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Understanding Productivity: A Review of Recent Technical Research

by Richard Dion and Robert Fay

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Abstract

The authors provide an extensive review of the rapidly expanding research on productivity, both at the macro and micro levels. They focus primarily on papers written about Canada, but also draw on selected studies from other countries, especially the United States, where such work sheds important light on particular aspects of productivity growth. The authors extract the key results of the studies and signal important methodological features that underpin those results. They also identify areas for further research.

JEL classification: D24, O31, O40, O47
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Résumé

Les auteurs procèdent à une recension du nombre croissant d'études, tant macroéconomiques que microéconomiques, consacrées à la productivité. Bien qu'ils accordent une grande place dans leur recension aux travaux canadiens, les auteurs analysent aussi certaines études réalisées dans d'autres pays, notamment aux États-Unis, où la recherche éclaire par des contributions importantes des aspects précis de la croissance de la productivité. Les auteurs présentent les principaux résultats des travaux et leurs éléments méthodologiques les plus importants. Ils signalent enfin des pistes de recherche à explorer.

Classification JEL : D24, O31, O40, O47
Classification de la Banque : Productivité

1 Introduction

The analysis of productivity growth has come to the forefront of the agenda in most Organisation for Economic Co-operation and Development (OECD) countries. Since the publication of influential papers in the United States (e.g., Oliner and Sichel 2000), a wide range of studies have sought to determine whether the factors that have propelled productivity growth in that country are at play elsewhere. Probably no area has garnered more attention than the impact of information and communications technology (ICT) on productivity growth, given initial findings from the United States that it was a driving force behind the productivity resurgence, both in the production and use of ICT equipment. This has led researchers around the world to study how ICT may have influenced productivity growth in a wide range of countries. With access to new types of data, analysts have also explored several other areas related to productivity, including the effects of international exposure, regulation, competition, research and development (R&D) effort, management practices, and, most recently, aggregate productivity levels. At the same time, theorists have developed new models related to productivity convergence, trade and productivity, and competition and innovation, among other areas. These models have provided underpinnings to existing empirical results, and spawned new ones.

This paper serves two purposes. Primarily, it provides an extensive review of the rapidly expanding research on productivity and, in some instances, it links the various strands of research. This review focuses mainly on papers written about Canada, but it also draws on selected studies from other countries, especially the United States, where such work sheds important light on particular aspects of productivity growth. It aims not just to extract the key results of the studies but also to signal important methodological features that underpin those results so that a better understanding of both the productivity process itself and the methods used to probe it can be gained. The second purpose of this paper is to point out areas where further research is warranted. These areas are noted near the end of each section and are gathered together in the concluding section.

This paper proceeds from a macroeconomic perspective to a microeconomic one, starting with studies at the aggregate level and ending with research at the firm level. Each section is written to stand alone. Section 2 deals with trend productivity growth at the aggregate level, reviewing recent techniques used to extract it from the data and comparing their results. Section 3 turns to the workhorse of productivity analysis: aggregate growth accounting. It discusses the limitations of this methodology, along with studies that have examined key inputs (i.e., labour and capital, and, more particularly, ICT investment), before reviewing the findings of these studies for a wide range of OECD countries; the section also discusses adjustment costs and capital composition effects. Section 4 discusses recent research on productivity growth at the industry level. Section 5 reviews another new area of analysis: the size of productivity-level gaps and the role of structural factors. Section 6 examines innovation and productivity growth, including the impact of R&D. Section 7 turns to micro-level studies, which have typically used firm-level data to examine productivity growth. With access to new datasets, productivity analysis has explored inter alia the role of heterogeneity and reallocation, and adjustment to aggregate shocks such as trade liberalization. Section 8 looks at the role of firm and plant characteristics associated with productivity growth: firm size, exporting, multinational orientation, and managerial quality and competition. Section 9 provides conclusions and a summary of areas for further research.

2 Trend Productivity Growth

Regarding a country's welfare in the long term, few economic measures are as important as trend productivity growth. Detecting shifts in this trend in a timely fashion permits a country to avoid persistently overestimating or underestimating its potential output growth and thus committing costly policy errors. This task poses two challenges: first, identifying the magnitude of cyclical influences and the role of transitory but sometimes persistent shocks, and, second, capturing in real time statistically significant breaks in the underlying path of productivity growth. A variety of statistical techniques have been employed for these purposes, and they all treat trend productivity growth as an exogenous phenomenon to be measured in the data. This section discusses their applications and results, along with two non-econometric approaches, and it focuses on the period since the mid-1990s when the U.S. productivity resurgence emerged. Table 1 summarizes the conclusions of recent statistical studies.

The range of techniques used to assess the profile of trend productivity growth is wide. At the simplest level, measuring growth between business cycle peaks has the benefit of removing cyclical effects, but it misses shifts in the trend that could occur between the cyclical peaks, and it makes the estimation of the trend beyond the last peak quite problematic. A split-time trend technique applied to the productivity growth series would at least avoid the first problem. A recent Bank for International Settlements (BIS) study applying an iterative version of this technique, with restrictions to the labour productivity series for the business sector of the OECD countries over 1966–2004, concludes that trend output per hour has accelerated significantly in the United States since the late 1990s, in fact reverting to its pre-1970s pace of about 3 per cent (from about 1¼ per cent). Trend productivity growth has remained stuck at about 1¼ per cent since the mid-1970s in Canada, and has declined from 2½ per cent in the late 1970s to 1½ per cent in the mid-1990s in the euro area (Skoczylas and Tissot 2005).

Relying on the more statistically rigorous Bai-Perron technique, which endogenously determines both the number and the date of the trend breaks, Maury and Pluyaud (2004) estimate from quarterly data running to 2002Q4 that trend hourly productivity growth in the U.S. total economy has shifted to 2.2 per cent in 1995Q3 from 1.5 per cent back to 1968Q1. The latter date differs widely from the consensus view that sets the negative break around 1974. In the United Kingdom, trend hourly productivity growth has remained the same at 1.9 per cent since 1972Q2, whereas in France trend GDP per capita has fallen to 1.1 per cent in 1990Q1 from 2.2 per cent back to 1973Q2. Thus, the Bai-Perron and split-time trend techniques agree that the United States is the only large country to have experienced a trend break in the second half of the 1990s. Fernald (2005) also applies the Bai-Perron technique to U.S. data, but for private-business labour productivity growth over the 1950Q2–2004Q2 period. He uncovers two breaks: a slowdown after 1973Q1 to about 1.5 per cent, and a speed-up after 1997Q1 to around 3.2 per cent.

Benati (2006, 17) argues, however, that "when time-variation in equilibrium productivity growth does take place, it is most likely to take place *gradually* – ie without sudden jumps – so that the best way of analysing it is via time-varying parameter models, rather than via break tests." Roberts (2001) models trend productivity growth as a random walk with drift and allows the drift term to be a time-varying parameter. His estimates show that trend labour productivity growth in the United States progressively rises from an average of 1.6 per cent per year over the 1973–94 period to 2.7 per cent by 2000Q2, at the end of his sample period. Because capital accumulation plays a considerable role in this rise, estimated trend total factor productivity (TFP) growth moves by a smaller magnitude in the late 1990s, in fact to 1.1 per cent between mid-1998 and the first half of 2000, from about ½ per cent in the decade ending in the mid-1990s.

The Kalman filter/unobserved components approach assumes that changes in the trend growth are normally distributed and, like the Hodrick-Prescott (HP) filter, that they are continuous over time (French 2001). As shown in Table 1, the HP filter estimates of U.S. trend productivity growth after the mid-1990s provided by Fernald (2005) are comparable with those reported by Roberts (2001) using the Kalman filter. Both exhibit a steadily rising trend in productivity growth. This adaptation feature of the Kalman and HP filtering techniques makes them well suited to replicate the process of learning about changes in trend productivity growth. In fact, Edge, Laubach, and Williams (2004) use an estimated Kalman filter to provide an updating rule that replicates well the gradual process of learning about shifts in trend productivity growth that the experiences of the 1970s and 1990s reveal.

French (2001) nevertheless submits that innovations in trend TFP growth rates are far from normal, and that, if one allows for large outliers, the estimated trend growth rate changes only infrequently. This finding and accumulating evidence of a shift in U.S. productivity growth occurring in the mid-1990s lead him to combine the Kalman filter with a Markov-switching process that attaches to the mean growth rate of productivity some probability of switching between high and low regimes at any point in time (French 2005). He finds that such a combined model diagnoses shifts in trend TFP growth considerably more quickly than a linear Kalman filter, notably after the major turning points in 1963, 1982, and 1995.

Kahn and Rich (2004) adopt a still richer approach to identify shifts in U.S. trend labour productivity. They use a dynamic factor model to identify a common permanent component and a common transitory component from the co-movements of labour productivity, compensation per hour, and consumption per hour – all cointegrated variables in accordance with the neoclassical growth model – and they allow for changes between a high-growth regime and a low-growth regime for both components. Their model clearly signals a switch in the mid-1990s to a higher long-term growth regime (2.9 per cent), just as it detects a shift from high to low growth (1.4 per cent) in the early 1970s. Interestingly enough, the probability of a switch in the mid-1990s would have remained low without the corroborating evidence from compensation per hour and consumption per hour. These cointegrated variables also help to detect changes in trend more quickly: used in real time, the model would have detected the regime switch in the mid-1990s within six quarters of its actual occurrence, a year before the comparable signal that a model ignoring these variables (using detrended hours to control for business cycles) would have indicated. Moreover, it proved able to recognize the transitory nature of the occasional productivity growth slowdowns during the years 2000–04, and, in spite of the weaker productivity data in 2006, it still indicates that trend productivity growth remains high (Kahn and Rich 2006).

Because it exploits restrictions imposed by economic theory, the Kahn and Rich methodology has rapidly aroused interest outside the United States. Applying it to quarterly Canadian data over the 1966–2005 period, Dolega (2007) finds a shift in the trend growth rate of labour productivity from a high-growth regime (2.5 per cent) to a low-growth regime (1.1 per cent) in the late 1970s, but no shift back to a high-growth regime in the late 1990s, in spite of a surge in productivity growth over 1997–2000 and the role that cyclical weakness likely played in 2001 and 2003. For Germany, Italy, France, and Spain, Jimeno, Moral, and Saiz (2006) detect a switch towards a low-mean growth regime in the early to mid-1990s, but in the case of the United Kingdom they find no evidence of a break after the mid-1980s.

A totally different, non-econometric approach to inferring trend productivity growth is to control for factor utilization in an augmented growth accounting framework applied to industry-level data, such as the one created by Basu, Fernald, and Shapiro (2001). Their results suggest that the post-1995 shift in productivity growth is structural rather than cyclical, since there was little change in utilization in the late 1990s.

Pakko (2005) uses a dynamic stochastic general-equilibrium (DSGE) model that incorporates a role for stochastic technology growth trends to gain insight into the issue of whether the increase in the trend growth rate of U.S. productivity over the late 1990s is likely to persist. In his model, shifts in the underlying pace of technology improvement, particularly of the embodied type that is most manifest in ICT investment, provide incentives to alter the mix of capital and labour in the production process, and they give rise to extended transition periods during which measured productivity lags behind the technology trend. Simulations of the post-war U.S. economy suggest that positive technology growth shocks depress capital stock growth in the mid-1980s and early 1990s, and then raise trend productivity growth in the late 1990s. As this acceleration represents only a transitory phase in the adjustment of productivity to technology, trend productivity growth remains strong and may even accelerate, but over a limited horizon of five to ten years.

Areas for further research

The idea of regimes of trend productivity growth, which conveys the notion of infrequent, marked shifts in long-term productivity advance, contrasts with the more traditional view that changes in equilibrium productivity growth occur gradually. The most promising approach to exploit this idea of regimes makes use of corroborating evidence from economic series that are cointegrated with productivity in accordance with economic theory. Until recently, this approach has signalled that Canada has not shifted to a high-growth regime, in contrast with the United States over the last decade.

No matter how improved the latest approaches to evaluate trend productivity growth may have become relative to data-smoothing techniques, they remain blunt instruments for detecting trend breaks in real time. Benati (2006, 17) admits that "Given that, when changes in trend productivity growth do take place, even the very best available econometric techniques may turn out to be of limited help to policymakers, this naturally suggests the necessity of supplementing such techniques with any possible piece of additional evidence, anecdotal or otherwise."

In raising confidence levels about where trend productivity growth stands in real time, even advanced techniques can extend only as far as the quality of the productivity data permits. Anderson and Kliesen (2006, 181) warn that data revisions were at times large enough to reverse preliminary conclusions regarding U.S. productivity growth slowdowns and accelerations. They conclude that "the unanticipated acceleration in the services sector and the large size of revisions to aggregate data combine to shed light on why economists were slow to recognize the [mid-1990s] productivity acceleration." Clearly, judgment will continue to play an important role in figuring out the underlying trend in productivity growth. Nevertheless, the better informed this judgment is by approaches that have solid economic and statistical foundations, the less risk there is to commit large, persistent errors. Moreover, analyzing the patterns of revisions to Canadian productivity data over history would help delineate the risks associated with future revisions.

3 Aggregate Growth Accounting

Growth accounting provides a framework for analyzing the sources of aggregate productivity changes in terms of capital deepening, changes in labour quality, and TFP growth. It is through growth accounting studies that the contribution of ICT investment to aggregate productivity growth since the mid-1990s has been brought to light for many countries.

3.1 Model assumptions and limitations

Before reviewing the key results of this work, it is useful to bear in mind some of the limitations imposed by the assumptions of the pure Solow model that underpins the standard growth accounting approach. These limitations have attracted considerable attention, because they may have serious implications for the size and exogeneity of the measured Solow residual (or TFP growth), and because they mask the potential effects of tangible capital composition, embodied technical change, and intangible capital, inter alia.

First, the model assumes that output adjusts fully and instantaneously to capital accumulation or hiring. Lags in the response of output, because resources are temporarily diverted from production to adjustment, may imply that the capital share overestimates the true contemporaneous output elasticity to capital, in which case the measured contribution of capital deepening is overstated and TFP growth is understated. As discussed below, there is some evidence that such adjustment costs have played a role and that this can change the interpretation of the results coming from growth accounting studies. As an illustration, Crafts and Mills (2005) estimate that, in the pre-1973 postwar period in both Germany and the United Kingdom, adjustment costs in the form of a rising supply price of capital goods largely account for an estimated positive bias in excess of 2 percentage points per year in traditional estimates of TFP. A fall in adjustment costs subsequently brought the total bias to much lower values in the 1974–96 period (–0.6 percentage point in the United Kingdom, and 0.1 percentage point in Germany).

Second, instantaneous adjustment assumes away the problem of cyclical variations in capital utilization, and therefore any mismeasurement of capital services out of the capital stock data. Basu, Fernald, and Shapiro (2001) estimate that rapidly diminishing underutilization contributes markedly to measured TFP growth in the 1992–94 period of recovery from recession in the United States. Leung (2004) finds that a failure to adjust TFP growth for varying capital utilization rates causes the current ratio of investment to capital stock for both total investment and machinery and equipment to have first a positive and then a negative effect on TFP growth, an unexpected result that disappears once TFP is adjusted for a changing utilization rate.

Since varying utilization affects TFP growth, it can make it appear to be endogenous to variables that condition domestic output growth, such as monetary variables and U.S. output growth in the Canadian case (Cozier and Gupta 1993). Paquet and Robidoux (2001) find that when the capital stock is adjusted for variations in utilization rates, the Solow residual for Canada is statistically exogenous to various monetary policy shocks and to changes in the relative price of oil, the terms of trade, the price level, and government expenditures.

Third, the standard growth accounting framework rests on the assumptions of perfect competition and constant returns to scale. In the presence of imperfect competition, the measured income shares are not appropriate proxies for the cost shares of the various inputs. The income share of capital is inflated by excess profits, and as a result measured TFP growth is biased downwards in periods of positive capital deepening. Increasing returns to scale, on the other hand, result in a larger marginal response of output to capital accumulation than the average one as proxied by the measured income share of capital. Consequently, TFP growth based on the constant returns assumption is overstated in the presence of increasing returns. Basu, Fernald, and Shapiro (2001) find that deviations from constant returns and perfect competition leave the results of the standard growth accounting largely unchanged for the United States over the 1990s. Paquet and Robidoux (2001) estimate that constant or slightly decreasing returns to scale and perfect competition broadly characterize the aggregate Canadian data, provided that capital is adjusted for varying utilization; otherwise, the empirical evidence suggests that increasing returns to scale and imperfect competition prevail. Since these two deviations from the standard assumptions generate biases in the opposite directions, the net bias in TFP growth that results from the application of the standard growth accounting technique could be quite small.

Fourth, the capital service flows used in growth accounting exercises are derived by weighting the growth of the stock of each asset by its respective rental price or user cost, the rationale being that optimizing firms choose the quantity of each asset such that its marginal product is equal to its implicit rental price. For certain assets, however, the marginal product may depart considerably from the measured rental price and, as a result, aggregate capital services and TFP may be mismeasured. Using a rich dataset on firm-level, asset-specific investment by businesses in the United States, Wilson (2007) find that investment in computers, communications equipment, software, and offices is statistically associated above the 99 per cent level with output conditional on labour and book value of capital, hence with TFP. His results also imply that the marginal products of ICT capital goods are above the U.S. official estimates of their rental prices. This may be because rental price estimates are too low to properly measure normal returns for ICT capital or because ICT effectively earn excess returns. Wilson mentions three possible reasons for such excess returns: unobserved complementary co-investments, such as improvements in workplace practices; adjustment costs, such as learning by doing; or expectational errors by firms in terms of the marginal products of their capital investments.

Besides ICT, public infrastructure capital appears to have spillover effects on productivity beyond capital deepening. The econometric results of Harchaoui and Tarkhani (2003) show that such capital boosts TFP growth in the Canadian business sector, especially in transportation, trade, and utilities. They estimate a translog cost function and linear output demand equation for each of 37 industries, and derive elasticities that allow them to decompose industry TFP growth into four elements: an exogenous demand effect, a factor price effect, disembodied technical change, and a public capital effect. They find that the latter accounts for nearly 20 per cent of TFP growth in the overall business sector over the 1961–2000 period. For the United States, Cohen and Morrison Paul (2004) apply a cost-function model to 1982–96 state-level data on prices and quantities of aggregate output and inputs for manufacturing, and on stocks of public highway infrastructure. They find that intrastate infrastructure makes a significant contribution to manufacturing production, which is markedly enhanced by beneficial interstate cost effects arising from highway infrastructure in neighbouring states.

For Italy, Bronzini and Piselli (2006) use a method that is robust to endogeneity and serial correlation to estimate a significant long-run impact of public infrastructure, human capital, and R&D on the level of TFP across various Italian regions between 1980 and 2001. Public infrastructure levels per capita likely differ markedly across countries. Calculations by Kamps (2006) for the OECD countries, based on identical assumptions across countries about depreciation rates, show that government net capital stock per capita at 1999 purchasing-power parities for gross fixed capital formation was nearly 37 per cent lower in Canada than in the United States in 2000 and had grown slightly slower in Canada than in the United States between 1990 and 2000. To what extent differences in public infrastructure capital contributed to differences in the productivity performance of the business sector across countries remains to be ascertained.

