital inputs by moving them to the left-hand side of the equation. However, the problem still remains for ICT capital (and is possibly made worse by the fact that ICT capital growth enters the left-hand side of the equation as well).

b. Production Function Estimation

Econometrics provides a useful tool set to estimate production functions, allowing for the standard assumptions of the neo-classical growth accounting framework to be relaxed.[20] With the help of econometrics, different functional forms can be used, the assumption of perfect competition can be relaxed, and returns to scale can be estimated instead of assumed. All of these factors (and many others) may have an impact on the elasticity of output with respect to ICT capital, and hence on the impact of ICT on productivity. A detailed discussion of the more technical aspects related to estimating production functions in the transportation sector can be found in Button (2010).

A starting point for the econometric estimation of production functions is the standard ordinary least squares (OLS) technique, which minimizes the sum of squared residuals. The recent literature, however, has emphasized the use of more sophisticated techniques in order to correct estimation biases that might occur when OLS is used, such as the endogeneity bias described above (Draca *et al.*, 2006).

[20] Alternatively, econometrics can be used to estimate the *dual* of the production function, the cost function. For every production function that relates output produced to inputs used, there is a cost function that specifies the cost of producing a certain quantity of output for given input prices. Cost functions can be easier to estimate than production functions when dealing with firms that produce more than one output (Button, 2010:153).

One such technique is the general method of moments (GMM), which has a wide range of applications in economics. Broadly speaking, this method makes assumptions about the population moments of random variables in a model so that it can be estimated. Moments are measures that describe the shape of probability distributions. The first moment of a distribution, for instance, is its mean; the second, its variance (a measure of the dispersion of the distribution; the third, its skewness (a measure of the lopsidedness of a distribution); the fourth, its kurtosis (a measure of the tail of the distribution); and so on. The general method of moments can be broken down into three steps

1. Assumptions are made about the population moments of the random variables included in the model;

2. The data provide us with the sample moments of the model's random variables;

3. The objective function is minimized so that the parameters estimated are consistent with the smallest possible difference between the population moments and the sample moments (for a more detailed introduction to GMM, see Drukker, 2010).

Draca *et al.* (2006) provide an example of how GMM can be used to estimate the link between ICT capital and productivity in the case of a single input production function. Their example can, of course, be extended to a multi-input production function. The advantages of using GMM are twofold. First, it allows for a great amount of flexibility in the chosen functional form. Second, with the help of instrumental variables (IV),[21] it can help minimize endogeneity problems.

Brrynjolfsson, Hitt and Kim (2011) also employ an IV technique to estimate a production function as a means of evaluating the impact of data-driven decisionmaking (DDD) on firm performance. This method is employed to reduce the potential endogeneity bias that may be realized if firms with high productivity are more likely to adopt DDD than firms with lower productivity. By accounting for this problem, an IV approach allows for better assessment of the impact of ICT and non-ICT labour on firm productivity.

Another technique that is used to estimate production functions is the Olley-Pakes method. This method was originally developed by Olley and Pakes (1996) to analyze the dynamics of the U.S. telecom industry using firm level data. It is a three-stage method that seeks to estimate production function parameters addressing two important problems: 1) the

[21] An instrumental variable is a variable that has all of the three characteristics listed here: 1) It is not included in the regression model; 2) it is correlated to an endogenous variable in the model; 3) It is not correlated to the error term of the model.

endogeneity of productivity and input demands described earlier; 2) a selection bias caused by the fact that firms with larger capital stocks can remain in the market even when they have productivity levels that would force smaller firms to shutdown.[22] Details on the technical aspects of this model, which are beyond the scope of this report, can be found in Olley and Pakes (1996) and Yasar and Raciborski (2008).

ii. Main Results in the Econometric Studies Literature

As noted previously, although there are econometric studies that look into the link between ICT and productivity at the aggregate economy level, most of this literature focuses on the industry-level or the firm-level. Below, we highlight the main conclusions of the industry-level and firm-level literature.

Industry-Level Studies

Early industry-level econometric studies such as the ones done by Stiroh (2002) find little evidence of "excess" productivity gains related to ICT investment in the U.S. economy in the post-1995 period. Stiroh finds that ICT capital was not correlated in any meaningful way to contemporaneous MFP growth, which weakens the case for ICT-related spillovers.

Basu *et al.* (2008) argue, however, that ICT can affect aggregate MFP growth through channels other than spillovers. In fact, the lack of correlation between ICT capital and contemporaneous MFP growth is consistent with the existence of complementarities between ICT capital and intangible organizational capital. For firms to benefit fully from ICT, they first have to reorganize their production process, shifting resources from actual production, which could account for the low (or even negative) correlation between ICT capital and contemporaneous MFP growth. Once the process of accumulating organizational capital gains momentum, firms start benefiting more from ICT. Since organizational capital is not observed, productivity gains associated with it show up in MFP growth. Basu *et al.* (2008) find evidence for this hypothesis using an MFP-based approach.

Firm-Level Studies

Firm-level econometric studies show not only a significant link between ICT and productivity in U.S. firms, but also reveal that the magnitude of this link is much larger than the magnitudes implied by growth accounting models (see, for example, Brynjolfssen and Hitt,

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[22] The underlying assumption here is that profits are positively correlated to capital stock size. Thus, holding productivity constant, firms with a higher capital stock would have higher expected future profits, and thus would be able to survive in situations where smaller firms would not.

2003). There is evidence that these high magnitudes are explained by complementarities between ICT and organizational capital (see Bresnahan *et al.*, 2002).

A meta-study by Stiroh (2010) found a large variation in estimates of the elasticity of output with respect to ICT capital, from -0.006 to 0.177, with the mean elasticity being 0.050.[23] Although part of this variation is undoubtedly caused by methodological differences between studies, the other part is probably caused by different ICT coefficients by country, industry, and type of firm. An example of this can be seen in Bloom, Sadun, and Van Reenen (2007), who find that U.S. firms receive, on average, higher returns from ICT investments, especially in ICT-intensive sectors.

Aral *et al.* (2006) argue that causation between ICT use and productivity goes both ways. Firms that manage to successfully incorporate ICT in their business models tend to invest more in ICT in the future. Thus, the authors suggest "replacing 'either-or' views of causality with a more specific 'positive feedback loop' conceptualization in which successful IT investments initiate a 'virtuous cycle' of additional investment and additional gain (Aral *et al.*, 2006:2).