Fifth, in the growth accounting framework, the contribution of technological progress is associated with TFP growth. This is clearly an oversimplification even if the standard assumptions of the Solow model hold, because innovation is also embodied in new capital. Cummins and Violante (2002) use changes in the quality-adjusted price of equipment goods relative to consumption goods to infer the rate of embodied technical change. Their quality-adjusted price for equipment combines national accounts prices for computers and software with prices for some 20 other investment categories reflecting the extrapolated values of Gordon's (1990) estimated quality changes for these categories over 1947–83. They find that a 4 per cent rate of embodied technical change prevailing in the postwar period accelerates to nearly 6.4 per cent in the 1990s, with particularly large gains in computers and peripheral equipment (24 per cent), communications equipment (9 per cent), and aircraft (8 per cent). Using a similar approach for equipment and allowing for 1 percentage point per year quality improvement in non-residential structures, in accordance with the conclusions of a study by Gort, Greenwood, and Rupert (1999), Pakko (2005) estimates that, since the early 1970s, the growth rate of investment-specific technology in the United States has been quite rapid, particularly after 1987. If this unmeasured embodied technical change is added to measured capital, TFP growth becomes negligible over the whole period.

In a careful exploratory study, Wilson (2002) shows that the decline in the relative price of a variety of capital goods is positively correlated with the R&D that is done by the economy as a whole on each of the capital goods. Constructing measures of capital-embodied R&D, he establishes through econometric tests on industry panel data that they have a strong effect on conventionally measured TFP growth. His investigation reveals that part of this effect would stem from the mismeasurement of quality change in capital stock, but another part would reflect a real phenomenon – a positive relationship between embodied and disembodied technological change. He speculates that this positive relationship may arise inter alia from true knowledge spillovers within an industry, stemming from the business interactions between capital goods suppliers and innovating customers.

Finally, growth accounting is not synonymous with causality. The correlation between capital deepening and an increase in productivity, for instance, may partly arise from the fact that strong productivity growth boosts profits and stock prices relative to the replacement cost of capital, and thereby stimulates investment. As Baily (2002, 8) puts it, "the coincident timing of the surge in productivity and in investment in information technology is a key reason for thinking the latter caused the former, but correlation does not determine the direction of causality or even whether a causal relation exists." In other words, evidence from industry/firm data and case studies is needed to confirm the causality suggested by growth accounting.

Areas for further research

Standard growth accounting is an indispensable tool for tracing the immediate sources of productivity variations. It has several limitations, but they do not appear to be serious enough to invalidate the broad conclusions that emerge from its application. Some studies have revealed that adjustment costs associated with investment, particularly in ICT, tend to delay the response of productivity to capital accumulation and embodied technical progress. Partly for this reason, the measured respective contributions of capital deepening and TFP growth do have significant margins of error, and these would be prone to widen in periods of investment boom and/or pronounced under/overutilization of capital. Better measuring the size and timing of adjustment costs would help interpret the dynamics of productivity, including the prospects for shifts in trend productivity growth.

3.2 Labour quality and labour market conditions

One of the key inputs into growth accounting exercises is the measurement of the contribution from labour. Various growth accounting exercises reveal that variations in labour quality, in terms of education and experience, for instance, have generally had a positive but moderate effect on labour productivity growth since the early 1970s (Gu et al. 2002). In Canada, labour quality is measured as the difference between unweighted and weighted total hours worked, with the latter broken down according to 56 types of workers, each weighted by its relative hourly compensation. Workers are classified according to seven age groups, four education levels (primary, secondary, post-secondary, and university), and two employment categories (paid and unpaid, the latter including self-employed). Thus, the measure of labour quality rests critically on the assumption that observed wage differentials by worker type are good proxies for relative productivity levels. This is probably more the case over spans of several years than over one year or two.

Labour quality accounts for one-quarter of total labour input growth over the 1961–2000 period, and for as much as three-quarters of that total over the 1988–95 period (Gu et al. 2002). Rising education attainment has systematically been the main contributor to the increase in labour quality since 1961, but it has lost some momentum in the post-1995 period. The increasing age of workers, a proxy for experience, made a very significant positive contribution over the

15-year period to 1995, but has since diminished in importance. A gain in the relative importance of self-employment has slightly reduced measured labour quality since the late 1980s.

The experiences of OECD countries reveal that there is also a cyclical dimension to labour quality changes: weak labour market conditions encourage employers to recruit better-educated staff at the expense of those with fewer skills, while labour shortages oblige employers to hire low-educated workers with little experience (OECD 2004). Ireland and the Netherlands are examples of countries where labour shortages have resulted in a reduction in average labour quality and depressed productivity growth over the 1990s.

Historical experience suggests that it is not just the average level of human capital, such as may be measured in productivity statistics, that matters in sustaining technological progress, but also the density in the upper tail of the distribution of talent. Reflecting on the role of human capital in technological progress since the Industrial Revolution, Mokyr (2005) submits that "it may well be that the best models to explain technological progress (in the sense of inventing new techniques rather than implementing existing ones) should focus not on the *mean* level of human capital (or, as model-builders have it, the level of human capital of a representative agent), but just on the *density in the upper tail* of the distribution. In other words, what mattered above all was the level of education and sophistication of a small and pivotal elite." The current worldwide competition for talent by companies and governments, recently documented by Wooldridge (2006), seems consistent with this view. And so is the Acemoglu, Aghion, and Zilibotti (2002) model of economic growth, in which the switch from a regime of adaptation of existing technologies to one that generates leading-edge innovations depends on the selection of an elite of high-skill managers.

3.3 Capital input and ICT investment

With evidence indicating that capital composition can matter for productivity growth, it is not surprising to see the interest in the past decade in the impact of ICT on productivity growth. With the rapid decline in ICT prices, it was natural for firms to substitute towards these types of capital goods. This was the case in Canada. After growing, on average, in the 6 per cent range between 1987 and 2005, nominal ICT investment growth doubled to 13 per cent between 1995–2000 (Table 2). The jump was particularly strong in communications technologies, which went from 3 per cent average growth to over 17 per cent. In the current decade, however, ICT investment has slumped, falling about 1.5 per cent, with declines in both hardware and communications equipment. By contrast, software investment has continued to grow, advancing about 5 per cent. Canada's growth rates in ICT investment over these periods are comparable to those in the United States.

In 2004, Canada's share in total non-residential investment averaged about 20 per cent, ranking eighth among OECD countries, and above the OECD average (Chart 1). Nevertheless, this was a sharp jump compared with 1990, when the ICT investment share amounted to about 14 per cent. The United States was the leader, devoting about 30 per cent of investment towards ICT. Canada's share was similar in magnitude to that of the Nordic countries, Australia, New Zealand, the United Kingdom, and the Netherlands. Canada's investment by asset class – hardware, communications, and software – was also around eighth (Charts 2, 3, and 4).[1]

Investment data do not give the complete picture necessary for productivity analysis. For such analysis, capital stock (or capital services) data are preferable.[2] Data from the OECD indicate that, in 2002, Canada's capital intensity in the total economy – capital per hour worked – was about 74 per cent of that of the United States (Schreyer 2005).

Several OECD studies (OECD 2003, 2004) indicate that the following factors can help to diffuse ICT capital throughout the economy:

- Most obviously, the costs of such equipment. Despite the fact that such goods are highly traded, there are persistent cost differences, particularly in Europe, where costs are much higher.

- The cost of communications, since this is important for deriving the network benefits that come from ICT investment. Canada and the United States tend to have relatively low costs, and Europe higher.

- Countries with strict labour and product market regulation typically have lower ICT investment. In this area, Canada fares better than many European countries, but less well than the United States.

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1. Comparisons of capital stock data and data by asset type must be made with caution. Countries differ in the measurement of investment by asset class, particularly for software. On the real side, Canada and the United States largely use hedonic pricing techniques to measure volumes, but many European countries do not.
2. Total capital services is an aggregation of industry capital services. Within each industry, capital services represent a weighted average of capital stock by asset type, with the weights corresponding to the user costs of these assets. In this way, each asset is weighted by its rate of return and capital services reflect changes in capital "quality."

- Greater ICT investment is strongly correlated with innovation as measured by patents, and in this measure of innovation, Canada ranks low.

- The availability of qualified personnel to take full advantage of the benefits of ICT equipment, and scope for organizational change. Several studies for various OECD countries, reviewed by Pilat (2004), confirm the link between skills and either ICT take-up or greater benefits from ICT use (see next bullet).

- Typically, ICT take-up increases with firm size (Pilat 2004). Large firms may have a stronger skills base to draw upon, or may be able to use the technology to redesign their information flow.

Some researchers have investigated how the diffusion of ICT might influence productivity growth quite apart from the capital input channel. Diffusion intensifies networks and the question is how much increasing participation in networks may have contributed to productivity growth. Atrostic and Nguyen (2005) use plan-level data for U.S. manufacturing to estimate the separate effects of computer networks and computer input on labour productivity, controlling for other inputs, industry, plant size, the mix of production and non-production workers, and whether the plant belongs to a multi-unit firm. A dummy variable for the presence of computer networks takes on a value of one if the plant reports having any of several kinds of computer network, and zero otherwise. The authors find that computer networks and computer investment both have positive and significant relationships to labour productivity.

In a somewhat different vein, Fuss and Waverman (2005) combine growth accounting data with information on the penetration rates of telephones, personal computers, and the degree of digitization of telecommunications infrastructure for 16 OECD countries over the 1980–2000 period. They find in their panel regressions that after controlling for non-ICT capital deepening, ICT capital deepening and the growth of total hours worked, the penetration rate of personal computers exerts a very significant influence on labour productivity growth.

Areas for further research

The data suggest that, on the surface, differences in ICT capital accumulation may have played an important role in productivity growth divergences in the 1990s, but less so in the current decade. Nevertheless, several of the factors that appear to explain ICT investment are probably also contributing factors to diverging patterns of productivity growth.

3.4 ICT and complementary investments

ICT is seen as a general-purpose technology (GPT), because it is pervasive, less and less costly to use, and facilitates the invention and production of new products and processes (Jovanovic and Rousseau 2005). Theoretical models of GPTs predict that productivity should slow down and the skills premium should rise as the economy adjusts to the diffusion of ICT. The effect of ICT on productivity is therefore likely to be contingent on the supply of skilled labour and on complementary investment in workplace reorganization. "Case studies and econometric work point to organizational complements such as new business processes, new skills and new organizational and industry structures as a major driver of the contribution of information technology" (Brynjolfsson and Hitt 2000, 45).

Gu and Wang (2004) show that ICT use is linked to the TFP growth acceleration through ICT-induced organizational innovation and network or spillover effects. Gu and Wang (2004) also find evidence consistent with lags between capital deepening and TFP growth. For example, a 0.1 percentage-point increase in ICT capital share is associated with a 0.4 percentage-point acceleration in annual TFP growth after 1995. Within the manufacturing sector, Gu and Gera (2004) find that Canadian manufacturing industries that invest in ICT perform better than those that do not, and firms that invest in ICT and adopt new organizational practices perform even better. Their findings suggest that firms need to adopt a cluster of changes – ICT and organizational – to reap the full benefits of ICT. In the services sector, Gu and Gera (2004) find that firms that adopt a greater number of ICT as well as human resource management (HRM) practices tend to perform better. These results are consistent with earlier findings (Bresnahan, Brynjolfsson, and Hitt 2002) for the United States of complementaries among ICT, workplace reorganization, and new products and services in driving demand for skilled labour at the firm level.

Dostie and Trépanier (2005) also find evidence that organizational investment enhances the returns to ICT in Canada, but from a somewhat different angle. Using the longitudinal Workplace and Employee Survey, which contains information on both wages at the worker level and organizational practices at the firm level, they find a significant wage premium of 5 per cent to 6 per cent associated with computer use, after controlling for unobserved firm heterogeneity in addition to worker heterogeneity. This is consistent with computer use boosting labour productivity. Furthermore, they establish that the returns to computer use are related to organizational practices that emphasize decentralization and worker autonomy.

Bloom, Sadun, and Van Reenen (2005), using a large panel of manufacturing and non-manufacturing establishments in the United Kingdom over the 1995–2003 period, show that “US firms in the UK were able to get significantly more productivity out of their IT than other multinational (and domestic British) firms, even in the context of a UK environment. This suggests that part of the IT-related productivity gains in the US may be due to the management/organizational capital of firms rather than simply the ‘natural advantages’ (geographical, institutional or otherwise) of the US environment.” One reason why U.S. firms would have achieved these ICT-facilitating organizational forms to a greater extent than their foreign competitors is that they are more “organizationally devolved” because of their greater supply of college education skills, relative absence of family-owned firms, and/or their history of technological leadership.

Whereas Bloom, Sadum and Van Reenen. (2005) infer the role of organizational capital from the significance of a dummy variable for U.S. multinational firms in their regressions, Crespi, Criscuolo, and Haskel (2007) directly evaluate the impact of changes in organizational capital on labour productivity growth across U.S.-owned, other foreign-owned, and domestic firms operating in the United Kingdom, using a measure of organizational capital derived from a survey. They confirm that U.S.-owned firms are much more likely to introduce organizational change than U.K. and other foreign counterparts. They estimate that changes in organizational capital have a significant effect on productivity growth through their interaction with information technology (IT) investment relative to real output. In other words, investment in IT has more impact if accompanied by an increase in organizational capital. The authors also find that investment in organizational capital responds to competitive pressures: firms that lose market share in previous periods are more likely to undertake organizational change in the current period.

A strong positive correlation emerges in studies at the firm and industry levels between ICT use and human capital. Gu and Wang (2004), for instance, find that industries with larger shares of knowledge workers are more likely to benefit from ICT. Abowd et al. (2007) uncover a strong positive relationship between the capital intensity, the computer investment, and the computer software expenditure intensity of a business in the United States and the share of high human-capital employment at the business. One new result that their work reveals is that firms that use advanced technology are more likely to use high-ability workers, but less likely to use high-experience workers. These results hold even after controlling for unobservable heterogeneity.

The positive correlation between ICT and human capital may reflect the fact that the supply of skilled labour has a positive effect on ICT adoption, but it may also be taken as evidence that

ICT diffusion has increased the relative demand for skilled labour by reducing the labour input of routine tasks, for example, and raising the labour input of non-routine cognitive tasks (Autor, Levy, and Murnane 2003; Yan 2005).[3] As Doms and Lewis (2006) state, "Properly identifying how the supply of skills affects technology adoption, and how technology adoption affects the demand for skills, has proven challenging." Using a rich dataset on computer usage by businesses and the share of college-educated workers in the total workforce across 230 U.S. cities over the 1990–2000 period, they go to great lengths to identify the supply of skills by deriving instruments for the college-educated share by city and controlling for a number of factors. Inasmuch as the great variations across cities allow them to build more plausibly exogenous measures of supply, their results provide the strongest evidence so far that a robust, positive relationship exists between the supply of skills and computer adoption by businesses. Beaudry, Doms, and Lewis (2006) extend Doms and Lewis (2006) by specifying and testing a neoclassical model of endogenous technology adoption in which relative factor prices influence technology choice. They examine how the initial supply of skilled labour affects the diffusion of personal computers (PCs), and how this diffusion influences the demand for labour. Consistent with their model predictions, they find that the cities where college-educated labour was cheapest (and most abundant) relative to less-skilled workers in 1980 were those that adopted the PC most intensely (the supply effect) between 1980 and 2000 and saw the returns to college education increase fastest (the demand effect).

Baldwin and Sabourin (2001) find that greater use of advanced ICT in firms is associated with higher labour productivity growth and gains in market share. Their study is unique in that it looks at different combinations of ICT to determine which boost growth the most. They find that the productivity gain is largest in firms that adopt communications technologies. And firms that adopt the suite of ICT – hardware, software, and technologies – have higher relative productivity than those that do not adopt any advanced technology. In a case study of the food processing industry, Baldwin, Sabourin, and Smith (2004) examine the use of advanced technologies using a broader set than in Baldwin and Sabourin's 2001 study. They find that labour productivity growth is positively related to the number of advanced technologies adopted. In particular, ICT investment works best with the adoption of other technologies. By contrast, the use of some advanced technologies by themselves has a limited impact on productivity growth. For example, the adoption of advanced process control technology has little effect on productivity growth,

3. Autor, Levy, and Murnane (2003) find that the shifts in tasks associated with computerization can explain 60 per cent of the estimated relative demand shift in favour of college-educated labour in the United States between 1970 and 1998.

but when combined with ICT, the effect becomes significant. These findings are robust to the inclusion of several control variables, such as activities and firm characteristics.

Dufour, Nakamura, and Tang (2006) explore a related hypothesis for Canada, that certain technologies and business practices are complementary and that bundles of such complements lead to higher productivity than technologies or practices used in isolation. For this purpose, they link the Annual Survey of Manufactures (ASM) for 1995 and 1998 with the 1998 Survey of Advanced Technology, which provides information on whether manufacturing establishments use any of 26 different advanced technologies and 12 different business practices. This information allows them to identify bundles of commonly co-occurring business practice and advanced technology (CoBAT). They find that establishments that have adopted such bundles tend to have superior ex ante labour productivity performance, after controlling for capital intensity, head office location, export orientation, and size. The direction of causality between CoBAT bundles and productivity is unsettled, however, as logit analysis reveals that ex ante productivity itself boosts the probability of adopting technologies or business practices, and more so when they are bundled.

Areas for further research

There is some evidence that firms need to adopt a suite of technologies and/or human resource policies to derive full benefits from ICT. Other studies suggest that the greatest benefit comes from the adoption of particular types of technology, especially communications technologies. This may be due to the network effects that can arise, allowing firms to rethink how they do business. Further research is needed to understand the complex linkages that exist between the adoption of ICT, or types of ICT equipment, and practices in areas such as human resources (e.g., recruitment, training) that help to diffuse it and spur productivity growth.

3.5 Sources of productivity growth across countries: evidence from growth accounting studies

As noted earlier, growth accounting studies have been the stalwart of productivity analysis. Growth accounting estimates, however, are sensitive to the period of analysis and to data revisions. In comparing the results of recent studies, differences in endpoints may have a significant effect on the size and sources of average productivity growth.

Nevertheless, it has become standard in growth accounting to compare the late 1990s with the early 1990s following the publication of influential U.S. studies that showed a substantial revival in labour productivity growth over this period. Indeed, labour productivity in the United States has been in a high-growth regime since the mid-1990s, with the pace almost doubling to 3 per cent in the non-farm business sector relative to the previous regime (Table 3). The acceleration has resulted from increases in capital deepening and TFP, particularly in the ICT sector. For example, Oliner and Sichel (2002) find that ICT capital deepening accounted for over 40 per cent of labour productivity growth between 1996 and 2001. These results are similar to those of Jorgenson, Ho, and Stiroh (2005). Moreover, the acceleration in growth resulted largely from greater capital deepening, despite a pickup in TFP growth via ICT.

More recently, studies point to a large increase in TFP growth from the ICT-using sector as the reason behind the acceleration in aggregate labour productivity growth (Jorgenson and Stiroh 2000; Triplett and Bosworth 2002, 2004). This became more clear in the 2000–05 period, when the direct contribution of ICT from both a capital deepening and TFP growth perspective diminished considerably, with the shortfall more than made up by a sharp pickup of TFP growth in the non-ICT sector (Tables 3 and 4). This analysis is supported by Jorgenson, Ho, and Stiroh (2005), who also find that, between 2000–04, the surge in labour productivity growth was accompanied by a large pickup in TFP in the non-ICT sector, as well as by an increase in non-ICT capital deepening.[4]

The growth accounting results for the United States change somewhat if investment in intangibles is factored into capital services and GDP (Corrado, Hulten, and Sichel 2006). Besides computer software, which is already included in the published investment data, these intangibles include scientific R&D, non-scientific R&D, brand equity (mainly advertising expenditures), and firm-specific resources, including the costs of employer-provided worker training. Their inclusion raises the pace of labour productivity growth in the non-farm business sector by about 0.15 percentage point per year relative to the official figures (e.g., 3.09 per cent vs. 2.95 per cent over 1995–2003), but has no effect on the size of the upward shift in productivity growth after 1995. Capital deepening then accounts for 54 per cent of productivity growth over 1995–2003, instead of 43 per cent, while the contribution of TFP falls to 35 per cent from 45 per cent. More recent estimates by Oliner, Sichel, and Stiroh (2007) show that including intangible assets considerably affects not only the size but also the direction of the productivity shift between 1995–2000 and 2000–06. Including tangible assets boosts labour productivity growth substantially over 1995–2000 relative to published data, but also results in a marked slowdown

4. Measurement differences probably account for some of the discrepancy. In addition, as Triplett and Bosworth (2004) note, there is no inconsistency in their finding that TFP growth in services was largely responsible for the labour productivity growth acceleration vs. other studies that attribute it to IT production. In fact, it has been strong in both, but the total contributions of industries that have been growing are greater than the net productivity growth in a particular sector. Moreover, IT capital deepening has been important and its contribution large, but it did not increase in the latter part of the 1990s, and so it cannot account for the acceleration in labour productivity growth.

of productivity growth over 2000-06, in contrast with the significant acceleration shown in the published data.

In contrast to the U.S. experience, the European Union (EU) as a whole experienced a productivity slowdown in the second half of the 1990s (Table 3), following almost two decades of trend productivity growth in the neighbourhood of 2½ per cent per year (Skoczylas and Tissot 2005). Moreover, labour productivity growth weakened markedly in the first half of the 2000s, probably partly for cyclical reasons, but also because the contribution of ICT, either through capital deepening or TFP growth in the producing sector, was tepid (van Ark and Inklaar 2005). However, the falling rate of labour productivity growth mostly reflects a plummet in TFP growth in the non-ICT sector. Thus, a growing labour productivity gap between the United States and Europe in the first half of this decade essentially arose from divergent profiles of TFP growth in the non-ICT sectors.

Studies that focus on Canada for the period up to 2000 point to similarities and differences with respect to the United States and Europe (Table 5):[5]

- Between 1988–95, the largest contribution to aggregate labour productivity growth in the business sector was capital deepening. This is in contrast to both Europe and the United States, where about half the gains came through capital deepening. Capital deepening increased mainly via ICT and, more specifically, computers. Labour quality was also an important contributor. The studies differ on the role played by TFP. Harchaoui and Tarkhani (2003, 2004) find a negative contribution from TFP growth, whereas Gu and Wang (2004) find a sizable positive contribution. Since TFP is a residual, the difference lies in the greater contribution from labour quality and capital deepening.

- In contrast to both Europe and the United States, TFP became the main source of labour productivity growth in Canada between 1995 and 2000. Moreover, all of the acceleration in labour productivity growth came through TFP.

5. Most of these studies use the KLEMS data from Statistics Canada. KLEMS is the productivity database and consists of data on capital (services) and labour (quality adjusted) inputs, as well as data on energy, materials, and services. The data run to 1997 based on the standard industrial classification (SIC). After this, data are available on the new industry classification system, NAICS. Because of this, data used in these studies from 1997–2000 were converted to an SIC basis to obtain time series comparability.

- In Canada, the acceleration in TFP growth appears to have been largely the result of increases in the non-ICT sector. But even within the ICT production sector, TFP growth has been much slower in Canada. Moreover, the pace of growth in Canada decelerated in the 1995–99 period, whereas in the United States it accelerated.

The productivity gains recorded in Canada over the better part of the 1990s were not sustained. A recent study by Statistics Canada (Baldwin and Gu, 2007) reveals that labour productivity growth slowed from 3.1 per cent between 1996 and 2000 to 1.0 per cent from 2000 to 2006 (Table 6). Although the contribution from capital deepening and labour composition each diminished, it was the plummet in the contribution from multifactor productivity growth that was largely responsible for the deceleration. This was in sharp contrast to the United States, which witnessed an increase in the contribution from TFP. Thus, any search for an explanation behind the deceleration in labour productivity growth in Canada must comprise an examination behind the lacklustre TFP performance. The latter appears to be related in part to business cycle developments and the bust in the demand for ICT in the early 2000s. Other studies suggest that a sharp slowing in TFP took place outside of ICT production (Harchaoui, Dachraoui, and Tarkhani 2003 and Rao, Sharpe, and Smith 2005; for the latter, the data are presented in Table 7).

3.6 Interpreting the growth accounting studies

Growth accounting studies suggest that both the use of ICT and efficiency gains in the production of ICT have played a key role in the American productivity resurgence since the mid-1990s. The initial lack of TFP growth improvement in non-ICT-producing sectors may have reflected adjustment costs associated with the surge of investment in ICT (Yellen 2005; Basu, Fernald, and Shapiro 2001). Basu, Fernald, and Shapiro (2001) find that adjustment costs depress TFP growth, and therefore may obscure the role of technology in periods of strong capital expansion, such as the late 1990s. In other words, the acceleration from the first half to the second half of the 1990s in U.S. TFP growth associated with technological change gets sharper when adjusting for non-technological factors that affect the measured Solow residual. Groth, Nuñez, and Srinivasan (2006) find that, for the U.K. non-farm private economy, the conventional Solow residual understates the underlying pace of technological progress during the 1990s, because it ignores falling utilization rates and high capital adjustment costs. Even without this distortion, however, the acceleration in technical progress in the second half of the 1990s remains the same as implied by the conventional estimate, in contrast with the results obtained by Basu, Fernald, and Shapiro (2001) for the United States.

Capital adjustment costs may originate from substantial but unrecorded complementary investments in learning and reorganization, especially in the case of ICT, which has attributes of a GPT. Drawing on macro models of GPT and the results of micro empirical studies, Basu et al. (2003) and Basu and Fernald (2006) derive, and empirically test, the theoretical implications of complementary capital accumulation for the measured TFP of ICT-using industries, based on the assumption that observed investments in ICT are a proxy for unobserved investments in organizational capital. They find that, consistent with these implications, ICT capital growth in the United States is positively associated with TFP growth with long lags of 5 to 15 years and that, given past investments, contemporaneous ICT capital growth is negatively associated with TFP growth (adjustment cost). In a Canadian context, Leung (2004) estimates that changes in the ratio of investment to capital stock for computer hardware from the early 1960s to 2001 have positive spillover effects on TFP growth adjusted for capacity utilization, but only after three years because of the temporary negative effects of adjustment costs.

Along a similar line, Baily (2004) cautions that growth accounting may overstate the impact of ICT, because of the coincident timing of the surge in productivity and in ICT investment. He stresses that innovation, critically dependent on building intangible capital, drives productivity, but that often it is not strongly related to ICT use. Indeed, Baily (2004) and Gordon (2004) emphasize the importance of intangible investment as a source of productivity gains. The argument is that while firms are investing in ICT equipment, they are also investing in the knowledge – or intangible capital – of how to use the equipment effectively. In the U.S. case, it was not until 1995 that the payoff from investment outweighed the adjustment costs. Baily (2004) notes that in the current decade, one potential reason for the surge in productivity growth in the United States may be a reduction in this intangible investment which, if true, may lead to a slowdown in productivity growth later in the decade.

Studies that have used growth accounting data at the industry or aggregate level to look into the potential role of earlier ICT investment in the acceleration of U.S. TFP growth in the last decade, and particularly after 1999, yield mixed results. Bosworth and Triplett (2007) find that over 5-year periods from 1995 to 2005, TFP growth in the U.S. non-farm business sector is negatively related to contemporaneous ICT intensity and positively related to lagged ICT intensity, as predicted by theory, but that the relationships are mostly statistically insignificant. Oliner, Sichel, and Stiroh (2007) estimate cross-sectional regressions that compare the change in U.S. productivity growth over two periods to a measure of ICT intensity from the end of the first period. They find that the most ICT-intensive industries in 1995 experienced the largest increase in productivity growth after 1995 and that these gains persisted through to 2005. Their results, however, do not support the view that the post-2000 acceleration in U.S. productivity is related to the accumulation of ICT capital in the late 1990s, and therefore to the notions of lags in learning how to use ICT effectively or of time to build complementary capital. Corrado et al. (2007), on the other hand, find that a significant positive relationship between the acceleration of U.S. TFP growth by industry in 2000 to 2004 relative to 1995 to 2000 and the extent to which ICT investment by industry was above trend in the late 1990s suggests that the productivity-enhancing effect of ICT capital (beyond its direct effect through capital deepening) contributed to the strong pace of productivity growth since 2000. The conclusions reached about the importance of adjustment costs and spillover effects associated with ICT capital growth will likely remain fragile to data revisions for a while.

At the firm level, several studies uncover a significant relationship between ICT investment and TFP growth for U.S. businesses. Brynjolfsson and Hitt (2003), for instance, examine the relationship between growth in computer spending and growth in output and TFP for 527 large firms over 1987–94. They find that over a 1-year horizon, computer investments earn normal returns, i.e., they contribute to output growth but not to TFP growth, but over 5- to 7-year horizons, they earn up to five times normal returns. They judge their results consistent with the argument that computers complement other long-term productivity-enhancing investments, that are carried out over a period of several years. Wilson (2007) also uncovers supernormal returns on ICT capital at the firm level and suggests that the trend towards more use of ICT capital relative to other capital by U.S. businesses will be an important driver of productivity growth going forward.

The results concerning the relationship between ICT investment and TFP growth for countries other than the United States are also mixed. Leung's (2004) estimates for Canada reveal that, among total investment, machinery and equipment investment, and ICT, only the latter have a positive impact on TFP growth. Likewise, Connolly and Fox (2006) find that, in aggregate, high-tech capital is more productive than other capital in the market sector of the Australian economy. At the industry level, the positive relationship between the high-tech share of capital and TFP is significant in wholesale and retail trade; finance, insurance, and real estate (FIRE); accommodation and food; construction; and agriculture. Inklaar and van Ark (2005), on the other hand, show that for an aggregate sample of seven large countries (France, Germany, the Netherlands, the United Kingdom, Canada, Australia, and the United States), ICT earns its normal returns, but no supernormal returns, in the early phase of ICT investment, followed by a period of negative effects on TFP growth and finally a return to normal returns after several years. At best, ICT has no positive effect on TFP growth for this group of countries.

In the European context, van Ark and Inklaar (2005) argue that Europe at best has drawn normal returns from what they label the direct, "hard" savings permitted by ICT in the 1990s, but may well have been recently in the next phase of experimentation to reap the supernormal returns from the more far-reaching, "soft" savings to be drawn from ICT. During this phase, ICT and TFP growth tend to be negatively related, pending the realization of complementary innovations and the weeding out of inefficient users of ICTs. Since this process importantly hinges on competitive pressures and flexibility in product and labour markets, an area where Europe is deficient relative to the United States, they argue that "Europe risks getting stuck in an environment where the productivity gains from soft savings from ICT remain unrealized."

Several studies, including those by the OECD, suggest that the United States has benefited the most from ICT use, because it already had a high level of competition in the 1980s. The United States had strengthened its regulatory environment, allowing it to reap the benefits of ICT as prices fell. By contrast, poor progress in these areas, as well as slow adjustment to labour market institutions, has probably hampered Europe (Gust and Marquez 2002).

The OECD finds evidence that an increasing disparity in productivity performance among advanced countries reflects, in part, different levels of anti-competitive regulation across countries (Conway et al. 2006). Such regulation hampers the catch-up process, mainly through barriers to diffusion of ICT, and the impact increases with the distance of a country from the global technology frontier. In Canada's case, given significant gaps in productivity and anti-competitive regulation in ICT-intensive sectors relative to the best OECD performers, Conway et al. (2006) estimate that average annual productivity growth in the business sector would have been 1 percentage point higher over the period 1995–2003 had regulation been eased to the least restrictive of competition in non-manufacturing sectors in OECD countries in 1995. In interpreting this large impact, extra caution must be exercised, since it derives from a partial-equilibrium approach.

Endogenous growth theory has recently paid considerable attention to the question of how a country's growth performance will vary with its distance from the technological frontier, how far convergence will go, and under what policies. While recognizing that the further a country is from the global technology frontier the faster it will grow, endogenous growth theory suggests that the interaction of policies with state variables (e.g., distance to the frontier, institutional environment) has an important effect on productivity performance (Aghion and Howitt 2005). Acemoglu, Aghion, and Zilibotti (2002), for example, develop the ideas that institutions/strategies that favour implementation/adaptation of borrowed technologies are not the same as those that promote leading-edge innovations, and that, at some point, a switch to the latter is necessary for a country to catch up with the frontier level of output per capita/productivity. Based on these ideas, Aghion and Howitt (2005) venture the following explanation for the United States–European Union growth discrepancy since the mid-1990s:

> A plausible story . . . is that the European economy caught up technologically to the US following WWII but then its growth began to slow down before the gap with the US had been closed, because its policies and institutions were not designed to optimize growth when close to the frontier. . . . the IT revolution resulted in a revival of [growth at the technology frontier] in the late 1980s and early 1990s. Since Europe was not as well placed as the US to benefit from this technological revolution the result was a reversal of Europe's approach to the frontier . . . the fact that Europe is not adjusting its institutions in order to produce the growth maximizing innovation policy, acts as a delaying force on growth convergence towards the US.

In this vein, Gordon and Dew-Becker (2005) submit that the slowdown of European productivity growth since the early 1990s is a direct consequence of labour market reforms enacted in the mid-1990s in many EU countries. In their view, relaxing rigid work rules and high wage floors has allowed employers to hire more low-wage, low-productivity workers, and as a result has pulled down average productivity growth in Europe. In a similar vein, Gomez-Salvador et al. (2006) argue that policies designed to raise the employment of low-skilled workers may have reduced average labour quality growth in the EU since the mid-1990s. They also attribute the concurrent fall in capital deepening to sustained wage moderation and continued progress with labour market reforms, the effect of which was to incite firms to shift to more labour-intensive production. Empirical work in Canada (Leung and Yuen 2005) and New Zealand (Hall and Scobie 2005), for instance, suggests that moderation in the relative price of labour to capital leads to less capital-labour substitution, and hence less absorption of capital-embodied technologies. Hall and Scobie (2005) report that the cost of labour relative to capital fell sharply in New Zealand relative to Australia between 1987 and 2002, thereby contributing to lesser capital deepening and productivity growth in New Zealand. In a similar vein, Rao, Tang, and Wang (2007) estimate from panel data for 41 industries that lower wages and higher investment goods prices in Canada as well as lower R&D intensity and skill levels are major determinants of the manufacturing and equipment (M&E) capital intensity gap relative to the United States.

The absence of a cyclical slowdown in U.S. productivity growth in the early 2000s indicates an absence of labour hoarding that is unusual during an economic slowdown. This suggests that structural adjustment conducive to faster efficiency gains had been under way in those years. Indeed, Oliner, Sichel, and Stiroh (2007) find empirical support for the view that competitive/ profit pressures in an environment of more flexible and efficient labour markets led to relatively fast productivity growth via labour shedding. Industries that experienced the largest decrease (increase) in profits through 2001 recorded significantly slower (faster) hours growth and faster productivity growth from 2001 to 2004, without output growth being affected significantly differently from other industries. In their view, the resulting labour shedding essentially reflects how firms chose to trade off productivity and hours growth to achieve a certain amount of output growth.

Areas for further research

Growth accounting for Canada shows that, while ICT was an important driver of productivity gains in the late 1990s, the acceleration in labour productivity growth came from TFP. These gains were not sustained, however, and a slowdown in TFP growth has contributed to slower labour productivity growth.

The slump in this decade appears to reflect, in part, robust employment gains and a shift to more labour-intensive production in response to wage moderation. This issue requires more rigorous analysis. Moreover, taking on new staff would initially lower productivity growth via adjustment costs, and lacklustre growth would continue until knowledge to complement technology was built up. Leung's (2004) finding for Canada that investment in ICT has a positive effect on aggregate TFP growth only after considerable lags raises two questions: (i) why the large increases in ICT investment in the late 1990s do not appear to have paid off in more sustained strengthening of productivity growth recently, particularly in the non-ICT sector, as in the United States, and (ii) whether the slowing in ICT investment in this decade will temper productivity growth going forward, in contrast with the very recent experience of the United States. As advocated earlier, better measuring of the size and timing of adjustment costs would help interpret the dynamics of Canadian productivity.

Cyclical factors may have played a role in the divergence in productivity growth across countries, but they are unlikely to have been a dominant factor. For example, the United States experienced a more severe economic slowdown than Canada in 2001 and 2002, but this does not show up in the U.S. productivity numbers. In this comparison, the U.S. experience appears to be more atypical than the Canadian one, clearly suggesting that a new regime was in place in the United States but not in Canada. The United States was better able to adapt, and more quickly, to changing economic circumstances than did Canada. Rao, Sharpe, and Smith (2005) identify several related factors, including the slowing in growth of the ICT capital stock, a smaller R&D intensity in the business sector, and lower growth in university-educated workers.

Capital composition matters for productivity growth, since some types of investment, notably in ICT and public infrastructure capital, have positive spillover effects on TFP growth in the business sector, while others do not. This suggests that a rise in the shares of ICT and public infrastructure in total capital would stimulate labour productivity. It would be worth updating these results by systematically testing the impact of capital composition on TFP growth in Canada at the aggregate and industry levels.

4 Industry Productivity Studies

The wide diversity in productivity experience, against a background of strong ICT investment in many countries, suggests that other factors besides ICT are important in determining productivity growth. This has led analysts to examine industry-level data to determine whether it is possible to better identify critical factors associated with a stronger productivity performance. As Jorgenson, Ho, and Stiroh (2005) note, the enormous heterogeneity of TFP growth across industries means that analysts should focus on industry-level detail understand the origins of (U.S.) growth resurgence.[6] They also argue that while, in aggregate, the sum of industry productivity data is similar to findings from growth accounting using aggregate data, it is nevertheless important to use industry-level data to fully understand the origins of the (U.S.) productivity revival, partly because aggregate data miss this heterogeneity that can be important to understanding productivity growth. Pilat (2004) and Pilat, Lee, and van Ark (2002), for instance, note that the diffusion of ICT may help establish networks, allow firms to expand their product range, customize services offered to meet client demand, reduce inventories, and so on, which suggests that ICT should have an impact on a wide range of industries, and that the impact may vary tremendously.

The OECD, along with the Groningen Growth and Development Centre, have made the most comprehensive comparisons of industry-level productivity growth across countries. However, comparisons of services sector productivity across countries are fraught with difficulty, given measurement problems in services sector output and prices, and hamper cross-country analysis. Nevertheless, even taking these into account, the divergence in productivity experiences across OECD countries is remarkable.

6. Other reasons to examine industry-level data include measurement error. For example, negative TFP growth could indicate problems measuring output or input (Jorgenson, Ho, and Stiroh 2005).