Air and Rail Transportation

There are several studies that estimate production functions (or cost functions) in air and rail transportation, but, again, there is no specific focus on ICT. These studies tend to be more concerned with estimating output elasticities with respect to *total* capital (as well as other inputs), elasticities of substitution, and returns to scale. Examples of such studies include Keeler (1974), Friedlander *et al.* (1993), and Bitzan and Keeler (2003) in the case of rail transportation; Caves *et al.* (1984) and Gillen *et al.* (1990) in the case of air transportation.

To the best of our knowledge, there are no studies that use the MFP-approach to measure the impact of ICT specifically on air and rail transportation productivity.

Exhibits 5 and 6 list some of the main studies that use econometric models to estimate the link between ICT and productivity.

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[23] This should be interpreted as: a one per cent increase in ICT capital increases output by X per cent where X is the elasticity estimate.

Exhibit 5: Review of Econometric Studies Literature (Industry Level)

Canada	United States	Other
- *Gu and Wang (2004)* Aggregation: Industry-level Time Period: 1981-2000 Methodlogy: MFP-based approach using weighted least squares Key Results: 1) ICT use is linked to MFP growth acceleration through IT-induced organizational innovation and network or spillover effects; 2) Industries with larger shares of knowledge workers are more likely to benefit from IT. 3) Manufacturing industries that are more open to international trade may have larger gains from ICT. -*Baldwin and Sabourin (2001)* Aggregation: Manufacturing sector Time Period: 1988-1997 Methodology: Weighted least squares Key Results: 1) Growing firms increased productivity relative to declining firms over the period; 2) Users of ICT and users who combined technologies increased their relative productivity the most.	- *Atrostic and Nguyen (2005)* (see also Atrostic and Nguyen, 2007) Aggregation: Industry level Time Period: Methodology: Key Results: 1) Finds some positive effects of ICT on average labour productivity but not MFP; 2) Telecommunication capita has a negative association with productivity; 3) In general, no strong evidence of spillover-type effects of ICT on productivity. - *Basu et al. (2003)* Aggregation: Manufacturing and services industries Time Period: 1977-2000 Methodology: MFP-based approach Key Results: ICT capital growth negatively correlated with TFP growth in late 1990s (consistent with model of unmeasured complementary investments). - *Stiroh (2002)* Aggregation: Industry level Time Period: 1984-1999 Methodology: Panel data, difference in difference, OLS, IV, fixed effects Key Results: 1) Finds some positive effects of ICT on average labour productivity but not MFP; 2) Telecommunication capital has a negative association with productivity; 3) In general, no strong evidence of spillover-type effects of ICT on productivity.	- *Inklaar et al. (2008)* Country/Region: Europe and the US Country and industry-level Time Period: 1980-2004 Methodology: OLS Key Results: 1) Increased investment in ICT and growth in human capital contributed substantially to labor productivity across all European countries and the US; 2) Authors find no evidence of an externality driven relationship between efficiency changes and growth of ICT use. - *Hempell (2005)* Country/Region: Germany and Netherland Time Period: 1998 Methodology: GMM Key Results: Significant ICT effect; many complementarities - *Gretton, Gali and Parham (2004)* Country/Region: Australia Time Period: Panel data using 1988-89, 1993-94, 1998-99 Methodology: Productivity growth equation (OLS) Key Results: IT positive in most specifications, significant in only 2 specifications - *Basu et al. (2003)* Country/Region: UK Aggregation: 34 industries Time Period: 1979-2000 Methodology: MFP-based approach Key Results: ICT capital services growth positively correlated with MFP. However, ICT investment positively correlated with MFP suggesting scope for the GPT hypothesis (given shorter lags in the UK).

Source: Draca *et al.* (2006) and CSLS.

Exhibit 6: Review of Econometric Studies Literature (Firm Level)

Canada	United States	Other
-*Turcotte and Rennison (2004)* Time Period: 1999 Methodology: Non-linear least squares Key Results: Computer skills training can augment the qualifications of lower skilled workers and make firms equally well off in terms of the productivity gain associated with technology use - *Gera and Gu (2004)* Time Period: 1999 Methodology: Probit Model Key Results: 1) Organizational changes in the areas of production and efficiency practices along with ICT use have been found to be related to better firm performance; 2) While ICT is productive on its own, it is more productive in firms that combine it with high levels of organizational change; 3) ICT and human capital are complements in the service sectors.	- *Atrostic and Nguyen (2007)* Time Period: 1999 Methodology: Production function estimation (OLS and 2SLS) Key Results: 1) OLS indicates that labour productivity is 3.8 per cent higher for network-using establishments; 2) 2SLS indicates a 7.2 per cent effect; 3) Lower productivity in earlier periods associated with networks. Interpreted as evidence that establishments may use networks to catch up. - *Brynjolfsson and Hitt (2003)* Time Period: 1987-1994 Methodology: Production function estimation (OLS, short differences, and long differences) and MFP equations Key Results: In long differences IT coefficients above IT capital share in revenue - *Bresnahan, Brynjolfsson and Hitt (2002)* Time Period: 1987-1994 Methodology: Correlation analysis, input choice functions Key Results: 1) Complements (IT, organization and skills) significantly and positively co-vary; 2) Skills and organization significant as determinants of IT demand; 3) IT-skills and IT-organization interaction variables significant in production function	-*Todhunter and Abello (2011)* Country/Region: Australia Time Period: 6,442 businesses from the 2005-06 and 2006-07 waves of the ABS Business Longitudinal Database Methodology: Binary probit and ordered probit regressions. Key Results: 1) Businesses which use sophisticated types of ICT are more likely to be innovative; 2) More intense ICT users are more likely to undertake more types of innovation, more novel innovation. - *Bloom, Sadun and Van Reenen (2006)* Country/Region: UK Time Period: 1995-2004 Methodology: Production function estimation and MFP growth regressions Key Results: 1) IT significant impact on productivity. Effect greater for U.S. than non-U.S. multinational or domestic firms. U.S. effect also stronger in IT intensive industries

Source: Draca *et al.* (2006) and CSLS.

C. Case Studies

The methodologies described above can be very useful in an effort to quantify the impact of ICT at a more aggregate level (be it total economy, business sector, a particular industry, or a group of firms). However, as we have seen, they also have important limitations: simplifying assumptions might distort the estimated contribution of ICT to productivity; intangible inputs such as organizational capital can be very hard to measure, etc. Due to these limitations, case studies can complement both growth accounting and econometric studies by providing concrete examples of how ICT affects productivity gains either at the industry level or at the firm level.