Data from the OECD for the period 1996–2002 reveal a sharp contrast between continental European countries and others. For example, productivity growth improved in ICT-using industries – and contributed to over half of the productivity growth in the United States and the United Kingdom. In Canada, the figure was about 25 per cent, and in Australia it was just over a third (Table 8). By contrast, productivity growth made up a small share, and fell in France, Germany, Italy, and Belgium. A large share of Canada's labour productivity growth came from non-ICT (other) activities, the most important of which was non-ICT manufacturing, probably associated with the transportation sector. Several European countries also saw non-ICT activities generate a large proportion of productivity gains.

The United States was not the only country in the late 1990s to experience a surge in labour productivity growth from the manufacture of ICT equipment,[7] reflecting both its weight in the economy as well as its performance (Pilat and Wolfl 2004). In Korea, Ireland, and Finland, the manufacture of ICT made up a sizable share of labour productivity gains, contributing almost 1 percentage point to aggregate labour productivity growth (or about half the growth), almost double that of the United States (OECD 2003). In Canada, productivity gains were very large in these industries, but the small weight in output meant a low contribution to aggregate productivity growth. At about 0.1 percentage point, Canada placed thirteenth of the OECD countries examined.

ICT-producing services (telecommunications and computer services) were also a source of rapid progress, in part reflecting the fact that they were directly tied to the development of ICT. Their weight tended to be quite small. Canada, Korea, Finland, France, Germany, and the Netherlands, for example, experienced aggregate productivity gains, of only about 0.2 percentage point as a result of ICT-producing services.

Other OECD countries, because of their small ICT production sectors, relied on the use of ICT equipment to boost productivity growth. This would typically show up in the services sector, which invests substantially in such equipment. Here, the OECD experience is quite diverse. Countries outside of continental Europe have generally seen aggregate increases as a result of the contribution from ICT-using services. This was most pronounced in Mexico, the United States, and Australia, where they contributed over a percentage point to aggregate growth between 1996 and 2002. Canada gained about half a percentage point. By contrast, relative to the early part of

7. These figures are based on labour productivity growth defined as value added per person employed, which would tend to understate growth relative to studies that use hours worked.

the 1990s, the contribution was lower in France, Germany, Italy, and Japan (Pilat, Lee, and van Ark 2002; OECD 2003).

Gordon and Dew-Becker (2005) signal that productivity growth is also quite diverse within the EU. They refer to the fast-growing countries – including Ireland and Finland – that have shown a marked acceleration in productivity after 1995 as "Tigers," whereas the laggards, or "Tortoises" – including France and Italy – have experienced a sharp deceleration. Two-thirds of the growing productivity differential between the Tigers and the Tortoises have their source in "old economy" industries, such as non-ICT manufacturing and construction.

Studies that focus solely on Canada and the United States reach similar conclusions. For example, Harchaoui and Tarkhani (2004), Rao, Sharpe, and Tang (2004), and Ho, Rao, and Tang (2004) attribute much of the productivity acceleration in Canada to service industries. In addition, Ho, Rao, and Tang (2004) find that retail trade, followed by other services, business services, and FIRE, contributed most to labour productivity growth in Canada in the late 1990s. Moreover, the main source of strength in these industries (other than intermediate inputs) was TFP growth, except for business services, where the main driver was ICT capital deepening.

The acceleration in TFP growth in the late 1990s was pervasive across industries: industries that experienced an acceleration in TFP growth accounted for more than 70 per cent of output, and eight of the 10 largest contributors were in service industries. Gu and Wang (2004) find that, in 63 industries in Canada, average labour productivity growth accelerated post-1995, and this was also the case for TFP in 62 industries. In addition, 49 industries had an increase in both labour and multifactor productivity. For the period 1995–2000, ICT-intensive industries[8] contributed 0.71 percentage point, or 66 per cent of the aggregate TFP growth. Gu and Wang (2004) find a statistically significant increase in TFP of 0.3 percentage point in the post-1995 period across Canadian industries. This seems consistent with the notion that ICT boosted productivity in these sectors.

Jorgenson, Ho and Stiroh (2005) find widespread labour productivity gains across U.S. industries, and to a large extent these are associated with increases in TFP growth. This is consistent with findings of Triplett and Bosworth (2004). For example, 28 of 41 industries experienced greater TFP growth. This was also the case for labour productivity growth. Jorgenson and Stiroh (2000) note that the U.S. industries that invested most heavily in ICT assets in the 1980s and early 1990s had the largest acceleration in labour productivity growth. This

8. These industries exclude the manufacturing sector.

investment would therefore have resulted in an initial productivity burst in the late 1990s through capital deepening, as well as TFP gains in the ICT production sector. In this decade, there has been a further jump in TFP, but largely concentrated outside the ICT sector. Thus, the lags between this investment and its full appearance in labour productivity growth may be longer than first assumed, perhaps owing to adjustment costs and the building of intangible capital, as noted earlier.

More recent data from Inklaar, Timmer, and van Ark (2007) show that, between 1995–2003, the services sector contributed about two-thirds of the growth in business sector labour productivity in Canada. This was also the case in the United States, Australia, and the United Kingdom. Of this, the bulk of the gains came from TFP growth in Australia and Canada, whereas, in the United States and the United Kingdom, it came from both TFP growth and ICT capital deepening, with the latter contributing relatively more. Within non-ICT services, for Canada, TFP growth in retail trade was particularly robust over the 1995–2000 subperiod.

Given the size of the retail trade industry in output and employment, this has spurred researchers to examine more closely the factors that pushed up growth in this industry in the United States, and, conversely, to examine reasons for its lagging growth in many European countries. These are discussed further in Appendix A, which highlights the finding that more than investment in ICT is needed to push up productivity growth, including workplace and process reorganization; this finding is supported by Black and Lynch (2003), as well as other international evidence (OECD 2004). The link between investment in ICT and greater productivity growth may well vary by industry. Still, it remains to be seen whether these changes lead to permanent higher growth or a level shift in productivity. An Australian study finds that the growth effects taper off over time, implying that ICT may simply lead to level shifts in productivity in some industries once the new technology is adopted (Gretton, Gali, and Parham 2004).

As noted earlier, a puzzling aspect of Canada's productivity performance is the stagnation in this decade. Industry data show that productivity growth first slowed in the manufacturing sector, with plummeting growth in computer-related industries. Services sector productivity growth then began to taper off (Table 9). As reported in Rao, Sharpe, and Smith (2005), between 2000 and 2004, manufacturing accounted for 42 per cent of the slowing; mining, oil, and gas extraction 29 per cent; and construction 12 per cent. After 2002, almost all industries other than manufacturing were responsible for the slowing, the largest being FIRE.[9] There may be a cyclical element to this waning performance, since some of the larger service industries had

9. The decomposition was based on unrevised Statistics Canada data.

boosted employment substantially in 2002, when demand was strong. The oil and gas extraction sector appears to be a special case. Rao, Sharpe, and Smith (2005) and the Conference Board (2004) each note that high commodity prices and greater profitability have encouraged producers to begin to exploit more marginal resources, which lowers productivity.

Areas for further research

Industry analysis is a useful complement to aggregate data. The data show that the services sector has been responsible for a larger contribution to productivity growth in some, but not all, OECD countries. This variation serves to highlight the point that ICT by itself will not boost aggregate productivity growth. Lags between ICT investment and productivity growth may differ substantially across industries, and be quite long. The interaction between product and labour market regulations and industry performance may also be quite different. There is further evidence that getting the framework right is important. Countries such as Australia and the United States, which put considerable effort into their regulatory framework in the 1980s and 1990s, may be seeing the benefits of this effort now. There is also evidence that fostering competition can be very important to the diffusion of ICT, as witnessed by the differing performance of the retail trade sector.

Industries that comprise the Canadian ICT production sector are unlikely to contribute as much to aggregate productivity growth as they have in the past, chiefly because of their much smaller size and also because they are unlikely to achieve the same pace of growth as they had in the past. This implies that tracking developments by industry, particularly in the services sector, will become even more important to understanding aggregate productivity developments; i.e., the industries that drove up productivity growth in the past may be quite different from those in the future. Moreover, non-ICT-using industries (as defined by the OECD) are important sources of productivity growth in many countries, including Canada. These industries have typically not garnered the same amount of attention in productivity analysis.

5 Canada–U.S. Productivity Level Gaps

In recent years, productivity analysis has turned to estimating productivity gaps, chiefly against the United States, which is viewed as the productivity leader. This analysis has also examined productivity level gaps in industry. Estimates of productivity levels should be viewed as preliminary, because a number of conceptual and data issues need to be resolved that can severely hamper cross-country comparisons (see below). Keeping this in mind, the goal has been to determine which industries/sectors have the largest gaps relative to the United States, to help better understand Canada's lagging productivity performance. In particular, productivity levels indicate the magnitude of the gap that must be overcome and can help to identify where policies may be required.

5.1 Productivity levels: how large is the gap?

Rao, Tang, and Wang (2004, 2006) show that the labour productivity gap (per employee) in the business sector has widened significantly over time, and that much of this widening has taken place in this decade, when, as discussed earlier, labour productivity growth stalled. Estimates of the actual size of the gap vary with the methodology and time period examined (Table 10), but the limited number of studies all find the gap to be sizable.[10] Much of the gap is due to a TFP gap, although its contribution has fallen slightly, implying a widening in the capital gap over the past 10 years (Table 11).

Rao, Tang, and Wang (2004, 2006) were the first to provide estimates of productivity levels by industry in Canada relative to the United States. Their work revealed a sizable productivity shortfall in 2001, on the order of about 15 per cent in the business sector. At the industry level, Canada's labour productivity level was lower in the primary, manufacturing, and services sectors, but higher in construction. In general, Canada had a productivity advantage mainly in resource-based industries, such as wood products; paper, printing, and publishing; primary metals; and transportation equipment. Typically, when the level of labour productivity was higher than for the United States, it was because of even higher TFP levels.

Based on the relative weights of the industries, those driving the aggregate labour productivity gap in 2001 were manufacturing (particularly electronic and electrical equipment) and services, specifically wholesale and retail trade, and FIRE (Rao, Tang, and Wang 2004). Given the latter's weight, it was responsible for about 27 per cent of the labour productivity gap.[11] These industries were also the main reason for the widening in the gap between 1997 and 2001. In addition, Rao, Tang, and Wang (2004) examine gaps in TFP, and a similar story holds: Canadian TFP levels were generally substantially lower in the same industries. Service industries contributed about three-quarters of the aggregate TFP gap, although this had declined slightly from 1997. On the other hand, the TFP gap in manufacturing increased 6 percentage points over the same period. The electronic and electrical equipment industry was largely responsible, seeing its relative

10. Part of the difference results from the use of employed persons vs. hours in the calculation of the productivity level, owing to data availability.

11. Measures of output and productivity of services in the national accounts (SNA) is likely subject to large errors, given severe measurement problems, particularly for finance and insurance. Relying on output measures taken directly from the balance sheets of Canadian and U.S. banks, Allen, Engert, and Liu (2006) find that Canadian banks are as productive and efficient as U.S. banks, a result that is hard to reconcile with the large productivity gap in FIRE estimated by Rao, Tang, and Wang (2004).

productivity level plummet from 1.04 in 1997 to 0.59 in 2001. Finally, capital intensity (capital stock per hour worked) was an important factor behind the gap in the manufacturing sector, but not for the gap at the business sector level.

More recent data from Rao, Tang, and Wang (2006) paint a similar picture.[12] Furthermore, the business sector labour productivity and TFP gap has widened substantially from the early part of the decade. In 2004, the TFP gap stood at just over 30 per cent and the labour productivity gap at just over 35 per cent. About 90 per cent of the labour productivity gap in the business sector was accounted for by the TFP gap in 2004. Moreover, the large widening of the TFP gap in computer and electronic equipment to only 23 per cent of the U.S. level was particularly stunning (Table 11).

Inklaar, Timmer, and van Ark (2007) provide estimates of productivity levels across a range of OECD countries. In 2003, Canada's labour productivity level in the business sector would have been lower than the U.S. level by 17 per cent. It would also have been lower than that of France (6 per cent), Germany (9 per cent), and the Netherlands (16 per cent), but higher than that of Australia (12 per cent) and the United Kingdom (11 per cent).

5.2 Factors influencing the size of the productivity gap

Appendix B summarizes the key results of studies that compare indicators of performance and structure between the two countries. Canada fares more poorly than the United States across a broad range of productivity-enhancing factors, whether they relate to capital intensity, ICT penetration, inputs and outputs of innovation, higher education attainment, or training participation. In most cases, a lower intensity of these factors at the industry level in Canada appears to play a more important role than an unfavourable mix of industries.

Differences in industry mix appear to affect the productivity level gap for manufacturing. Nadeau and Rao (2002), for instance, find that the average annual productivity growth in Canadian manufacturing over the 1980–96 period would have been higher by 0.3 percentage point if the mix of manufacturing industries in Canada had been the same as in the United States. This partly reflects lower weights in Canada on computers, chemicals, and electronic equipment, which tend to register above-average productivity growth. The evolution of differences in industry mix over time appears to have only a small effect on the discrepancy in aggregate labour

12. As noted earlier, however, it is very difficult to derive productivity levels and they are very sensitive to a wide range of assumptions. For example, in a cross-country comparison, Jorgenson, Ho, and Stiroh (2005) find that Canada had higher TFP levels than all G-7 countries, apparently because of a sharp rise in the quality of IT capital as well as non-IT capital.

productivity growth: Tang and Wang (2004), for instance, estimate that, over the 1987–98 period, virtually all of the cumulative labour productivity growth shortfall relative to the United States is accounted for by productivity growth differentials at the industry level, keeping the nominal output share weights by industry at their values in the initial period.

Using detailed data, Fisher and Rodriguez (2006) examine the role that ICT equipment plays in the M&E investment gap – and thus capital deepening – between Canada and the United States. About 90 per cent of the gap in the business sector – which stood at close to 1 per cent of investment as a share of GDP over the 1990–2001 period – can be attributed to lower ICT investment in telecoms and software. This finding is supported by Sharpe's (2005) exhaustive study of the ICT investment gap with the United States. He notes that, despite broadly similar investment growth rates, various measures of ICT intensity reveal that Canada's gap was sizable, rising over time, and that it existed in each of the ICT components.[13] Software contributed the most to the gap, accounting for about half of ICT investment. In addition, all industries contributed to the ICT investment (per worker) gap, but the highest contributions were in professional, scientific, and technical services, and in manufacturing.

Analysis by Baldwin et al. (2005) points to the need to use comparable data. While it is true that the capital-output ratio is lower in Canada using national data sources, when comparable depreciation rates are used, Canada's capital-output ratio (capital intensity) is about 6 per cent higher than in the United States, owing to a much larger share of engineering capital (Appendix B), which was about 15 per cent above that in the United States in 2002. This larger share of engineering capital was a result of both a different industrial structure as well as higher capital intensity, particularly in manufacturing and utilities. Canada had a lower capital intensity in all other assets: ICT, non-ICT, and buildings, in the range of 1 to 3 per cent. Canada's industry structure, however, is favourable to capital intensity. In fact, the authors note that Canada has a larger share of output in more capital-intensive industries. However, within these industries, Canada tends to have lower capital per hour worked. This is particularly the case in manufacturing, business services, and other services, as well as education and health. Turning to the ICT gap, Canada's ICT capital intensity was 43 per cent below that of the United States in 2002. It was widespread across industries and particularly large in construction, primary goods,

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13. As a share of business sector GDP, Canada's nominal investment in ICT was only 61.6 per cent of the U.S. level, and this had fallen from 74 per cent in 1987. Another measure of ICT intensity, ICT investment per worker, was only 45.1 per cent of the U.S. level. Once again, this share had fallen; in 1987, ICT investment per worker was 60.4 per cent of the U.S. level. There were large gaps in each asset class in 2004: Canada's levels relative to those of the United States were 54.1 per cent, 44.1 per cent, and 43.5 per cent, respectively, for computers, communications, and software.

manufacturing, and FIRE. Canada's ICT capital intensity gap has been persistent, existing since at least 1987. Fisher and Rodriguez (2006) also find that Canadian firms invest in less ICT equipment, and that this is the main reason for the ICT shortfall, and not industrial structure.

Several potential reasons may explain why Canada invests less in ICT equipment than the United States. In a comprehensive study, Sharpe (2005) finds that firm size contributes 2.8 percentage points to the Canada–U.S. difference, since large firms typically invest more. In particular, very small firms – having fewer than 20 people – lag considerably in the adoption of advanced ICT. This may be related to the skill level of employees and managers. More surprising is the finding from various surveys that costs are a significant barrier, given evidence cited by the OECD. However, it may also reflect the fact that labour is relatively less costly in Canada. Differences in the measurement of ICT capital do not appear to play a role, consistent with Baldwin et al. (2005), nor do marginal effective tax rates on capital, given that they are close to those in the United States (although they may have played a more important role in past differences).

The ICT gap between Canada and the United States is found to be a driving factor in the labour productivity gap between the two countries (Fuss and Waverman 2005). In their regression analysis, about half of the gap is accounted for by ICT spillovers, which they define as telecom and PC penetration, each of which is necessary for ICT to diffuse throughout the economy. Thus, factors that impede diffusion can be important in explaining the gap. This also seems consistent with the aforementioned work that explains the differences between the United States and the European Union regarding productivity growth.

In a regression analysis of the factors behind the TFP gap between Canada and the United States, Rao, Tang, and Wang (2006) find a significant role for differences in the M&E capital-labour ratio. For each percentage point increase in the M&E capital gap, the TFP gap increases by 0.14 per cent. In fact, the M&E capital gap in 2003 explains almost 90 per cent of the TFP gap. Surprisingly, Rao, Tang, and Wang (2006) also find that ICT capital did not play a specific role. Other explanatory factors that played a small but significant role include innovation effort (as proxied by R&D expenditures), skills (as proxied by the share of university hours worked in each industry), and capacity utilization differences. Rao, Tang, and Wang's results suggest that narrowing the M&E capital gap is important to improving our relative productivity performance. And despite the fact that ICT capital did not play a specific role, this may reflect the fact that it takes time for ICT to improve TFP growth.

Leung, Meh, and Terajima (2006) build a dynamic general-equilibrium (DGE) model and find that the greater proportion of small firms/establishments in Canada, and the lower scale of operations for both small and large firms relative to their U.S. counterparts, can potentially explain a significant part of the level and change in the productivity gap over the 1990s. The most likely cause of the more sluggish firm-size dynamics in Canada is a higher cost of technology adoption, on which information is unfortunately very hard to obtain.

A third factor relates to self-employment in Canada, more specifically to its lower net income relative to paid employment than in the United States, and Canada's relatively high and rising share of total employment compared with that for the United States. Baldwin and Chowhan (2003) show that these two features sufficiently depress labour productivity growth in Canada relative to the United States to account for almost all of the cumulative gap in actual productivity growth over the 1987–98 period.