In this subsection, we first discuss general case studies where the impact of ICT on productivity is analyzed; next, we focus on the effects of ICT on air and rail transportation productivity. The reader should bear in mind that the objective of this section is not to provide a detailed overview of the case study literature on the topic, but to offer concrete examples of how ICT can be used to increase productivity, particularly in air and rail transportation.

i. General Case Studies

The use of computers, including internet use, has modified the way businesses interact and manage their inventories. Before the mass diffusion of ICT use, it was typical for large firms to integrate vertically to facilitate the coordination of the various stages of production by avoiding dependence on suppliers of inputs or intermediate goods. But since the 1980s, the decline in the costs of information exchange has changed this.

Brynjolfsson and Hitt (2000) give the example of supply networks in the hospital sector, where manually filled purchase orders were replaced by a computerized ordering system, linking the hospitals to their suppliers electronically. The suppliers gained a direct and almost instantaneous access to hospitals' inventories and could therefore manage stocks in an optimal manner while eliminating paperwork at the same time. Similar improvements in inventory management using automatic orders were introduced in retailing. These innovations lead to productivity improvements by reducing the amount of time spent on managing inventories and orders, as well as a better use of perishable inputs. The authors note that even General Motors, a classic example of large vertically integrated firms, started relying more on sub-contractors for the provision of inputs.

Hughes and Morton (2005) argue that there are a series of organizational conditions that are required before the payoff from ICT can be realized. In other words, ICT has a productivity enhancing role only when used in sequence with other complementary assets. The authors point to changes in organizational structure that allow a business to harness ICT to achieve its primary goals as fundamental to harnessing the potential for growth through ICT.

Hughes and Morton study the rise and stability of Schneider National Inc., which is the second largest full truckload transportation company in the United States with revenues over $3 billion and 20,000 employees. The authors point to global competition pressures in the transportation sector bringing about fundamental change. For example, just-in-time manufacturing and the rise of FedEx in the 1980s and 1990s led everyone to “expect everything overnight.” They identify the key dimensions of competitive advantage in the sector being low cost-per-mile, good on-time delivery rate, and a solution to the deadhead and small-load problem.

Schneider’s success, according to the authors, can be traced to its early adoption of ICT and also their intelligent implementation of these investments to help deliver on the three factors influencing competitive advantage. For example, Schneider uses an On Line Real Time shipment planning and management system that they helped design. Moreover, the company invests $3,500 per truck on satellite tracking systems and a further $7-10 million each year on satellite transmission costs. The authors argue that it is not the ICT investment itself that led to Schneider’s performance but how they used ICT to improve their operating structures.

The case study of Schneider provides a clear example of how focusing on integrating ICT capital in areas where it can affect the fundamentals of an organization are key to harnessing its growth potential. Thus, the way in which ICT investment is utilized by firms matters much more than the quantity of ICT investment. Schneider reduced its cost-per-mile from $1.00/mile to $0.60/mile from 1980 to 1998 in constant dollar terms Moreover, they were able to reduce internal costs by 24 per cent and satellite tracking has been linked to reducing deadhead miles by 25 per cent.

The use of the internet to market products has also changed the way businesses deal with customers and consequently affected productivity by reducing the need for intermediaries such as wholesalers and sometimes distributors. Dell’s strategy is a classic example of this phenomenon, where significant emphasis is given to an online sales platform that allows for a considerable degree of product customization. Brynjolfsson and Hitt (2000) note that Dell’s build-to-order business model gives Dell as much as a 10 per cent advantage over its rivals in production costs, compared to the previous build-to-stock model. These cost savings are partially attributable to the elimination of wholesale distribution and retailing costs while others reflect lower levels of inventory throughout the distribution channel.

There is evidence that Canadian firms are integrating ICT investment into organizational and operational procedures as well. Bison Transport, a Canadian truck transport firm based in Winnipeg, implemented the Truckload Cost Information System (TL/CIS) in 2002 (Transportation Costing Group, 2006). TL/CIS provides Bison with data on various components of its cost structure (e.g., fuel prices, maintenance expenses, and driver turnover) that allow it to conduct analysis on what aspects of their operation can be improved to increase efficiency. This ICT investment was also accompanied by other investments in complementary assets that have likely increased the success of TL/CIS. For example, the adoption of the software coincides with a change in the culture of their sales and marketing efforts in order to understand the drivers of the firm's success and avenues for growth. Moreover, the TL/CIS investment was supported by previous investments in the firm's financial systems and IT staff.

Satellite communication and on-board computers are now in all power units in their fleet (Natural Resources Canada, 2010). This has led to cost reductions in communicating with drivers and planning their schedules. Further, their ICT systems also enable them to track fuel economy statistics for each of their units and as a result they have improved their fuel economy to 36.7 litres per 100 kilometres. Bison estimates that through their ICT systems they will be able to further improve their fuel efficiency by 2.2 litres per 100 kilometres, which would save them approximately $1.4 million in fuel costs annually.

The success of Bison Transport illustrates that the proper integration of ICT investment can bring about productivity improvements in the transportation sector, and the firm could serve as a model for other firms in the sector. However, the scale of ICT investment on its own is not enough to guarantee improved efficiency. ICT investment requires investments in complementary assets such as organizational structures and IT support in order to reap the benefits. Moreover, a clear understanding of how to use new technology to affect firm costs is also necessary to maximize the effect of ICT on productivity.

ii. Rail Transportation Case Studies

According to Nash *et al.* (2009), ICT can substantially increase the efficiency and productivity of rail transportation in three main areas:

- Railway scheduling: ICT can help rail companies utilize existing capacity more efficiently by creating optimized train connections, constructing realistic and conflict-free train paths, improving the quality of resource planning, providing short-notice access to rail routes, and helping in pricing decisions.

- Railway operations: ICT can also help in the creation of more efficient dispatching systems (which ensure the punctuality and reliability of a railway system), improved train control systems, and improved customer information systems.

- Railway simulations can help railways expand existing capacity by identifying investment opportunities and implementing improvement programs.

As a case study, Nash *et al.* (2009) look at the challenges faced by Thalys, a company that operates high-speed passenger trains between Paris, Brussels, Cologne, and Amsterdam. Demand for Thalys' services had been increasing consistently over recent years. The company had to seek ways to accommodate the increasing demand for its services without loss of efficiency and quality. This however, was not a trivial task.

The trains operated by Thalys ran on shared tracks that belonged to other railways. Different track segments had different speed limits, as well as different infrastructure operators and maintenance schedules. A wide variety of passenger and freight trains from different companies used these tracks, all with different speeds, acceleration rates, and braking capacities. Making matters even more complicated, infrastructure operators required train operators to bid for specific train slots five years in advance.

To deal with those issues, Thalys made use of the Viriato[24] software, which allowed it to identify both physical bottlenecks (low speed tracks, capacity constraints, shared track situations, etc) and institutional bottlenecks (out of date regulations, for example). Once these bottlenecks were identified, the company could evaluate the optimal ways of dealing with them based on the data gathered by the software (data-driven decision making). The results of the analysis were used by Thalys not only to plan their own activities, but also to suggest operational and institutional changes to the government and to other companies that used or maintained the shared tracks.

Transport Canada funded several case studies through the Freight Sustainability Demonstration Program (FSDP) and Freight Incentives Program (FIP) to investigate the impact of specific technologies and practices on fuel consumption and greenhouse gas emissions. Some of these studies show additional areas where ICT can contribute to increased productivity in rail transportation. We discuss one of these studies here.

The study was conducted by Southern Railway of British Columbia during the 2003-2007 period. In the initial phase of the study, the company installed SmartStart® automatic engine stop-start controls in two of their diesel switcher locomotives (models SRY 124 and SRY 153). The objective of these controls was to "reduce idle time and fuel consumption when units were on standby, without sacrificing their ability to move freight cars when needed" (Transport Canada, no date). After a 20-month testing period, the fuel consumption of the two locomotives equipped with the stop-start controls was compared to the baseline fuel consumption for those

[24] Viriato is a software that integrates timetable and planning tools into a single technology. It offers "a broad spectrum of planning capabilities, ranging from strategic studies for new projects down to the granular assessment of an existing pinch-point." (Kingsley, 2008)

locomotives. Overall, the controls led to a significant decline in fuel consumption and idle time. Table 14 illustrates the results.

Table 14: Comparison of Idle Time, Shutdown Hours, and Fuel Savings between Locomotives Equipped with SmartStart® and Baseline Case

	Locomotives	
	SRY124	SRY 153
Days of operation with SmartStart® controls	496	478
Reduction in idle time (hours)	1,455	921
Shutdown hours achieved (hours)	2,776	2,007
Fuel savings (litres)	36,427	33,859

Source: Transport Canada (no date), p. 3.

The second step of the study consisted in equipping 18 additional SRY 124 and SRY 153 locomotives with the automatic engine stop-start controls and comparing their fuel consumption with that of other locomotives which were not equipped with SmartStart®. Again, a substantial reduction in the fuel consumption of SmartStart®-equipped locomotives was observed. In particular, SRY 124 fuel consumption declined by 26 per cent, while SRY 153 fuel consumption dropped by 31 per cent. Due to the reduction in fuel consumption, the use of SmartStart® technology paid for itself in only nine months.

iii. Air Transportation Case Studies

A study conducted by WestJet and funded by Transport Canada's FSDP concluded that the use of Required Navigation Performance (RNP) significantly reduced both fuel consumption and greenhouse gas emissions.

RNP consists in a global positioning system that, through the use of a network of satellites, can "locate and guide aircraft via their onboard navigational computers" (Transport Canada, no date). RNP-based approaches were developed for 22 Canadian airports. Fuel consumption and greenhouse gas emissions of RNP-based approaches were compared to that of non-RNP-based approaches during a ten month period between 2006 and 2007. Table 15 shows that there were significant savings associated with RNP-based approaches.

Table 15: Fuel Savings and Greenhouse Gas Reduction in RNP-Based Approaches

Approaches	Fuel Savings (litres)	CO2 reduction (tonnes)	Methane Reduction (kg)	Nitrous Oxide Reduction (kg)
9,716	743,000	1,895	5.8	18.5

Source: Transport Canada (no date), p. 2.

Although the study focused on fuel consumption and greenhouse emissions it notes that the use of RNP can provide a variety of other benefits that could potentially affect efficiency and productivity in air transportation. These benefits include:[25]

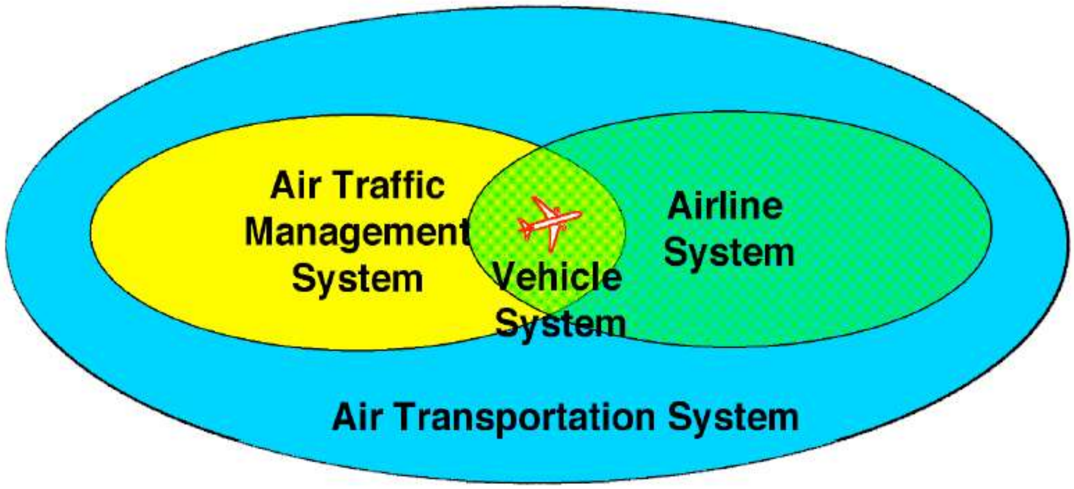
- More reliable (repeatable), predictable flight paths;
- Optimized approaches and departures, resulting in lower thrust settings and noise levels;
- Time and fuel savings;
- Shorter route distances;
- Higher takeoff weights/reduced thrust;
- Reduced training costs;
- Consistent 'common instrument approach' for all operations;
- Fewer weather-related diversions or cancellations;
- Flight safety enhancements

Hansman (2005) looks at how the use of ICT transformed air transportation over the years. He notes that the increase in the cost efficiency of air travel in the United States – with the average cost per available seat mile for U.S. airlines declining by more than 40 per cent since the late 1970s – is highly correlated with the deregulation of the U.S. airline industry and ICT use. Hansman emphasizes that the air transportation system is made of interacting subsystems, and ICT can have differentiated impacts in each of those subsystems. The three main subsystems in the air transportation system are: the air traffic management system, the vehicle system, and the airline system (Exhibit 7).