Long-term, structural differences between two countries in average hours worked or the employment rate can also give rise to a labour productivity gap in the presence of decreasing returns on labour utilization. Economizing on labour then yields productivity gains and opens up a gap between measured productivity and what Bourlès and Cette (2005) label "structural" productivity. With the European situation in mind, they test this hypothesis using a panel of OECD countries over the 1992–2002 period. Their approach consists in estimating the long-run elasticities of changes in labour productivity to changes in average hours worked and in the employment rate, controlling for changes in capacity utilization, in ICT investment intensity, and other factors, and using the instrumental variables method to mitigate any simultaneity problem. They find significant diminishing returns to average hours worked and the employment rate, particularly in the younger and older age groups with respect to the employment rate. They then apply these long-run elasticities to the observed differences vis-à-vis the United States with respect to the two variables of labour utilization, and show that, in 2002, Canada's labour productivity shortfall relative to that for the United States would have been 2 per cent larger than conventionally measured if hours worked and the employment rate had been the same as in the United States. "Structural" productivity would have been much lower in Europe than in Canada, relative to observed productivity.

Choices made by statisticians in their measurement of productivity elements have a surprisingly large effect on the estimated gap in performance between Canada and the United States. Harmonizing measurement methods between the two countries would reduce performance gaps considerably. Maynard (2007) estimates that about half of the 14.3 per cent Canadian labour productivity shortfall at the total economy level in 2000, as measured from the official productivity growth programs in the two countries, can be ascribed to different methods of estimating average hours of work per job. Indeed, if the Canadian method is applied to the

U.S. data in this respect, the gap shrinks to 7.2 per cent. Likewise, officially measured capital intensity is considerably lower in Canada than in the United States, because the Bureau of Economic Analysis (BEA) uses lower depreciation rates than the Canadian productivity program, particularly for engineering structures and buildings. Baldwin et al. (2005) show that the capital intensity gap virtually disappears when Canadian depreciation rates are applied to U.S. data. While there is no compelling reason why detailed depreciation rates by asset type should turn out to be identical in the two countries, the large differences found for some asset types would imply differences in technology, capital usage, or asset markets that are hard to explain.

Assumptions about the purchasing-power parity (PPP) rates used for translating the Canadian and U.S. GDP figures into comparable real currency units may also have a considerable bearing on the measured productivity gap. Because the conventional PPP price relatives that are used in the comparisons of standards of living are limited to detailed final domestic demand components, assumptions must be made about the PPP rates to apply to exports and imports in order to properly compare overall GDP levels. Baldwin et al. (2005) show that deviating from the conventional assumption that the PPP rate for exports and imports corresponds to the bilateral nominal exchange rate can have a significant impact on the measured productivity gap. Adjusting the U.S. methodology for measuring hours worked to make it comparable to the Canadian one, they estimate that Canadian labour productivity for the total economy was at 94 per cent of the U.S. level in 1999, using the nominal exchange rate as the PPP rate for exports and imports. When they assume instead that Canadian exports are priced 10 per cent cheaper and Canadian imports 10 per cent dearer than suggested by the exchange rate, the productivity gap swings by 10 percentage points and turns in favour of Canada. The authors attach no particular value to these alternative assumptions; they simply caution against placing too much emphasis on point estimates of the productivity gap when the extent to which Canadian trade prices deviate from the law of one price is unknown, as is currently the case.

Areas for further research

Productivity-related performance gaps relative to the United States arise mostly from differences in intensity within industries or firms, rather than from differences in industry mix. Besides the industry mix, however, such structural characteristics as smaller firms and more prevalent and lower-paid self-employment in Canada may account for significant parts of the productivity gap, according to recent studies.

Part of the considerable productivity and capital intensity gaps is illusory, since harmonizing the methods of measuring them in the two countries has the effect of reducing these gaps markedly. It must be borne in mind, however, that harmonization does not guarantee full comparability if the design of U.S. surveys and the quality of U.S. input data are not fully compatible with Canadian methods. This is a particularly relevant consideration in the case of average hours of work per job, an important source of measurement differences between the two countries.

Canada has large gaps in productivity levels relative to the United States in most industries other than those in the resource sector and non-ICT manufacturing. Thus, closing the gaps, particularly in large sectors, will be important to closing the aggregate labour productivity level gap. A sector that is particularly important is retail trade, given its large weight in output (or employment). Relative to restrictions that appear to have hampered growth in Europe, the situation appears good for Canada. On the other hand, it may be difficult for Canada to achieve the same gains as in the United States, given differences in the Canadian marketplace. It would be interesting to analyze the lags between ICT adoption at the industry level, including retail trade, and its appearance in TFP growth, and compare them with those for the United States.

6 Innovation and Productivity Growth

The OECD (2006) states that "Innovation in all its forms – product, process, organization and marketing – is a key source of productivity growth . . . but some key aspects of innovation remain relatively poorly understood." Innovation's contribution to national productivity growth reflects both domestic creation and international diffusion, the latter playing a clearly dominant role in most countries through the adoption of imported ideas and technologies (Keller 2004). But the successful adoption of technologies and practices, whether foreign or indigenous, depends partly on domestic absorptive capacity, as enhanced by human capital accumulation, R&D activity, and openness to trade and foreign direct investment. The various stages of the creation process itself – R&D, patenting, and commercial applications – have empirically been shown to be positively linked, so that policies that influence R&D will eventually have an effect on patenting and commercialization (Trajtenberg 2002; Jaumotte and Pain 2005).

Innovation can be measured by relying on indicators drawn from surveys of innovation itself, or from other sources of data on inputs (e.g., R&D, skilled labour intensity), output (e.g., patents per worker), or from the effect of innovation on productivity (e.g., TFP, high-tech capital deepening). Surveys gather information on whether firms have introduced new or significantly improved products or processes, or on the number and types of advanced technologies that they use. The other indicators are more indirect and have all their drawbacks (Keller 2004): input flows ignore the stochastic nature of technology improvement, as when R&D projects turn out to be “dry holes.” Raw patent counts ignore the high degree of heterogeneity in the quality and value of patents, the fact that a small number of patents account for most of the value of all patents, and the fact that many innovations are not patented. Hall, Jaffe, and Trajtenberg (2005) suggest weighting the different patents by the number of citations they receive, to better capture their value as successful inventions. TFP is subject to measurement errors and perhaps biases as an indicator of disembodied technological progress, while high-tech capital deepening only proxies for embodied technical change.

Recent studies follow two approaches to gain insight into the impact of innovation on productivity growth, at least in Canada. One relates supply-side inputs, mainly R&D, to productivity growth, while controlling for other factors. The other investigates at the firm level whether technology adoption, as revealed by innovation surveys, is associated with superior productivity performance, while controlling for other factors. On balance, studies using the first approach seem to suggest that R&D has more impact in other advanced countries than in Canada.

One particularly revealing international study is by Griffith, Redding, and Van Reenen (2004), who use a panel of manufacturing industries across 12 OECD countries over the period 1974–90 and control for a number of measurement and econometric issues. At the aggregate level, they find evidence of a positive impact of R&D on TFP growth via both a direct innovation channel and an indirect absorption channel.[14] A term of interaction between the R&D intensity and the distance of a country from the TFP frontier conveys the idea that technology transfer depends on the absorptive capacity of the recipient country. Thus, non-frontier country industries catch up with their respective frontiers to an extent that depends on the strength of R&D investment relative to value added in these industries. Not surprisingly, human capital, as conveyed by a measure of industry-specific educational attainment, has a marked impact on rates of both innovation and technology transfer. Results for Canada show that the total effect of R&D on TFP growth is somewhat weaker than average: the technology transfer or absorptive capacity component plays a less important role, since Canada is at a shorter-than-average distance to the technological frontier over the estimation period.

14. The findings of Jaumotte and Pain (2005), that the share of scientists and engineers in total employment plays an important role in explaining R&D expenditures in their econometric model for the OECD countries, is consistent with the notion that domestic R&D is an indicator of absorptive capacity. Jaumotte and Pain take the share of scientists and engineers as an indication of absorptive capacity.

This approach of estimating the effect of R&D in a model where innovation and technology transfer provide two channels for productivity growth in countries behind the technology frontier has begun to be applied to individual countries. For the United Kingdom, Cameron, Proudman, and Redding (2005) investigate the contributions of R&D, international trade, and human capital to TFP growth at the manufacturing level through these two channels. They find that R&D makes a significant contribution, but only through invention, while international trade facilitates the transfer of technology. For France, Khan (2006) also works with panel data on manufacturing industries, and finds that both R&D and trade with technologically advanced countries significantly contribute to TFP growth via the innovation channel, but that they do not facilitate technology transfer.

Acharya and Keller (2007) also investigate the contributions of domestic R&D and various channels of foreign technology transmission to TFP and labour productivity growth for 22 manufacturing industries in 17 advanced countries over the 1973–2002 period. They use the generalized method of moments techniques and the Olley and Pakes approach to address the endogeneity problem arising from the possibility that the observed input choices made by firms are a function of unobserved inputs. They also allow for country-, industry-, and time-fixed effects in their panel regressions. They find that both domestic R&D and international technology spillovers are significant determinants of productivity differences across industries and countries, with the spillovers gaining in strength over time. Foreign direct investment (FDI) and, to a lesser extent, imports, are effective channels through which U.S. R&D enhances domestic productivity performance.

Acharya and Coulombe (2006) also use international data, but to test the influence of the composition of R&D expenditures to GDP on labour productivity growth within an error-correction framework in which productivity growth depends both on its initial level and on its steady-state level as proxied by tangible investment intensity, trade openness, and population growth. Thus, in contrast with the previous studies, the technology gap relative to the frontier country does not play any role. Acharya and Coulombe's panel-data regressions, using different estimation methods and covering 16 OECD countries from 1973 to 2000, show that business R&D intensity has a significant positive effect on labour productivity growth after controlling for the business cycle. The estimated elasticity is in the range of 0.2 to 0.5 in the long run. R&D at universities also has a significant impact, but not any other form of public R&D or foreign R&D.

This last result concerning foreign R&D is in stark contrast with the results of an earlier analysis of panel data for 16 OECD countries over 1980–98 by Guellec and van Pottelsberghe de la Potterie (2001). They estimate that a 1 per cent increase in the stock of foreign R&D boosts TFP by 0.44 per cent and that this effect is larger the higher the R&D intensity in the recipient country, and therefore its capacity to absorb and make efficient use of the new knowledge. In contrast, their estimated long-run elasticity of TFP with respect to domestic business R&D stock is much smaller at 0.13 per cent, but nonetheless highly significant.

While recent studies based on data for OECD countries suggest a significant influence of domestic R&D intensity on productivity growth, the recent evidence from Canadian data alone is less clear. Gu and Tang (2003) fail to find any significant effect of lagged R&D intensities on labour productivity in panel regressions involving 14 Canadian manufacturing industries over the 1980–97 period. Their regressions control for industry fixed effects, time-fixed effects, and three sector-specific factors – capacity utilization, the capital/labour ratio, and the employment share of large-sized firms – but they ignore the effect of the technology gap relative to the frontier. Other indicators of innovation activity, such as patents per worker and real investment in M&E per worker, also are insignificant when included separately in their regressions. Only the share of scientists, engineers, and other R&D professionals in total employment is statistically significant, with lags of two and three years. However, when they combine the four indicators of innovation activity into a single index using a latent variable approach, they find that lags in this innovation index distributed over three years have a statistically significant effect on labour productivity. Gu and Tang interpret their results as implying that the various indicators of innovation activity are too partial to convey the multidimensional character of innovation when taken individually. One puzzling feature of their results, which deserves further investigation, is that the raw patent count is by far the best indicator of innovation in their combined index, while the adoption of embodied technical progress plays a very minor role.

A number of Canadian studies on innovation rely on indicators derived from Statistics Canada’s Survey of Innovation (SI). Researchers set up a rich database by linking the SI to the ASM, and this enables them to investigate the characteristics and impact of the innovation process in some detail, albeit in a cross-sectional rather than a longitudinal way. Research based on SI data focuses on three themes: supply and demand for innovation, impediments to innovation, and the effect of innovation on productivity.

Work investigating supply and demand for innovation in Canada has reached the following conclusions inter alia:

- On the supply side, R&D is more important for product innovation than for process innovation (Le and Tang 2003). This is consistent with a finding by Baldwin and Sabourin (2004) that performing R&D boosts the market share of manufacturing firms but not their relative productivity growth. Small firms are less likely to undertake innovation activities than large firms, but those that do so are as effective as large firms in converting innovation inputs into innovation outputs (Le and Tang 2003).

- Also, Canada has a higher proportion of innovative firms than in selected European countries, reflecting a larger firm size, a greater tendency to co-operate with other firms, and stronger government support. However, the Canadian firms that do innovate draw a lower proportion of their sales from innovative products (Mohnen and Therrien 2003).

- On the demand side, "to develop product" drives technology invention in firms of all sizes and "to improve the production process" is key for technology adoption. R&D and engineering and design (E&D) are the most important innovation inputs into technology invention, but E&D is a key contributor to technology adoption in all firms and R&D in high-tech firms only (Tang 2003).

Regarding impediments to innovation, Baldwin and Hanel (2000) find that a shortage of skilled personnel is by far the most frequent impediment to innovations reported by both domestic and foreign-owned firms in the 1993 Survey of Innovation and Advanced Technology. The two other most important factors are lack of information on technology and lack of information on markets, which in turn could arise from lack of skilled personnel. There seems to be no evidence available from survey data on whether lack of skilled personnel is a chronic phenomenon. If it is, then one would expect persistent upward wage pressures in occupations related to R&D, and relatively high rates of return on advanced educational degrees in the related professions. An examination of the returns to a university education in Canada by field of study reveals that the marginal net returns to masters and PhD degrees in engineering, math, and physical science are barely positive, if not negative, while those in agriculture and biology are appreciable only for PhD degrees (Stark 2006). In contrast, the net returns to MBAs are very high, at around 20 per cent. The lesser valuation of the high scientific qualifications by the market suggests that they are less productivity-enhancing than MBAs. In this connection, one recommendation by the Institute for Competitiveness and Prosperity is to increase university places in MBA and other business programs, so as to reinforce the strategic and management side of the innovation process and boost demand for innovation.

A few studies relying on surveys of innovation explore the link between innovation and productivity. Corrazin (2003), for instance, relates firm performance in terms of labour productivity, employment, price-cost margin, and market share to two innovation measures:

one is the number of new products and/or new processes that a firm introduced over the 1997–99 period; the other refers to the novelty of each firm's innovations: world-first, Canada-first, or firm-first. Corrazin's key result is that world-first innovators perform better than other innovators or non-innovators with respect to labour productivity and the other performance indicators. World-first innovators tend to be large firms that undertake R&D and are willing to spend over two years developing and bringing product innovations to market, or implementing process innovations within the firm.

Linking the 1993 Survey of Innovation and Advanced Technology and the ASM, Baldwin and Gu (2004a) obtain results similar to Corrazin's with respect to the effect of world-first innovations. Their analysis extends to other important dimensions of innovation as well. They find that product and process innovations have different effects on productivity growth and the survival rate of firms. Process innovation, which relates to the adoption of advanced technologies, boosts both productivity growth and the survival rate whereas product innovation has no significant effect on productivity growth and a negative effect on the survival rate. These results are generally in agreement with previous studies. The authors also show that large firms have higher rates of process innovation than small firms but similar rates of product innovation. They submit that small firms are generally at an earlier stage in their life cycle than large firms and as a result tend to focus more on developing new products than reducing production costs in the innovation strategy.

Parisi, Shiantarelli, and Sembenelli (2006) explore some of the same questions as Baldwin and Gu (2004a), but they extend the analysis to issues that are somewhat different. Linking balance-sheet data to information from two surveys of Italian firms taken in 1998 and 1995, they find a positive, significant, and sizable effect of innovation on productivity, when they include a dummy, representing whether an innovation has been introduced or not, in a standard production function. The productivity effect of a process innovation is larger than the one of a product innovation. Whereas the probability of introducing new products is strongly positively related to R&D spending, that of introducing a new process is strongly associated with investment in M&E, consistent with the notion of technologies embodied in new capital goods. Even then, however, R&D spending enhances the effect of investment in M&E on the probability of introducting a new process, implying that R&D increases the capacity of a firm to absorb new technologies. The authors find evidence of persistence in product innovation, which they think might be due to time-invariant characteristics of the firm, such as managerial quality, or to "learning to invent by inventing." Process innovation shows little persistence, which could be related to important capital-adjustment costs.

Baldwin and Sabourin (2004) link the 1993 Survey of Innovation and Advanced Technology with the 1998 Survey of Advanced Technology in Manufacturing and the ASM, to investigate the extent to which the adoption of advanced technologies, both ICT and non-ICT, leads to productivity growth and gains in market share. They find that it is indeed the case, controlling inter alia for changes in capital intensity, plant size, foreign control, whether R&D is performed, and initial levels of market share and labour productivity. They establish that large amounts of market share are shifted from declining firms to growing firms and they show that R&D importantly contributes to the growth of a plant's market share, presumably via the development of new products. It is worth noting that the results from the market share and productivity equations come out stronger when the authors use two-stage least squares and Heckman's two-step procedure to pre-empt problems of simultaneity and selection, respectively.

Areas for further research

Innovation stimulates productivity. This is particularly clear from studies on the impact of adopting advanced technologies. What leads to this adoption – the demand for innovation – needs more empirical investigation in a Canadian context, particularly the role played by competitive pressures, managerial quality, absorptive capacity, and the relative costs of adopting advanced technologies. We also need a better understanding of the extent to which the supply side of innovation contributes to productivity growth, not just gains in market share, via both invention and the capacity to assimilate and adapt process innovation created by others.. It would also be useful to test the effect of R&D on TFP growth in Canada using a model that allows for convergence effects through the use of a technology-gap variable.

7 Industry–Firm Dynamics and Aggregate Productivity Growth

Analysis of disaggregated data by industry, firm, or establishment can improve our understanding of the productivity process by more directly linking productivity performance to business practices (Greenspan 2000), and by accounting for the impact of reallocation across sectors or firms on aggregate productivity growth. Disaggregated data matter because of the substantial heterogeneity of industries, firms, or establishments in terms of output, employment, and productivity levels. It is important, however, not just to investigate micro relationships but also to evaluate their significance for the macroeconomy.

7.1 Heterogeneity, aggregate shocks, and adjustment

Firm/establishment heterogeneity underpins the dynamics found in microdata. Haltiwanger (2000) submits that several factors may cause this heterogeneity: uncertainty about the development, adoption, distribution, marketing, and regulation of new products and production techniques; uncertainty about future cost or demand conditions, which encourages firms to differentiate their choice of products and technology; and differences in entrepreneurial and managerial ability; slow diffusion of information about technology, distribution channels, marketing strategies, and consumer tastes; and differences in the vintage of the installed capital or in the vintage of the manager or the organizational structure.

The accumulation of evidence on firm heterogeneity from longitudinal microdata has led to a recent surge of theoretical models that embed this heterogeneity, especially in the context of the "new new trade theory." As will be shown later, such models predict that exporting boosts aggregate productivity growth through the same rationalization and reallocation effects as are revealed by the longitudinal studies. Two pioneer papers in this field are by Melitz (2003) and Bernard et al. (2003). Melitz builds a DGE model in which the firm's productivity heterogeneity arises from pre-entry productivity uncertainty: a potential entrant in an industry must incur an irreversible investment to get in, and then it draws its productivity level from an exogenous distribution common to all. Firms drawing a productivity level above the threshold necessary to generate a positive profit will start producing, while lower-productivity firms will exit immediately without producing. Firm turnover arises from the assumption that each producing firm faces an exogenous probability of death in each period, irrespective of its productivity level. Free entry drives the expected profit of entry to zero and endogenously determines the productivity threshold required to survive. In equilibrium, simultaneous flows of entering and exiting firms leave constant both the number of producing firms and the productivity distribution across firms.