At the traffic management system level, ICTs are used in several functions, including: communications, navigation, surveillance, decision support, and information sharing systems. At the airline system level, ICT helps with both airline flight operations (through improved communication and surveillance) and airline business (through optimization and simulation tools).

[25] The list below is taken from Transport Canada (no date).

Exhibit 7: Air Transportation System Elements



Source: Hansman (2005:2).

ICTs were also responsible for massive changes in aircraft systems. These changes affected the entire aircraft information flow, from the databus and sensors to actuation, control, displays, decision support, and crew. Regarding the effect of ICT on crew size, for example, the author says:

> In the 1950s a transoceanic cockpit crew would consist of 5 (Captain, First Officer, Flight Engineer, Navigator, Radio Operator). Advances in radio systems such as frequency tuning and selective addressing (SELCAL) allowed the radio operator to be eliminated. The incorporation of advanced long-range navigation systems (initially IRS systems and subsequently GPS) replaced the Navigator. System simplification and system alerting systems (e.g. EICAS, ECAM) allowed the Flight Engineer to be eliminated resulting in the current crew complement of 2 pilots (Captain and First Officer) (Hansman, 2005: 7).

VI. Measuring the Impact of ICT on Productivity Growth in Canadian Air and Rail Transportation

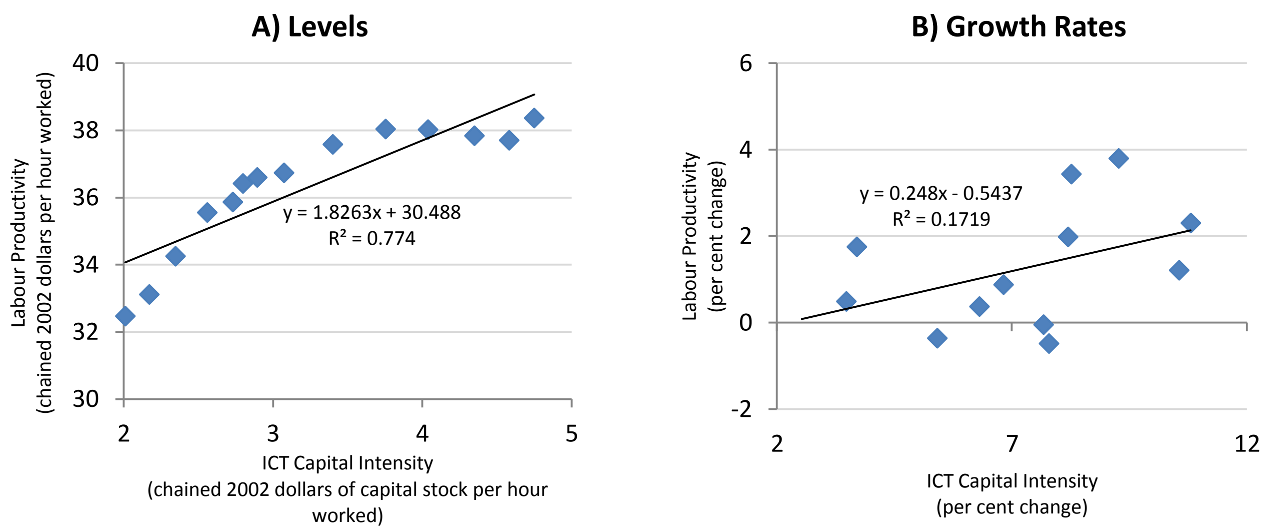
In the previous section, we discussed the main methodologies and techniques used by the economics literature to measure the impact of ICT on productivity growth. Although several papers have recognized the importance of ICT in increasing productivity in air and rail transportation, very few have actually tried to quantify its precise impact. This is the main objective of this section.

First, we look at the correlation between ICT capital intensity and productivity in Canadian air and rail transportation; next, we use the standard neo-classical growth accounting framework explained in the previous section to estimate the contributions of non-ICT capital intensity, ICT capital intensity, and MFP to labour productivity growth in Canadian air and rail transportation. Finally, we perform several exercises using the MFP-based approach to test whether there are "excess returns" associated with the use of ICT in air and rail transportation.

A. The Link between ICT and Productivity

At the business sector level, ICT capital intensity (defined here as ICT capital stock per hour worked) and labour productivity levels in Canada were highly correlated during the 1997-2010 period, with an R-squared of 0.77 (Chart 62). If we shift our attention to growth rates, however, there is a marked drop in the relationship between the two, with the R-squared declining to 0.17.

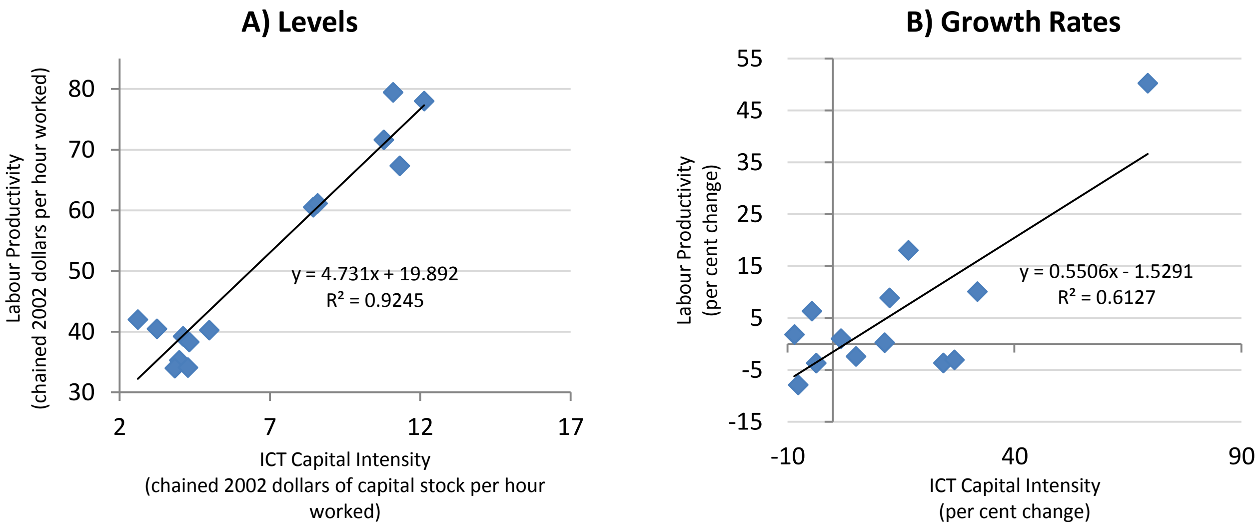
Chart 62: The Relationship between ICT Capital Intensity and Productivity in the Business Sector, Canada, 1997-2010



Source: CSLS calculations based on Statistics Canada data.