Evidence at the microeconomic level of high heterogeneity and lumpy adjustment of inputs leads Haltiwanger (1997) to hypothesize that the impact of aggregate shocks depends on the distribution of where individual producers are relative to their adjustment threshold. Thus, when we say that a shock is too small to have a significant impact, we really say that the number of producers for whom the shock is big enough to force them to adjust is relatively small. Changing distributions could naturally lead to time-varying elasticities of aggregate output and inputs to aggregate shocks, and could thus inform our understanding of macro developments, including aggregate productivity movements.

The huge heterogeneity at the firm/establishment level may make the behavioural patterns induced by aggregate shocks difficult to detect. Haltiwanger (1997) reports that annual 1973–93 data reveal no obvious trend in the pace of job reallocation in the United States, which he finds "striking," given concerns about rising job insecurity over this period. Even so, microdata have been successfully used to identify or characterize periods of structural change or adjustment to specific shocks.. Baldwin and Gu (2004b), for instance, use them to distinguish various periods by comparing the relative importance of particular adjustments during these periods. They show that 1988–97 is substantially different from 1979–88 and 1973–79 in terms of the types of adjustment that have taken place in Canadian manufacturing: in the 1990s, plant exits rose across a wide range of industries, not to be replaced by more entrants, as had been the norm in the 1980s and 1970s, but by growing continuing plants generally gaining more market share than in previous decades. Baldwin and Gu link these changed dynamics to adjustments to technological change and to restructuring associated with the Free Trade Agreement (FTA) and the North American Free Trade Agreement (NAFTA).

Deregulation and trade liberalization are two important policy shocks that have been scrutinized through microdata. This scrutiny has revealed, for instance, that the deregulation of the U.S. telecommunications industry was accompanied by a marked increase in resource reallocation in that industry, with many new plants and firms entering it, inefficient plants exiting it, and aggregate productivity rising through the changing market shares (Bartelsman and Doms 2000).

As for trade liberalization, it has received considerable attention in various contexts. In a very careful study, Pavcnik (2002) analyzes the effects of unilateral trade liberalization on Chilean manufacturing plants in the late 1970s and early 1980s by taking into account productivity variations both over time and across sectors. One distinguishing feature of Pavcnik's work is that she corrects for selection bias induced by plant closings and for simultaneity bias related to the fact that a plant's private knowledge of its productivity affects its choice of inputs. She shows that, after trade liberalization, the productivity (TFP) of plants in the import-competing industries increases faster than in the non-traded-goods sector, and that plant exit leads to productivity gains because exiting plants are less productive than the continuing plants. Moreover, the reallocation of market shares and resources from less to more productive plants makes a much larger contribution to aggregate productivity improvement following liberalization than within-plant productivity gains.

In the same vein, Trefler (2004) provides a meticulous analysis of the impact of the Canada–U.S. Free Trade Agreement on a range of Canadian variables, some reflecting the short-run costs of adjustment, and others the long-run gains from trade liberalization. His econometric strategy consists in modelling the difference in the average growth rates of these variables between the pre-FTA period of 1980–86 and the post-FTA period of 1988–96 within single equations. Trefler alternatively uses four-digit industry data and plant data for manufacturing, which enables him to draw conclusions about the effect of reallocation within industries. In attempting to isolate the effects of the reductions in Canadian and U.S. tariffs, he controls for trend industry growth, industry-specific shocks, and business conditions. In variants of his basic model, Trefler also instruments the Canadian and U.S. tariff variables to control for the endogeneity of tariffs. Among his key results, he finds that Canadian tariff reductions raise labour productivity by 15 per cent and depress employment by 12 per cent in the most impacted, import-competing group of industries. Many of the productivity gains come from the growth of high-productivity plants and the market-share loss or exit of low-productivity plants. At the same time, U.S. tariff concessions lead to a 14 per cent increase in productivity in the most impacted, export-oriented group. Overall, FTA raises productivity in all manufacturing by 6 per cent at the industry level.

Understanding not only the sources of productivity growth arising from trade liberalization but also the mechanisms through which this liberalization stimulates productivity gains is important. Baldwin and Gu (2004c) make a major contribution in this regard with respect to the effects of the Canada–U.S. Free Trade Agreement on export-led productivity growth, using linked plant-level data from the 1993 Survey of Innovation and Advanced Technologies and the ASM. They show that Canadian tariff reductions are statistically more significant than U.S. tariff reductions in prompting Canadian plants to enter the export market, consistent with the view that increased import competition and lower costs for imported inputs raised the incentive to expand into the international market. They find that export-market participation stimulated productivity growth and empirically establish that this may have occurred through several channels: more intense foreign competition; narrower product range and longer production runs; improved information about, and increased use of, foreign technologies, as well as intensified R&D collaborative agreements with foreign buyers; increased R&D activity; and reliance on a larger number of advanced technologies.

Another impact study that deserves attention both for its thoroughness and its conclusions is by Schmitz (2005), who investigates the sources of a jump in productivity in the U.S. and Canadian iron ore industries following their early 1980s crisis. The crisis arose from a dramatic increase in competition faced by these protected industries as a result of the entry of Brazilian iron ore in the Great Lakes steel market. Both industries doubled their labour productivity in a few years in response to this threat to their survival. Schmitz shows that changes in work practices were the primary cause of this improvement, since they cut overstaffing and increased the fraction of time equipment was in operating mode, thereby boosting labour, materials, and capital productivity. The “usual suspects” – the exit of low-productivity mines, changes in the scale of production at individual mines, improvements in technology, and upgrading of workforce skills – played only a small role.

Areas for further research

Heterogeneity at the micro level is substantial. In principle, this makes the distribution of micro behaviours an important factor for understanding how the economy adjusts to aggregate shocks. In practice, however, there are too few studies that relate micro adjustments to specific macro shocks, or that use microdata to identify or characterize periods of aggregate structural change, let alone the intensity of the underlying adjustment. Such studies would help to provide insight into how productivity growth evolves as the economy adjusts to large relative price movements. In sum, there is a clear need not only to better understand observed micro behaviours, but also to link these to macro developments, so that we can more confidently interpret aggregate productivity movements. One clear result that emerges from studies on the impact of industry or aggregate shocks is that more competition leads to better productivity performance.

7.2 Firm dynamics and reallocation effects

This decade has witnessed considerable interest in using accounting frameworks to better understand the industry sources of aggregate productivity growth, particularly the respective contributions of pure productivity growth by industry/firm and reallocation between industries/firms. Decomposition formulas have varied according to the measures of productivity – TFP or labour productivity; to the types of output data – gross output or value-added; and to the level of aggregation – industries or firms/establishments. In the latter case, the entry and exit of firms and changes in the market shares of incumbent firms increase the number of channels through which reallocation affects productivity growth.

This section focuses on studies that rely on value-added productivity measures at both the aggregate and industry levels. Value-added productivity at the aggregate level can be combined in two ways with gross output productivity at the industry level. The former is the preferred measure at the aggregate level, because it relates to final demand and welfare, whereas the latter imposes significantly fewer restrictions on the assumed relationship between output and intermediate inputs than value-added measures (Triplett and Bosworth 2004), hence its appeal to researchers. The first form of combination relates growth in aggregate value-added labour productivity to aggregate capital deepening by asset type, to labour quality, and to a weighted average of gross output TFP growth by industry, where the ("Domar") weights correspond to the shares of industry nominal gross output in aggregate nominal value added (Ho, Rao, and Tang 2004). This represents an enrichment of the standard growth accounting framework. The second form of combination (Stiroh 2002) relates value-added productivity growth at the aggregate level to a weighted average of gross output productivity growth rates at the industry level, and to the effects of labour and materials reallocations across industries (Appendix C). The weights correspond to the share of industry value added in aggregate value added. Applying this methodology to U.S. data, Bosworth and Triplett (2007) find that aggregated industry productivity growth is typically more important than reallocations in explaining aggregate productivity growth in the non-farm business sector. Reallocations tended to reduce aggregate productivity rates up to 2000 as resources were shifted towards industries that have lower productivity growth. In contrast, over the 2000–05 period, intermediate input reallocation made a positive contribution that sustained aggregate productivity growth at the same rate as over the 1995–2000 period in spite of a marked slowdown in the aggregated productivity rate at the industry level. The interpretation of this shift in the direction of the reallocation effect poses an interesting challenge.

Value-added labour productivity growth for the business sector or the whole economy has two sources at the industry level: valued-added productivity growth in each industry (the so-called pure productivity growth effect), and shifts of jobs or hours worked between industries that have different productivity levels (the so-called reallocation effect). Several formulas exist to capture those two components; they differ in the way in which each component is weighted, and in the richness of the reallocation effect. Two formulas that have been applied in the Canadian context are by Faruqui et al. (2003) and Tang and Wang (2004), both of which use nominal output weights. Tang and Wang allow for an interaction term, or "Baumol effect," which captures the interactions between productivity gains and changes in relative industry size: it is negative when industries with falling relative productivity grow in size (Baumol's disease), or when industries with rising relative productivity diminish in size. For instance, an increasing share of services in aggregate nominal output applied to the relatively low growth rate on average of productivity in services dampens aggregate productivity growth (for a variant on this theme, see Kozicki 1997). In the same vein, the fall in the share of computers and electronics in nominal output after 2000 has reduced the contribution of productivity growth in this industry relative to what it was before the ICT bust. Details on the construction of these two decomposition formulas are provided in Appendix D.

One point is worth noting about these formulas. The weight of an industry in the pure productivity and reallocation effects depends in part on its output price relative to the aggregate price. This has the effect of considerably limiting the contribution to growth of the fast-productivity ICT-producing industry in view of the fall in its relative price. It would also tend to boost the contribution of services over time because of their rising relative prices (Dufour, Tang, and Wang 2006).

Industry decomposition exercises yield fairly consistent results across countries and time: the pure productivity effect accounts for the great bulk of total productivity growth, with the reallocation effect contributing modestly, and often negatively. For example, Faruqui et al. (2003) estimate that the effect of reallocation across industries contributes nothing to the 2.2 per cent average annual growth rate of labour productivity in the Canadian business sector over 1996–2000. Rao, Sharpe, and Tang (2004) find that interindustry shifts in hours among service industries account for –0.4 percentage point of the 2.3 per cent average annual growth in labour productivity in the total Canadian services sector over 1995–2000. Thus, shifts in labour are not necessarily from low-productivity to high-productivity industries and, on net, have only modest effects. The Baumol effect per se has been found to be negative, implying that industries with high productivity growth do not attract resources from stagnant industries (Tang and Wang 2004).

One pervasive finding in research using longitudinal firm/establishment data is that industry aggregates hide enormous heterogeneity in productivity levels across establishments and firms in nearly all industries (Bartelsman and Doms 2000; Foster, Haltiwanger, and Krizan 2002). Inasmuch as the variations within industry are significantly larger than across industries, reallocation effects at the firm/establishment level potentially contribute considerably more to aggregate productivity growth than suggested by results at the industry level. In addition, the reallocation process within an industry includes not only shifts of resources across incumbent firms or establishments but also the entry and exit of firms/establishments in and out of that industry.

The results of decomposing productivity growth in a specific industry into a component that captures individual firm/establishment growth and other effects that reflect the reallocation across plants within this industry, including the impact of entry and exit, show a great deal of variation arising from differences in decomposition formula, countries, time periods, productivity concepts (multifactor vs. labour), and the horizon over which productivity growth is measured (Foster, Haltiwanger, and Krizan 2001). For instance, with the Foster, Haltiwanger, and Krizan (FHK) formula, the contribution of net entry to aggregate productivity growth tends to increase with the horizon of the change in productivity: thus, it is very small at an annual frequency, but can be considerable at a five-year interval.

A few general conclusions can be drawn from conventional decomposition exercises: labour productivity growth within each firm accounts for the bulk of industry labour productivity growth; entry and exit contribute significantly, but less than within-firm growth over five-year or ten-year horizons; and labour reallocation effects are modest, especially if interaction effects are ignored (Foster, Haltiwanger, and Krizan 2002; Scarpetta et al. 2002). Using the FHK formula, Baldwin and Gu (2004b) show, for example, that between-plant reallocation accounts for 9 per cent of average labour productivity growth in Canadian manufacturing over 1988–97, compared with 98 per cent from within-plant changes, 15 per cent from entry and exit, and –22 per cent from interaction effects.

Beyond the general conclusions just outlined, there may be significant variations across industries in the relative contributions of within-firm growth, entry and exit, and labour reallocation. Foster, Haltiwanger, and Krizan (2002) estimate that virtually all of the productivity growth in the U.S. retail trade sector over the 1990s reflects more productive entering establishments displacing much less productive exiting establishments, with the bulk of the between-establishment reallocation taking place within, rather than between, firms. Thus, entry and exit contribute to innovations and productivity growth to a much greater extent in retail trade than in manufacturing or the business sector as a whole.

Baldwin and Gu (2004b) extend the conventional decomposition framework by isolating the contribution of changing market shares within the population of incumbent plants. In their enriched framework, aggregate productivity growth has three sources: output reallocation arising both from changes in market share among continuing plants with different productivity levels and from entry and exit; productivity changes within plants holding market shares constant; and employment shifts across plants with different rates of productivity growth. They estimate that total output reallocation has a substantial impact on labour productivity growth in aggregate manufacturing over 1973–79 (72 per cent), 1979–88 (55 per cent), and 1988–97 (53 per cent), with output reallocation among continuing plants making a much larger contribution than entry and exit, especially over 1988–97. Within-plant productivity growth makes the largest single contribution (64 per cent over 1988–97), and an increasing one after 1979, but its relative importance is smaller than in conventional decompositions: in the latter, the within-plant growth component also reflects the impact of changes in market share among continuing plants. As for the labour reallocation effect, its relatively modest size compares with that of entry and exit over 1988–97 but, in contrast with the latter, it contributes to a depression of manufacturing productivity growth, because employment has tended to shift to plants with relatively weak productivity gains.

Within manufacturing, the forces that drive productivity growth vary in intensity across industries. Baldwin and Gu find that, in the high-tech sector and in atomistic industries such as clothing and textile products, the competitive process that shifts market share from less productive to more productive plants contributes more to productivity growth than does within-plant productivity growth. In contrast, the latter plays a dominant role in industries where economies of scale are more important; for example, in transportation equipment, chemicals, pulp and paper, and primary metals.

Areas for further research

Pure productivity growth by industry is far more important in explaining aggregate productivity growth than is labour reallocation between industries. At the level of firms, output reallocation as a result of changes in market share and, to a lesser extent, entry and exit, also play an important role. This suggests that free, competitive markets may be important to promote aggregate productivity growth, because they allow the process of Schumpeterian "creative destruction" to fully work. In this vein, employment protection legislation could impede production efficiency and productivity growth by "making it more difficult for firms to react quickly to changes in technology or product demand that require reallocation of staff or downsizing, and slowing the flow of labour resources into emerging high-productivity firms, industries or activities" (OECD 2007, 69).

Virtually all of the findings concerning the contributions of industry/firm dynamics to productivity growth come from studies that examine the manufacturing sector, which represents less than 20 per cent of the total GDP. It would be illuminating to extend the analysis to other industries, particularly to services in the private sector. The dynamics leading up to productivity growth might prove somewhat different from those observed in manufacturing, as appears to be the case in the U.S. retail trade sector.

8 Role of Firm/Plant Characteristics/Environment

Disaggregated data make it possible to establish links between firm/establishment dynamics and aggregate productivity growth, or at least to assess the role that reallocation and within-establishment/firm growth play. They also make it possible to link the heterogeneity of productivity performance to various characteristics, which in turn may inform our judgment about the business environment and practices that enhance productivity. To be sure, these characteristics – age, size, technology adoption, exporting, multinational orientation, and wages – are correlated between themselves and influenced by factors such as public policies, market conditions, and managerial quality, so that causal relations to productivity are generally not unidimensional.

8.1 Firm-size dynamics and productivity growth

Microdata show that firm size is positively correlated with productivity level (Foster, Haltiwanger, and Krizan 2001; Baldwin, Jarmin, and Tang 2004), wage rates (Baldwin 1998), and the adoption of new advanced manufacturing technologies (Baldwin and Sabourin 1995), and negatively correlated with exit rates (Baldwin et al. 1999). In both Canada and the United States, small firms and plants have had significantly lower productivity levels than medium and large ones, and the productivity gaps in favour of the latter, which have been systematically wider in Canada than in the United States, have increased over time, at least between 1972 and 1997 in the manufacturing sector (Baldwin, Jarmin, and Tang 2004).

Leung, Meh, and Terajima (2007) extend previous work on the firm size-productivity relationship in a Canadian context by broadening the analysis to include non-manufacturing industries and by estimating the contribution of differences in firm-size distributions between Canada and the United States to the productivity gap between the two countries. For this purpose, they construct firm-level measures of labour productivity and TFP using a Canadian administrative dataset covering the 1985–97 period.They find a significant firm size-productivity relationship in terms of both labour productivity and TFP. The prevalence of small firms in less productive industries reinforces the firm size-labour productivity relationship at the aggregate level. This relationship is stronger in the manufacturing sector than in the non-manufacturing industries, most likely because of a higher positive correlation between firm size and capital intensity for manufacturing. Large firms contribute disproportionately to labour productivity growth in manufacturing both through productivity growth in surviving firms and net entry. The authors estimate that the Canada-U.S. differences in the employment distribution across firm size categories can account for approximately 21 per cent and 48 per cent of the gap in sales per employee at the aggregate and manufacturing levels, respectively.

Beyond the accounting relationship between firm-size dynamics and productivity growth, two fundamental questions arise: why small firms are less productive than larger ones, and what drives firm-size dynamics. Leung, Meh, and Terajima (2006) try to answer this second question. More specifically, they use a general-equilibrium model of firm dynamics and technological adoption to measure the contributions of changes in taxation, in access to finance, and in the costs of technological adoption to changes in aggregate TFP via changes in firm-size distribution. The model calibrated on the parameter values of these factors for Canada generates a base-case solution, to which is compared an alternative solution in which the same parameters are set to U.S. values instead. This shock-minus-control experiment reveals that the three factors combined capture nearly 50 per cent of the estimated average Canada–U.S. TFP gap for the 1990–99 period.

According to the model simulations, the cost of adopting technology would play the key role in keeping the share of small firms higher and thereby productivity lower in Canada than in the United States. One limitation of this result, at least for policy purposes, is that this cost of technology adoption is undefined but presumably quite broad in coverage. Because there is no empirical measure of this cost for Canada to guide the selection of the associated parameter value, the latter is set so as to generate a good match between the predicted relative number of firms by size with the actual data. As a result, this parameter may reflect inter alia errors of measurement on the other parameter values of the model. Moreover, in the absence of any empirical measure for the United States, the shock-minus-control experiment has to rest on a pure assumption for the value of the parameter for the United States: that it is 20 per cent lower than for Canada. The contribution of the cost of adopting technology to the Canada–U.S. TFP gap would be different if another assumption was made about the relative size of the U.S. parameter.

The cost of adopting technology may not be observable at the aggregate level, but it is clearly identified as a major impediment to adoption by businesses in many advanced countries, including Canada (Centre for the Study of Living Standards 2005b). A survey conducted by the U.K. Department of Trade and Industry (2004) indeed reveals that set-up costs represent the single most important barrier to ICT adoption reported by Canadian businesses, and that, among the 11 countries in the survey, Canada ranks second only to the United States in terms of set-up costs as an impediment to adoption. This result is somewhat paradoxical in view of the fact that ICT intensity is particularly high in the United States.

Regarding the question of why small firms are less productive than larger ones, part of the answer can be inferred from the pattern of correlations of size with many other characteristics that are associated with productivity. Small firms use less-advanced technologies and less capital per worker. One reason may be that investment is more adversely affected by profit uncertainty in small firms than in large firms: Ghosal and Loungani (2000), for example, find a negative impact of uncertainty on investment that is substantially greater in industries dominated by small firms. The latter tend to be younger than larger firms because of a higher exit rate, undertake less R&D and engage less in product and process innovations (Le and Tang 2003), and spend proportionally less on worker training (Chowhan 2005). Also, they have less international exposure through exporting (within manufacturing).

In the Schumpeterian tradition, large firms have a marked advantage in innovation activity. Ahn (2002) reports the following arguments for a positive effect of firm size on innovation: economies of scale in R&D, since fixed costs of innovation are spread over a larger volume of sales; economies of scope in R&D, from spillovers between the various research programs of large, diversified firms; large firms can diversify the risks of R&D by undertaking many projects at one time; and large firms with market power can more easily secure stable external and internal funds for risky R&D. According to Ahn (2002, 14–15), however, "A broad consensus reached in recent literature surveys of the statistical evidence does not support the Schumpeterian hypothesis that large corporations are particularly more active in innovation." This does not seem to apply to Canada.

The characteristics of small versus larger firms are likely shaped by public policies (e.g., taxes), financial system efficiency (e.g., financial constraints), and the relative costs of technology adoption, as suggested by Leung, Meh, and Terajima (2006). The OECD (2006) submit that the current tax environment in Canada tends to discourage firms from growing through at least two channels: small firms face lower statutory tax rates than medium-large ones, benefit from more generous tax credits for R&D, and are less affected by the low capital thresholds of the provincial capital taxes; at the same time, provincial sales taxes on capital goods discourage firms from expanding through fixed investment. On the other hand, the OECD reckons that the majority of the small and medium-sized firms in Canada, as in most of the other OECD countries, are able to obtain financing when required.

A lack of managerial quality may also contribute to keeping firms small and less productive. If managers of small firms in Canada have a lower educational level than those of large firms, for instance, they may be less receptive to innovation, and less skilled at formulating and implementing business plans that tap into export opportunities. It is possible as well that they see fewer benefits to be gained from having a more educated workforce or employee training. Turcotte and Whewell Rennison (2004) estimate that a given increase in the share of university-educated workers raises productivity considerably more in small firms than in large ones. It would be useful to have data on the characteristics of business managers by firm size, including their educational level.

Inasmuch as the intensity of the factors contributing to the lower productivity of small firms is inversely reflected by the rate of "graduation" of these small firms into larger firms, they would affect the size distribution of firms. For instance, a lack of managerial quality by lower-educated managers might contribute both to weaker productivity in small firms and to a slower transition from small firms to larger firms. This is perhaps one reason why the lower relative productivity of small firms in Canada compared with the United States co-exists with a higher share of small firms in Canada than in the United States.

8.2 Exporting, international outsourcing, and productivity growth

The relationship between exporting and productivity growth has been the object of new theoretical models, as well as many empirical studies applied to a variety of countries, and has been found to be strongly positive (see Baldwin and Gu 2003, for example). On the theoretical side, the literature reveals two strands (Falvey and Yu 2005): one focuses on the channels through which exporting might be linked to within-firm productivity growth, and the other on the role of trade-induced interfirm market reallocation in enhancing industry productivity growth.

For a particular firm, the correlation between exporting and productivity growth may arise from several different processes. One is self-selection: firms have to raise productivity before they enter export markets in order to overcome the fixed costs of entry in terms of market research, setting up distribution channels, etc. Another process is learning by exporting: exposure to foreign markets stimulates productivity gains after entry, through increased incentives to innovate in the face of foreign competition and through vertical knowledge transmission from foreign buyers. There is still another process: exporting may allow firms to operate at a more efficient scale, and thereby at lower average costs. Baldwin and Gu (2004b) find evidence of this last mechanism at play in Canadian manufacturing, in that exporters are more specialized than non-exporters, which suggests that access to foreign markets allows them to exploit economies of scale.

A general result in the empirical literature is that self-selection would be considerably more important than learning by exporting in explaining the correlation between productivity growth and exporting (e.g., Bernard and Jensen 1999 for the United States; Greenaway and Kneller 2005 for the United Kingdom). The relatively weak econometric evidence on the role of learning by exporting for countries other than Canada is at odds with the case-study evidence that suggests that foreign customers impose higher product quality standards than domestic customers, while providing feedback on how to meet those higher standards (Keller 2004). The reasons for this discrepancy are not well understood.

Bernard and Jensen (1999) nevertheless estimate that labour productivity growth is about 0.8 per cent stronger among exporters than non-exporters and that, conditional on size, exporters have a 10 per cent higher probability of survival than non-exporters. Girma, Greenaway, and Kneller (2004) apply matching analysis to a large sample of U.K. firms to ensure that the characteristics of the exporters and non-exporters included in their panel-data regressions are as close as possible. They find that exporting boosts labour productivity growth, but with most of the effects confined to the first two years following entry into the export markets. Baldwin and Gu (2003) find that self-selection causes the most productive manufacturing plants in Canada to enter export markets and to stay there. But they also find that learning by exporting is important. Entrants into export markets subsequently experience higher productivity growth than non-entrants, and more so if the entrants are domestic-controlled plants and small plants, which are the ones that have the most to gain from knowledge transfers. At the same time, the least productive exporters have the highest probability of exiting from export markets. Overall, continuing exporters account for almost three-quarters of productivity growth in Canadian manufacturing over 1990–96.

Theoretical models developed by Melitz (2003) and by Bernard et al. (2003) both predict that exporting boosts aggregate productivity growth through rationalization (the least productive firms exit) and reallocation effects (the most productive firms gain output share), thereby showing outcomes that are consistent with the findings of Baldwin and Gu (2003). In the Melitz model, exporting firms are more productive than the non-exporting ones to start with, because they must be able to absorb fixed export costs. Export expansion, following trade liberalization, for example, raises labour demand and the real wage, thereby pushing higher the productivity threshold required to survive in the domestic and export markets. The least productive firms – those whose productivity level stands between the old and the new thresholds – will be forced to exit. At the same time, trade expansion induces new entrants as the expected profits from larger sales increase. With more producers around, individual shares of domestic sales decline, but the more productive exporters nonetheless increase their total sales and their share of output.

Lileeva and Trefler (2007) extend previous work on the issue of exporting and productivity by considering exporting and investing as complementary activities and by distinguishing the reactions of initially low-productivity plants from those of initially high-productivity plants to U.S. tariff cuts in the context of the FTA. They estimate plant-specific tariff cuts and use them as instruments for the decision of Canadian plants to start exporting to the United States. Their empirical results reveal that Canadian manufacturing plants that were induced to export because of improved access to the U.S. market registered labour productivity gains from exporting and investing. Those gains, however, were restricted to only those plants with low pre-FTA productivity. The productivity gainers also had high post-FTA adoption rates of advanced technologies and levels of product innovation. Because of that and the fact that the new exporters that experienced productivity gains increased their Canadian sales relative to non-exporters, the authors believe that the labour productivity gains reflected underlying TFP gains, not just the effect of the capital deepening associated with investing.

There is evidence that the productivity dividend from exporting depends to some extent on complementary investments. Aw, Roberts, and Winston (2005) use firm-level panel data to investigate the relationship between exporting and productivity growth in the Taiwanese electronics industry. They find that the ability of firms to draw productivity gains from their exposure to the export market depends on their investments in R&D and worker training. This is consistent with the results of Turcotte and Whewell Rennison (2004) for Canada, that the largest productivity gains accrue to establishments that have a larger share of university-educated workers, who also use a computer and participate in computer training.

Fears of the employment consequences of the growing international outsourcing of services have generated considerable public interest in the phenomenon (Amity and Wei 2005a), and studies of its impact on productivity have emerged. Olsen (2006, 3) provides a fairly exhaustive review of studies on the productivity impacts of offshoring and reaches the following conclusions:

> . . . there appears to be no clear patterns as to how offshore outsourcing affects productivity, . . . much depends on both sector and firm-specific characteristics. There are some indications that positive productivity effects from foreign material sourcing depend on the degree to which firms are already globally engaged. . . . There is little existing research on offshoring of services, but it appears that its productivity enhancing effects generally are small in manufacturing plants while being of a somewhat greater magnitude for firms in the services sector.

Beyond these conclusions, it may be worth examining the results of two specific studies. Amity and Wei (2005b) see offshoring as potentially boosting productivity through at least four channels: static efficiency gain, since the least-efficient parts of the production stage are relocated abroad; restructuring, since the offshoring of services might help by pushing the technology frontier and making the remaining workers more efficient; learning externalities from importing services; and variety effects, since the use of new material or service input varieties could increase productivity. Amity and Wei estimate the effect of offshoring on TFP and labour productivity in U.S. manufacturing between 1992 and 2000, using instruments to address the potential endogeneity of outsourcing. They find that the rising importance of offshoring contributes significantly to both TFP and labour productivity growth. Service offshoring has a much larger impact than materials offshoring, and affects productivity contemporaneously and with lags. Egger and Egger (2006) estimate a nested constant elasticity of substitution production function for 21 manufacturing industries and 12 EU member countries over the 1992–97 period to measure the influence of international outsourcing on the real value added of low-skilled workers. Their results show that changes in physical capital stocks and skills upgrading, rather than offshoring, drive low-skilled labour productivity in the short run. In the long run, however, international outsourcing boosts low-skilled labour productivity. Egger and Egger argue that this outcome is consistent with labour market rigidities in the short run, and the increased importance of mobility in the long run.

8.3 Multinational orientation

Another dimension of international exposure associated with better productivity performance is the multinational orientation of firms. Using data on 236 SIC four-digit industries in Canadian manufacturing, Baldwin and Gu (2005) find that foreign-controlled plants are more R&D intensive, introduce more innovations, use more advanced technologies and more skilled labour, and in the end are more productive than domestic-controlled plants, even after controlling for differences in size, capital intensity, and share of non-production workers. The advantages of foreign-controlled plants, however, arise from the multinational orientation of their parents, not from foreign ownership per se. Canadian plants belonging to Canadian multinational enterprises (MNEs) are as productive as foreign-controlled plants, and are more innovative and R&D intensive. This result is not unique to Canada. Doms and Jensen (1998) find that the domestic production units of U.S. multinationals have a productivity advantage relative not only to U.S.-owned plants with no overseas assets, but to plants of foreign subsidiaries in the U.S. market, even after controlling for industry, size, age, and state. This is consistent with the later findings of Bloom, Sadun, and Van Reenen (2005) on the superior productivity performance of U.S. multinationals operating in the United Kingdom (see section 3.4).

As is the case for exporting, there is likely a self-selection process at play in the superior productivity performance of Canadian MNEs relative to strictly domestic enterprises: the most productive Canadian firms are best able to overcome the fixed costs associated with FDI. Helpman, Melitz, and Yeaple (2004) exploit this idea in their theoretical model of export versus FDI with heterogeneous firms, which predicts that the least productive firms serve only the domestic market, the relatively more productive firms export, and the most productive firms engage in FDI. Likewise, Secrieru and Vigneault (2007) show in their theoretical model that FDI gives rise to higher productivity and wages than exporting and domestic production.

This leaves open the question of whether a firm, once it becomes multinational owing to its superior proprietary assets and productivity, reaps supplementary productivity gains in the domestic market by virtue of having operations in foreign markets. One possibility is that the foreign markets facilitate the acquisition of knowledge about the best technologies, production methods, and marketing practices used abroad. A number of studies find that such a technology sourcing effect is quite significant and in fact stronger than the technology transfer from MNE subsidiaries to domestic firms in the host countries (Keller 2004). This outcome, however, may be endogenous, in that it can reflect the strategy of the MNE parent to set up the foreign subsidiary with the explicit goal of technology sourcing. Another potential source of domestic productivity gains from outward FDI is that subsidiaries abroad may supply inputs to the domestic parent or affiliates at lower costs than arms-length domestic or foreign producers.

Exposure to foreign markets seems to lead to better choices and a superior productivity performance by multinational producers at the micro level.The empirical work of Criscuolo, Haskel, and Slaughter (2005) helps us understand why this is so. They estimate knowledge production functions on a data set providing detailed information on knowledge outputs and inputs for U.K. firms, paying attention to possible endogeneity in their estimation strategy. They find that both multinationals and exporters generate more ideas than their domestic counterparts, not only because they use more researchers but also because they have access to a larger stock of ideas through upstream and downsteam contacts with suppliers and customers. Multinationals, in addition, benefit from their intrafirm worldwide pool of information.

One relevant issue for policy that has generated a significant amount of empirical work is that of the FDI spillovers on host-country productivity through technological and managerial learning externalities for domestic firms. The typical approach is to regress productivity growth of domestic firms on changes in FDI and a number of control variables, trying at the same time to address the endogeneity issue. Keller (2004, 771) reaches the following conclusions after reviewing the empirical work: “In contrast to the earlier literature, recent micro productivity studies tend to estimate positive, and in some cases also economically large spillovers associated with FDI. This difference does not appear to be primarily due to endogeneity (or other problems).” His own study of technology spillovers to U.S. manufacturing firms via imports and FDI between 1987 and 1996 suggests that FDI generates substantial productivity gains for domestic firms, especially the less productive ones. FDI spillovers account for about 11 per cent of TFP growth over the period, and they appear to be much stronger in high-tech than in low-tech sectors (Keller and Yeaple 2003). Lileeva (2006) also obtains results that suggest significant FDI spillovers on labour productivity growth in Canadian manufacturing. She uses input-output tables to construct proxies for foreign control in supplier and customer sectors for each of 145 manufacturing industries and finds that vertical linkages with foreign-controlled plants boost productivity growth in domestically controlled plants. Spillovers from FDI in supplier sectors are particularly important; they have their largest effects on machinery and equipment, electronics, and chemicals. Moreover, the relatively important spillovers from FDI in science-based supplier industries suggest that technology diffusion and its associated skills upgrading are the main sources of productivity gains in domestically controlled plants.

8.4 Managerial quality, competition, and effort

Managerial quality belongs in those unidentified fixed effects that explain part of the large heterogeneity of productivity performance among firms in longitudinal micro studies. Bloom and Van Reenen (2006), in collaboration with McKinsey, innovate in this regard by developing explicit indicators of managerial best practices, combining a traditional survey approach with more in-depth case-study interviews to collect management practice data from 732 medium-sized manufacturing firms in Europe and the United States. They find that better management practice scores are strongly associated with superior firm performance in terms of the permanent component of TFP, profitability, Tobin's Q, sales growth, and survival. In a related McKinsey report, Dorgan, Dowdy, and Rippin (2006) state that an improvement of one point on a scale of 1 to 5 in the quality of management practices is correlated with an improvement of 6 percentage points in TFP. On average, U.S. firms are much better managed than European ones, with more intense product market competition and a lesser incidence of family firms in the United States accounting for between two-thirds (France) and one-third (United Kingdom) of the European management gap with the United States (Bloom and Van Reenen 2006). Management practice scores, however, vary more within countries than between them, implying that raising management quality closer to the best-practice frontier within each country can generate substantial productivity gains.

Using firm-level data for the United States, Bresnahan, Brynjolfsson, and Hitt (2002, 368) find a strong correlation between managers' opinions about ICT and skill requirements, on the one hand, and investment in ICT, skilled labour, and work organization, on the other. This supports their hypothesis that "the heterogeneity in firms' levels of IT, human capital, and work organization is in part driven by differences in managerial beliefs about what investment levels are optimal."

According to Feldstein (2003), "the ascendency of a new type of manager who had been trained in a business school to quantify goals and performance" likely boosted U.S. productivity growth in the 1990s. This would support the recommendation by the Institute for Competitiveness and Prosperity to increase university placements in MBA and other business programs in Canada in order to increase the supply of high-quality managers.

Management performance reflects not only the competencies of the business managers but also their effort. Nickell, Nicolitsas, and Dryden (1997) identify three factors that could reduce the degree of managerial discretion about their effort, and thereby boost efficiency and the rate of innovation: competition, financial market pressure, and shareholder control. Using panel data on U.K. manufacturing companies over 1982–94, they find that each one does indeed promote productivity growth, and that the last two can substitute for competition.

Competition affects managerial performance through several channels: it offers greater opportunities for comparing performance, which can lead to sharper incentives, and it raises the probability of bankruptcy at any given level of managerial effort (Nickell, Nicolitsas, and Dryden 1997). Increased competition sharpens incentives for incumbent firms to innovate in order to protect or reinforce their market position, and therefore escape competition (Aghion et al. 2005). In the Schumpeterian tradition, on the other hand, competition hampers productivity growth because it reduces the expected returns on innovation (see section 8.1, on small firms, for the arguments). One counter-argument is that the incentive to innovate arises not so much from the expected markup, which is lower with strong competition, as from the likelihood of a loss of market share and rents as a result of not innovating. This loss would be larger under strong competitition than under weak competition. Competition may also enhance the incentives to innovate through the pressures arising from a resource allocation process that is sensitive to market conditions and opportunities (Bartelsman et al. 2004). A more competitive environment promotes more rapid shifts in demand in favour of firms that have successfully implemented product or process innovation. If factor markets are flexible, firms will be able to adjust factor inputs to accommodate the demand for their products, and the most efficient producers will gain market share while the least efficient may be forced to exit.

The weight of the empirical evidence is that this adverse effect is more than offset by the positive effect of competition on managerial innovative effort (Crafts and Mills 2005). This is well illustrated by the recent study of Baggs and de Bettignies (2006), who use the Canadian Workplace and Employee Survey data set for 2001 to test that the impact of increased competition on managerial effort is positively related to the importance of agency costs in the firms. They find that the predictions of their theoretical model are consistent with the data. The importance that firms give to quality improvements and cost reductions, the presence of contractual incentives, and the number of unpaid overtime hours that employees work increase with product market competition. Moreover, the effects of competition on these variables are generally larger for firms with more employees and/or more hierarchical structures, where agency costs are more likely to prevail. As well, Griffith, Harrison, and Simpson (2006) show that "the reforms carried out under the EU Single Market Programme (SMP) were associated with increased product market competition, as measured by a reduction in average profitability, and with a subsequent increase in innovation intensity and productivity growth for manufacturing sectors." The study exploits variations in the timing and intensity of the SMP across industries and countries to obtain exogenous variations in product market conditions, thereby allowing identification of the impact of the reforms.

In the OECD's judgment, recent research shows that the relationship between traditional indicators of competition, such as markups and concentration ratios and product market competition, is not straightforward (OECD 2005). The OECD's own empirical work at the country level, using a model that relates productivity growth to changes in the global technology frontier and the speed of the catch-up process, establishes that anticompetitive product market regulations tend to depress productivity growth directly, and even more so indirectly, through a slower adoption of existing technologies (Conway et al. 2006). This is particularly the case the further a country is from the technology frontier, possibly because regulations reduce the scope of knowledge spillovers. In all of the countries, the detrimental effect is larger in industries that produce or use ICT intensively, because that is where the regulatory barriers to diffusion are the highest.