Looking at air transportation, we see a similar pattern, with the levels of ICT capital intensity and labour productivity being highly correlated (R-squared of 0.92), but growth rates showing less co-movement (Chart 63). Despite following the same overall patterns as those seen in the business sector, ICT capital intensity and labour productivity growth rates in air transportation were significantly more correlated than those in the business sector (R-squared of 0.61).

Chart 63: The Relationship between ICT Capital Intensity and Productivity in Air Transportation, Canada, 1997-2010

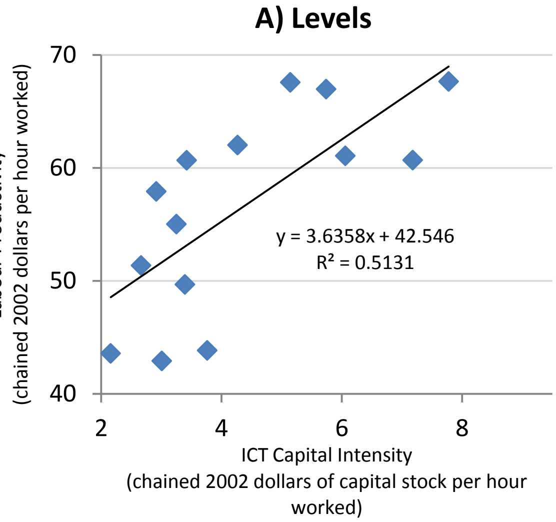


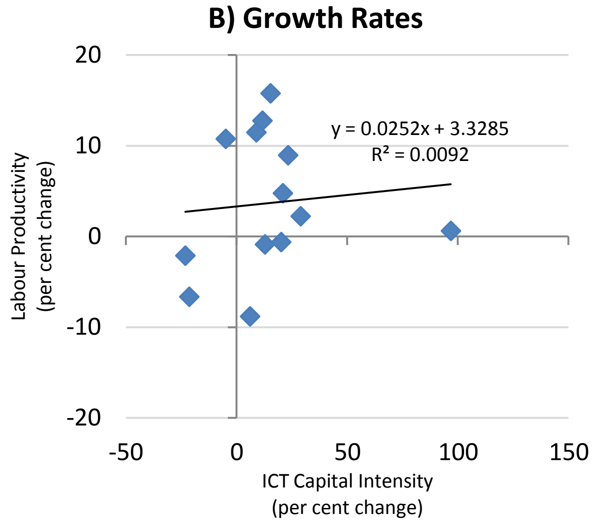
Source: CSLS calculations based on Statistics Canada data.

In rail transportation, the link between ICT capital intensity and labour productivity is much weaker than that of the business sector or air transportation (Chart 64). In the case of levels of ICT capital intensity and labour productivity, the correlation coefficient was 0.72; in the case of growth rates, it was only 0.10.

Although it might be tempting to draw quantitative inferences from the above relationships, it is important to keep in mind that they do not reflect causal connections. An increase of $1.00 dollar of capital stock per hour worked in air transportation *does not* cause a labour productivity increase of $4.73 per hour. More likely, as Aral *et al.* (2006) argue, there is a feedback loop between ICT and productivity, with firms that manage to successfully incorporate ICT into their production process being more likely to invest more in ICT in the future. Without additional controls, it is impossible to tell the magnitude of the impact of ICT on productivity growth. The above relationships clearly show, however, a positive correlation between ICT and productivity that warrants further investigation.

Chart 64: The Relationship between ICT Capital Intensity and Productivity in Rail Transportation, Canada, 1997-2010





Source: CSLS calculations based on Statistics Canada data.

B. Growth Accounting

Before discussing the results of our growth accounting exercise, it is important to make some observations regarding data limitations and the potential effect of simplifying assumptions on our estimates.

Growth accounting results are crucially dependent on the input series used. Precise input series lead to more accurate growth accounting results. Statistics Canada's growth accounting exercises from the Canadian Productivity Accounts (CPA) program use labour input and capital services as their main input series (in the case of gross output growth accounting, materials input is also used). Their labour input series reflect not only growth in hours worked, but also changes in labour quality.[26] By the same token, their capital services series take into account not only capital stock growth, but also changes in capital composition.

Since labour quality and capital composition estimates were unavailable for air and rail transportation, the CSLS has constructed growth accounting estimates from official Statistics Canada input series – more specifically, from hours worked, non-ICT capital stock, and ICT

[26] Statistics Canada's labour composition measure is the ratio of labour input to hours worked. Labour input, in turn, is the weighted sum of hours worked across different categories of workers, with the weights being equal to the relative labour compensation shares, i.e. categories of workers that receive a higher share of total labour compensation receive a higher weight. Thus, the labour services input can be decomposed into an hours component and a labour quality (or composition) component. The variables used to differentiate labour quality are education (four education levels), experience (proxied by seven age groups) and class of workers (paid employees versus self-employed workers). Overall, there are 56 different categories of workers.

capital stock series. The fact that we do not account for changes in labour quality and capital composition (which are usually positive, representing additional input growth) causes our MFP growth estimates (which represent output growth not explained for by input growth) to incorporate these elements. As a consequence, the CSLS MFP estimates used here are substantially higher than official Statistics Canada's estimates from the CPA.

Furthermore, the use of capital stock instead of capital services (which takes into account changes in capital composition) leads to a systematic understatement of the importance of ICT in productivity growth. The difference between capital stock and capital services growth rates stems from the fact that not all types of capital assets provide services at the same rate. Short-lived assets, such as a car or a computer, must provide all of their services in just a few years before they completely depreciate. Office buildings, on the other hand, provide their services over decades. As a consequence, over a single year, a dollar's worth of a computer provides relatively more capital services than a dollar's worth of a building. Compounding this problem, since a breakdown of non-ICT capital compensation and ICT capital compensation was unavailable for air and rail transportation, ICT capital compensation shares were assumed to be equal to the share of ICT capital stock in total capital stock.

Another important problem refers to the labour and capital compensation shares in Canadian air transportation. As we have seen in the previous section, under perfect competition the parameters α, β, and γ in equation (2) are equal to the labour compensation share in nominal output (in this case, GDP), non-ICT capital compensation share, and ICT capital compensation share, respectively. Historically, for the Canadian business sector, the labour compensation share of nominal GDP has been close to 60.0 per cent, while the capital compensation share accounted for the remaining 40 per cent of nominal GDP. The problem with air transportation in Canada is that labour compensation shares were actually above 100.0 per cent in 2003 and 2004, which implies that the subsector as a whole had negative capital compensation. This reflects the poor fiscal position of the sector those years. For growth accounting results to make sense, all compensation shares must be positive. To circumvent this problem, we assumed that the labour compensation share in air transportation was slightly below its historical average of 79.8 per cent during the 1999-2008 period.

One final problem has to do with the assumption of perfect competition. While this assumption might be approximately true when dealing with the total economy or the business sector, it is definitely not true in the case of heavily regulated activities such as air and rail transportation. Consequently, the compensation of labour and capital will not necessarily be equal to their respective marginal products.

Keeping in mind the limitations listed above, Table 16 shows the data used in the growth accounting exercise and summarizes the results. Although labour compensation shares in air and rail transportation were available only for the 1999-2008 period, we extended the growth accounting exercise to the 1997-2010 period by assuming that compensation shares in 1997, 1998, 2009, and 2010 were equal to a three year moving average of historical shares. Capital compensation shares were determined residually (i.e. nominal GDP minus labour compensation share in a particular activity). As mentioned above, ICT capital and non-ICT capital compensation shares were assumed to be equal to ICT and non-ICT capital stock shares in total nominal capital stock.

According to Table 16, ICT capital intensity growth was not a major source of labour productivity growth in the two transportation subsectors during the 1997-2010 period. In air transportation, it accounted for only 0.13 percentage points of labour productivity growth (5.02 per cent per year); in rail transportation, it was responsible for 0.09 percentage points of labour productivity growth (3.44 per cent per year). Non-ICT capital intensity was more relevant in air transportation, where it accounted for 1.49 percentage points of labour productivity growth, than in rail transportation, where it accounted for 0.67 percentage point. In both subsectors, MFP represented the lion's share of productivity growth (3.40 percentage points in air transportation vs. 2.68 percentage points in rail transportation).

In per cent terms, ICT capital intensity growth was responsible for only 2.6 per cent of labour productivity growth in both air and rail transportation, with non-ICT capital intensity accounting 29.7 per cent of total growth in air transportation and 19.5 per cent of total growth in rail transportation. MFP growth represented 67.7 per cent of total labour productivity growth in the case of air transportation and 77.8 per cent in the case of rail transportation.

The picture in the business sector is different. As noted in section IV, labour productivity growth in the Canadian business sector was only 1.29 per cent per year during the 1997-2010 period. Despite a lower ICT capital intensity growth rate, the contribution of ICT to labour productivity growth in the business sector reached 0.19 percentage points, higher than the contribution observed in both air and rail transportation. This was due to the fact that ICT capital compensation in the business sector (2.8 per cent) was more than twice that of air and rail transportation (1.2 per cent and 0.8 per cent, respectively). Non-ICT capital intensity played a less important role in the business sector, accounting for only 0.17 percentage points of labour productivity growth due to the very weak growth in this variable (0.38 per cent per year). MFP growth was responsible for the remainder of labour productivity growth, 0.93 percentage points.

Table 16: Sources of Labour Productivity Growth in the Business Sector, Air Transportation, and Rail Transportation, Canada, 1997-2010

	1997-2010	1997-2000	2000-2010
	(compound annual growth rates, per cent)		
Business Sector			
Labour Productivity	1.29	3.07	0.76
ICT Capital Intensity	6.95	8.58	6.47
Non-ICT Capital Intensity	0.38	-0.50	0.65
MFP	0.90	3.02	0.26
Air Transportation			
Labour Productivity	5.02	-3.02	7.56
ICT Capital Intensity	11.78	18.28	9.90
Non-ICT Capital Intensity	5.20	1.96	6.19
MFP	3.31	-3.80	5.44
Rail Transportation			
Labour Productivity	3.44	4.47	3.14
ICT Capital Intensity	12.05	20.39	9.66
Non-ICT Capital Intensity	1.26	-1.77	2.18
MFP	2.62	4.99	1.91
	(average compensation shares, per cent of nominal GDP)		
Business Sector			
Labour	57.4	58.8	56.9
ICT Capital	2.8	2.7	2.8
Non-ICT Capital	39.8	38.4	40.2
Air Transportation			
Labour	70.0	70.0	70.0
ICT Capital	1.2	1.3	1.1
Non-ICT Capital	28.8	28.7	28.9
Rail Transportation			
Labour	51.5	54.8	50.3
ICT Capital	0.8	0.8	0.8
Non-ICT Capital	47.7	44.5	48.9
	(contributions to labour productivity growth, percentage points)		
Business Sector			
Labour Productivity	1.29	3.07	0.76
ICT Capital Intensity	0.19	0.22	0.19
Non-ICT Capital Intensity	0.17	-0.19	0.29
MFP	0.93	3.04	0.28
Air Transportation			
Labour Productivity	5.02	-3.02	7.56
ICT Capital Intensity	0.13	0.22	0.10
Non-ICT Capital Intensity	1.49	0.57	1.78
MFP	3.40	-3.81	5.68
Rail Transportation			
Labour Productivity	3.44	4.47	3.14
ICT Capital Intensity	0.09	0.14	0.08
Non-ICT Capital Intensity	0.67	-0.71	1.10
MFP	2.68	5.04	1.96
	(contributions to labour productivity growth, per cent)		
Business Sector			
Labour Productivity	100.0	100.0	100.0
ICT Capital Intensity	15.0	7.3	25.0
Non-ICT Capital Intensity	12.9	-6.1	37.8
MFP	72.1	98.9	37.2
Air Transportation			
Labour Productivity	100.0	100.0	100.0
ICT Capital Intensity	2.6	-7.3	1.4
Non-ICT Capital Intensity	29.7	-18.8	23.5
MFP	67.7	126.1	75.1
Rail Transportation			
Labour Productivity	100.0	100.0	100.0
ICT Capital Intensity	2.6	3.1	2.4
Non-ICT Capital Intensity	19.5	-15.8	35.2
MFP	77.8	112.7	62.4

Source: CSLS calculations based on Statistics Canada data.

In per cent terms, ICT capital intensity growth accounted for 15.0 per cent of labour productivity growth in the business sector. The per cent contribution of ICT capital intensity growth to business sector productivity growth was greater than that of air and rail transportation productivity growth due to the significantly slower productivity growth experienced by the business sector during the period. Non-ICT capital intensity growth represented 12.9 per cent of labour productivity growth, while MFP growth accounted for 72.1 per cent.

It is important to note that the above results do not mean that ICT is not relevant to air and rail transportation productivity. More likely, it means that its contribution is not well captured by increases in ICT capital intensity (particularly when capital intensity is measured using capital stock instead of capital services). Even more important, equating the share of ICT in nominal output to its contribution to labour productivity might severely understate the productivity-enhancing capabilities of ICT. As we have seen in one of the case studies presented in Section V, Thalys made extensive use of the software Viriato to identify both physical and institutional bottlenecks. By doing so, the company managed to significantly improve the productivity of its operations. In fact, the benefits probably outweighed the cost of the software by a large amount.

C. Econometric Approach

In section V, we described two approaches to measuring econometrically the impact of ICT on productivity growth: the MFP-based approach and the production function approach. Here, we use the MFP-based approach to estimate whether ICT capital stock exhibits “excess returns” in air and rail transportation. In other words, we test if the contribution of ICT to output is greater than the contribution implied by its share in nominal output.

The MFP-based approach is usually applied in a time series or panel data context. Its flexibility allows us to test several alternative specifications in addition to the one presented in equation (8) (page 84). Since our main interest here is estimating the relationship between ICT growth and MFP growth in air and rail transportation, a time series approach is used.

We test three alternative specifications for air transportation, rail transportation, and the business sector. The first specification is the one described in equation (8), where the one-year change in MFP is regressed on the one-year change in ICT capital. In the second specification, instead of one-year changes we use two-year changes, while in the third we use three-year changes. Brynjolfsson and Hitt (2003:7) argue that long-differences can be useful in this context because

> (…) when adjustment is not instantaneous, longer differences can be interpreted as “long-run” effects of factor input changes. Such changes include not only the direct effect of factor inputs, but also the effects of adjustment of complementary factors.

Table 17 shows the regression results for air transportation, rail transportation, and the business sector. As we can see, in all specifications the ICT coefficient is positive but not statistically significant. The ICT coefficient represents the "excess returns" of ICT capital with respect to its "theoretical returns" (which should be consistent with its compensation share in nominal output). Non-significant ICT coefficients would imply that ICT does not show "excess returns" in Canadian air and rail transportation, as well as in the business sector as a whole.

These results should, however, be interpreted with caution. An important limitation of the regression analysis conducted here (and the reason why additional controls were not included) is that it relies on very few observations. In fact, specification (1) has only 13 observations. Other specifications have even less, as they incorporate long-differences. It is hard to reach any definitive conclusion on the impact of ICT on productivity growth with so few observations in our sample. If air and rail transportation data for a longer time period were available, this problem would be minimized. Alternatively, a panel data exercise could be conducted taking into account several three-digit activities. This would increase the number of degrees of freedom, and allow for more flexibility in terms of alternative specifications and different control variables.

A second reason why the above results are not particularly meaningful is related to the level of data aggregation. As seen in section V, studies that relied on industry-level data tended to find weaker links between ICT and productivity growth than firm-level studies. In this light, the lack of productivity and ICT capital stock estimates at the firm level for air and rail transportation represents a significant data limitation.

Table 17: Estimating the Relationship between ICT and Productivity Growth in Air and Rail Transportation Using the MFP Approach, Canada, 1997-2010

A) Business Sector

	(1) MFP 1yd	(2) MFP 2yd	(3) MFP 3yd
Constant	-0.00815	-0.01838	-0.02851
	(0.01223)	(0.02459)	(0.04527)
ICT Capital Stock 1yd	0.21685		
	(0.14303)		
ICT Capital Stock 2yd		0.21682	
		(0.14640)	
ICT Capital Stock 3yd			0.21292
			(0.18121)
Observations	13	12	11
Degrees of Freedom	12	11	10
R-Squared	0.17	0.18	0.13

B) Air Transportation

	(1) MFP 1yd	(2) MFP 2yd	(3) MFP 3yd
Constant	0.01522	0.03161	0.02657
	(0.21526)	(0.06926)	(0.10026)
ICT Capital Stock 1yd	0.03499		
	(0.22259)		
ICT Capital Stock 2yd		0.23617	
		(0.26041)	
ICT Capital Stock 3yd			0.37617
			(0.29523)
Observations	13	12	11
Degrees of Freedom	12	11	10
R-Squared	0.08	0.08	0.15

C) Rail Transportation

	(1) MFP 1yd	(2) MFP 2yd	(3) MFP 3yd
Constant	0.02580	0.05225	0.09011
	(0.02149)	(0.03745)	(0.04822)
ICT Capital Stock 1yd	0.00388		
	(0.09338)		
ICT Capital Stock 2yd		-0.01486	
		(0.13354)	
ICT Capital Stock 3yd			-0.03117
			(0.12390)
Observations	13	12	11
Degrees of Freedom	12	11	10
R-Squared	0.00	0.00	0.01

Note: 1) For each entry, the first number is the estimated coefficient and the second number is the estimated coefficient's standard error; 2) 1yd, 2yd, 3yd stand for one-year differences, two-year differences, and three-year differences, respectively.
*significant at 10% ** significant at 5% *** significant at 1%
Source: CSLS calculations based on Statistics Canada data.

VII. Conclusion

This report looked at the link between ICT and productivity growth in Canadian air and rail transportation during the 1997-2010 period. These two variables are highly correlated in both sectors (especially in air transportation) and increased at a significant pace during the period. However, when the two main methodologies used by the economics literature to assess the impact of ICT on productivity growth were applied to the case of air and rail transportation, the results were underwhelming.

Using the standard neoclassical growth accounting framework, we found that ICT capital intensity (defined here as ICT capital stock per hour worked) accounted for only 2.6 per cent of labour productivity growth in both air and rail transportation during the 1997-2010 period. Econometric estimations using the MFP-based approach yielded coefficients that were not statistically significant, implying that there were no "excess returns" associated with ICT use in air and rail productivity.

These results, however, are hardly conclusive. The standard assumptions of the neoclassical growth accounting framework (perfect competition, constant returns to scale, etc.) appear to be an ill fit to the realities of the air and rail transportation sectors, which are highly regulated. The econometric results should also be taken with a grain of salt. Since only annual data for the 1997-2010 period were available, the econometric estimations relied on very few observations. It is hard to reach any definitive conclusion on the impact of ICT on productivity growth when dealing with such a small sample. Furthermore, as previous literature has shown, the level of data aggregation matters, and industry-level data might not be appropriate to deal with this issue.

In light of these facts, we make two recommendations. First, future studies on the impact of ICT on productivity growth should rely on firm-level data instead of industry-level data. Second, future studies should be less reliant on growth accounting and use econometric techniques or case studies instead.

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