This last result for countries is at variance with the predictions for firms from a Schumpeterian growth model with multiple sectors, which differ in their distance to the technological frontier. Aghion et al. (2006) find empirical support from U.K. microdata for predictions that the threat of firm entry spurs innovation in sectors close to the technological frontier (levelled sectors) as incumbents try to prevent entry, whereas it discourages innovation in laggard sectors (unlevelled sectors) because it reduces the incumbents' expected rents from innovating. In an earlier paper, Aghion et al. (2005) find evidence from U.S. panel data on 17 industries over the 1973–94 period that the relationship between competition, as measured by a Lerner index, and innovation, as measured by citation-weighted patents, has an inverted-U shape: an "escape-competition effect" arises in levelled sectors and explains the positive segment of the competition-innovation relationship, whereas a "Schumpeterian effect," originating in unlevelled sectors, generates the negative segment.

It has been shown in section 7.1 that shocks that intensify competition, such as deregulation and trade liberalization, tend to stimulate productivity growth in the exposed industries in Canada.

There is also direct evidence that the perception of competitive threat stimulates productivity in Canadian manufacturing. Linking the ASM and the 1999 Survey of Innovation, Tang and Wang (2005) find that the productivity level of manufacturing firms was significantly positively related to the degree to which they agree with the statement that "the arrival of new products is a constant threat," and this after controlling for capital intensity, firm size, and industry. In a separate regression, they also obtain a significant, positive coefficient for a synthetic measure of product market competition built by applying a latent variable model to four indicators of competitive threat derived from the Survey of Innovation.

Financial market pressure would promote productivity gains by acting to discipline managers (Nickell, Nicolitsas, and Dryden 1997). The most common proxy for financial pressure is the level of debt or interest payments relative to cash flows, but this is not the only channel. Feldstein (2003) speculates that the emphasis on management performance and payment for creating shareholder value, which developed in the United States in the 1990s and has contributed to higher productivity growth, may have been a response to pressure from investment managers and Wall Street analysts to raise profits. Much of this, Feldstein thinks, may have reflected the growing professionalization of portfolio managers who were increasingly working for corporate pension funds, where performance is judged on a quarterly basis.

Areas for further research

A considerable amount of research focuses on firm characteristics as agents of productivity growth. Of particular relevance to Canada, firm size, exporting, and multinational orientation all make quite a difference in productivity performance across firms, although self-selection likely plays a significant, if not preponderant, role in the case of exporting and FDI. Moreover, vertical linkages with foreign-controlled plants have been found to boost productivity growth in domestically controlled manufacturing plants. Further work on the sources of firm-size dynamics and their impact on productivity growth is clearly warranted in a Canadian context. As well, investigating the impact of offshoring on productivity has become increasingly relevant as globalization continues to progress. Finally, exposure to foreign markets seems to lead to better choices by multinational producers at the micro level, but we need to better understand why this is so.

Rigorous empirical evidence on the contribution of managerial quality to productivity performance is scarce, but the careful quantitative work of Bloom and Van Reenen for the United States and a few European countries strongly suggests that management best practices matter a lot for productivity and other performance indicators at the firm level. This should not be a surprise, since the planning, coordination, and implementation of the key ingredients of strong productivity performance – adoption of advanced technologies and business practices, organizational change, and worker training – requires managerial quality. More work is needed along these lines for Canada, particularly in comparison with the United States and across firm sizes. The policy implications of the above findings depend partly on the extent to which strong management performance is driven by competitive pressures as opposed to business school training and other forms of skills acquisition; in other words, by effort rather than quality. Both seem to play a role, but this needs to be better understood.

9 Conclusions and Summary of Areas for Further Research

Increasing evidence of a shift in trend productivity growth in the United States and of a divergence of underlying growth performance between the United States, Canada, and Europe, has catalyzed a broader spectrum of research on productivity in this decade. At the most aggregate level, one key question has been how we can identify breaks in trend productivity growth in a more timely fashion. New approaches that emphasize the notion of probabilistic regime switching complement more traditional data-smoothing techniques that tend to convey the notion of gradual adjustment, rather than abrupt shifts in equilibrium productivity growth. The most promising of these regime-switching approaches uses corroborating evidence from economic series that are cointegrated with productivity in accordance with economic theory. Until recently, this approach has signalled that Canada is still in a low-growth regime, in contrast with the United States. Experimenting in real time with such models, using data-smoothing techniques as benchmarks, would provide valuable information on their usefulness and limitations. Even the best econometric techniques remain blunt detection instruments, however, and this suggests that additional evidence is needed to inform judgment.

Growth accounting provides the framework for analyzing the sources of aggregate productivity changes, and sheds light on the important contribution of ICT in the United States since the mid-1990s. Recent research has scrutinized the assumptions of the underlying Solow model to better understand the limitations and possible biases of the framework, and therefore the validity of its results. Overall, the framework's limitations do not appear to invalidate its broad conclusions. Nevertheless, studies have revealed that adjustment costs associated with investment, particularly in ICT, tend to delay the response of productivity to capital accumulation and embodied technical progress. To better measure the size and timing of adjustment costs would help interpret the dynamics of productivity, including the prospects for shifts in trend productivity growth. Research has also shown that capital composition matters for productivity growth, since some types of investment, notably in ICT and public infrastructure capital, have been found to have positive effects on TFP growth in the business sector, while others do not. It would be worthwhile to update these results by systematically testing the impact of capital composition on TFP growth in Canada at the aggregate and industry levels.

Growth accounting suggests that both the use of ICT and efficiency gains associated with the production of ICT have played a key role in the growth of American productivity since the mid-1990s. While the direct contribution of ICT from both capital deepening and TFP growth diminished considerably in the 2000–05 period, the shortfall was at least made up for by a pickup of TFP growth in non-ICT sectors, particularly in those private sector services that use ICT intensively. There is a strong hypothesis why TFP growth improvement in non-ICT sectors did not show up more before the mid-1990s: it takes time for the buildup in ICT investment to have a positive effect on efficiency gains because this requires a diversion of resources to complementary investments in intangibles, such as reorganization and learning. The European Union, in contrast, started experiencing a marked productivity slowdown in the second half of the 1990s, with TFP growth in the non-ICT sector vanishing over the 2000–04 period. For some, this reflects a deficiency in both investments in intangibles and the weeding out of inefficient users of ICT, owing to a lack of competition and flexibility; for others, it stems from labour market reforms in the mid-1990s that allowed employers to hire more low-wage, low-productivity workers, and from wage moderation that encouraged a shift to more labour-intensive production. Canada, on the other hand, experienced a productivity resurgence in the mid-1990s, which petered out in 2001 only to resurface again temporarily in 2005. The rise and fall in productivity growth around the turn of the millennium mostly reflect business cycle influences and the boom and bust in ICT-producing industries. Capital deepening came to a halt in the first half of this decade, including in ICT, while overall TFP growth slowed markedly. As in Europe, and relative to the United States, wage moderation appears to have induced a shift to more labour-intensive production and slowed productivity growth. This is a topic that deserves more rigorous analysis. The shortfall in productivity growth relative to that for the United States over this period arises from fewer efficiency gains in both the use and production of ICT, as well as less capital deepening in both ICT and non-ICT assets. Following the recent lead of Corrado, Hulten, and Sichel (2006) in the United States, it would be useful to estimate capital for intangibles in Canada since the early 1980s, and examine how it changes the results of growth accounting. One could also test whether slower investment in intangibles in Canada than in the United States (including worker training) has contributed to slower Canadian TFP growth in non-ICT-producing sectors, controlling at the same time for the spillovers of ICT itself.

Industry analysis reveals that, in the post-1995 period, the services sector has made a larger contribution to productivity growth in some but not all OECD countries, including Canada in the late 1990s. This variation serves to highlight the fact that ICT by itself will not boost aggregate productivity growth. Firms may need to adopt a suite of technologies and/or human resource policies and undergo organizational changes to derive the full benefits of their ICT investments. Lags between ICT investment and productivity growth may differ substantially across industries, and be quite long. The interaction between product and labour market regulations and industry performance may also be quite different. There is evidence that getting the framework right is important. Thus, countries such as Australia and the United States that put considerable effort into their regulatory framework in the 1980s and 1990s may have been seeing the benefits of this effort. There is also evidence that fostering competition can be very important to the diffusion of ICT, particularly in the retail trade sector, and that the greatest benefit comes from the diffusion of certain types of technology, especially communications technologies, perhaps owing to network effects that allow firms to rethink how they do business. Industries that comprise the Canadian ICT-producing sector are unlikely to contribute as much to aggregate productivity growth as they have in the past, owing to their relative downsizing in the wake of the ICT bust of the early 2000s. This implies that tracking developments by industry, particularly in the services sector, will become even more important to understanding aggregate productivity developments; i.e., the industries that drove up productivity growth in the past may be quite different from those in the future.

In recent years, productivity analysis has turned to estimating productivity gaps, relative mainly to the United States, which is viewed as the productivity leader. More recent work has also examined productivity level gaps at the industry level. Indeed, Canada has large gaps in productivity levels relative to the United States in most industries other than those in the resource sector and non-ICT manufacturing, and these gaps have widened over the past decade. Closing the aggregate labour productivity level gap will require that large sectors catch up, such as retail trade, where differences in marketplaces will constitute a serious obstacle to convergence. It would be useful to analyze at the industry level, including retail trade, the lags between M&E/ICT adoption and its appearance in TFP growth, and compare them with the United States, in order to determine the prospects of convergence offered by the relative profiles of M&E/ICT investment by industry in Canada and the United States in recent years.

The effort to explain Canada's gap relative to the United States with respect to productivity and related performance indicators has spawned a great deal of comparisons of structural characteristics, policy settings, and measurement methodologies between the two countries.

Studies reveal that productivity-related performance gaps relative to the United States mostly arise from differences in intensity within industries or firms, rather than from industry mix. Besides the industry mix, however, such structural characteristics as smaller firms and more prevalent and lower-paid self-employment in Canada may account for significant parts of the productivity gap, according to recent studies. Part of the considerable productivity and capital-intensity gaps, however, appears to be illusory, since harmonizing the methods of measuring them in the two countries has the effect of reducing these gaps markedly.

The need to more directly link productivity performance to business practices and the environment in order to better understand what drives the results of aggregate growth accounting has contributed to a proliferation of studies based on disaggregated data by industry, firm, or establishment. These studies have investigated the relationships between productivity performance, on the one hand, and innovation, firm dynamics, reallocation effects, and firm characteristics and the environment, on the other.

The link between productivity growth and the demand side of innovation – the adoption of new technologies and practices – has long been established, and recent studies reinforce earlier conclusions. These studies show inter alia that successful adoption partly hinges on two inputs for domestic invention – human capital and R&D – and that the integration of adopted innovations with advanced business practices, organizational change, and worker training enhances productivity growth. At the same time, what drives the demand for innovation needs further empirical investigation, particularly the role played by competitive pressures, managerial quality, absorptive capacity, and the relative costs of adopting advanced technologies. By contrast, much of the supply side of innovation has been analyzed fairly intensively, but it is important to better understand the nature and size of its contribution to productivity growth, including the roles played by absorptive capacity as a facilitator of adoption and by commercialization of inventions, an area in which Canada appears to lag other advanced countries. In this context, it would seem worthwhile to test the effect of R&D on TFP growth in Canada, using a model that allows for convergence effects through the use of a technology gap variable.

Heterogeneity is substantial at the micro level, which means that the distribution of characteristics across firms would affect how the economy adjusts to aggregate shocks. This finding has recently begun to be exploited in DGE models that make predictions about aggregate productivity growth, relying on the same rationalization and reallocation effects at the micro level as revealed by longitudinal firm studies. This strand of research is expected to develop considerably in the future. Too few studies, however, use microdata to identify or characterize periods of aggregate structural change, or the intensity of adjustment to aggregate shocks. Such studies are warranted, because they can shed light on how productivity growth may evolve as the economy adjusts to large relative price movements, for example. Indeed, how large movements in exchange rates and commodity prices can affect productivity growth in the broader context of firms' adjustment is an important topic for investigation. One clear result that emerges from studies on the impact of industry or aggregate shocks is that more competition leads to better productivity performance.

Because of the substantial variations in productivity levels across industries and firms, reallocation may have a significant bearing on aggregate productivity growth. Research has shown that labour reallocation between industries plays a very small role in this regard compared with pure productivity growth within industry. This means that understanding what drives productivity growth at the industry level provides a solid foundation for understanding what drives it at the aggregate level. At the level of firms, output reallocation as a result of changes in market share and, to a lesser extent, entry and exit, also plays an important role. This suggests that free, competitive markets may be important to promote aggregate productivity growth, because they promote a rich firm dynamics, thereby allowing the process of Schumpeterian "creative destruction" to fully work. Virtually all of the findings concerning the contributions of industry/firm dynamics come from studies examining the manufacturing sector, which represents less than 20 per cent of total GDP. It would be particularly illuminating to extend the analysis to other industries, especially to services in the private sector. The dynamics leading up to productivity growth might prove somewhat different from those observed in manufacturing.

A considerable amount of research has focused on firm characteristics as agents of productivity growth. Of particular relevance to Canada, firm size, exporting, and multinational orientation all make quite a difference in productivity performance across firms, although self-selection likely plays a significant, if not preponderant, role in the case of exporting and FDI. Moreover, vertical linkages with foreign-controlled plants have been found to boost productivity growth in domestically controlled manufacturing plants. Further work on the sources of firm-size dynamics and their impact on productivity growth is clearly warranted in a Canadian context. As well, investigation of the impact of offshoring on productivity is has become increasingly relevant as globalization continues to progress. Finally, exposure to foreign markets seems to lead to better choices by multinational producers at the micro level, but we need to better understand why this is so.

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Table 1
Estimates of Trend Labour Productivity Growth

	Techniques	United States				Canada	
		Previous trend	Level	Current trend	Level	Current trend	Level
Roberts (2001) non-farm business/hour	Kalman filter	1973	1.6 aver.	1995 2000	1.8 2.7		
Fernald (2005) non-farm business/hour	HP filter			1995 2000 2004	1.8 3.3 4.3		
Skoczylas and Tissot (2005) business/employee	Iterative split-time	Mid-1970s	1¼	Late 1990s	3.0	Mid-1970s	1¼
Maury and Pluyaud (2004) GDP/employee	Bai-Perron	1968Q1	1.5	1995Q3	2.2		
Fernald (2005) non-farm business/hour	Bai-Perron	1973Q2	1.5	1997Q1	3.2		
Kahn and Rich (2004) non-farm business/hour	Dyn. factor + regime switching	1974	1.4	1997	2.9		
Dolega (2007) total economy/ hour	Dyn. factor + regime switching					Late 1970s	1.1

Table 2
ICT Investment by Component, Average Annual Growth Rate in the Business Sector, $Can

	Total ICT		Computers		Communications		Software	
	Canada	U.S.	Canada	U.S.	Canada	U.S.	Canada	U.S.
1987–2004	6.3	7.7	3.9	5.5	4.9	5.1	9.8	11.6
1987–95	6.1	8.8	3.5	7.8	3.1	6.2	11.8	12.5
1995–2000	13.1	14.6	13.2	9.1	17.1	14.3	10.6	18.8
2000–04	–1.5	–2.2	–6.0	–3.1	–5.4	–7.3	4.9	1.5

Source: Sharpe (2005, Table 1)

Table 3
Growth Accounting Results for the United States and the European Union

	United States				United States			EU (15)		
	1973–95[1]	1991–95[2]	1996–2001[2]	1995–2003[1]	1987–95	1995–2000	2000–04	1987–95[3]	1995–2000	2000–04
	Business sector				Total economy			Total economy		
Labour productivity	1.47	1.54	2.43	2.95	1.2	2.3	2.8	2.3	1.8	1.1
Capital deepening	0.73	0.52	1.19	1.26	0.6	1.2	1.1	1.2	1.0	0.8
ICT	0.46	0.46	1.02	0.99	0.5	1.0	0.6	0.4	0.6	0.3
Non-ICT	0.27	0.06	0.17	0.27	0.1	0.2	0.5	0.8	0.4	0.5
Labour quality	0.27	0.45	0.25	0.37						
Total-factor productivity	0.47	0.58	0.99	1.32	0.6	1.1	1.7	1.1	0.8	0.2
ICT		0.41	0.77		0.4	0.7	0.3	0.2	0.4	0.2
Semi-conductors		0.13	0.42							
Other ICT		0.28	0.35							
Non-ICT		0.17	0.23		0.2	0.4	1.4	0.9	0.4	0.0

1. Corrado, Hulten, and Sichel (2006)
2. Oliner and Sichel (2002)
3. van Ark and Inklaar (2005)

Table 4
Growth Accounting Results for the U.S. Non-farm Business Sector

	1987–95	1995–2000	2000–05
Labour productivity	1.4	2.5	2.5
Capital deepening	0.5	0.9	0.8
• IT	0.4	0.8	0.5
• Other assets	0.1	0.1	0.3
Total-factor productivity	0.9	1.6	1.7
• Computers	0.3	0.7	0.3
• Services	0.3	0.9	1.1
• Others	0.3	–	0.1

Source: Bosworth and Triplett (2007)

Table 5
Growth Accounting Results for Canada

	1988–95	1995–2000[1]	1988–95	1995–2000[2]
Labour productivity	1.2	1.8	1.56	1.91
Capital deepening	0.8	0.5	0.64	0.40
ICT	0.4	0.5	0.33	0.48
Computers	0.2	0.4		
Software	0.1	0.1		
Communication	0.1	0.1		
Other M&E	0.1	0.2	0.31	–0.08
Structures	0.3	–0.2		
Labour composition	0.6	0.3	0.35	0.45
Multi-factor productivity	–0.2	1.1	0.57	1.06

1. Harchaoui and Tarkhani (2003)
2. Gu and Wang (2004)

Table 6
Sources of Productivity Growth in Canada

	1980–96	1996–2000	2000–06
Labour productivity	1.3	3.1	1.0
Capital deepening	0.9	1.1	0.8
Labour composition	0.4	0.4	0.3
Total-factor productivity	0.0	1.2	–0.1

Source: Baldwin and Gu (2007)

Table 7
Productivity Growth in the Early 2000s in Canada (contributions)

	2000–04	2000–02	2002–04
Output per hour	0.92	1.79	0.06
Capital per hour	0.35	0.80	–0.12
M&E	0.26	0.38	0.13
Structures	0.09	0.42	–0.24
ICT	0.22	0.28	0.14
Non-ICT	0.13	0.53	–0.26
TFP	0.57	0.99	0.17

Source: Rao, Sharpe, and Smith (2005)

Table 8
Contributions to Aggregate Labour Productivity Growth (per employed person)

	Canada	France	Germany	U.S.	U.K.	Australia	Finland
1990–95							
ICT-producing manufacturing	0.09	0.20	0.17	0.33	0.19		0.20
ICT-producing services	0.08	0.02	0.18	0.14	0.18	0.43	0.13
ICT-using services	0.16	0.01	0.17	0.24	0.37	0.47	0.10
Other activities	0.78	0.90	1.58	0.40	1.46	0.80	2.21
Total	1.11	1.13	2.11	1.12	2.20	1.71	2.65
1996–2002							
ICT-producing manufacturing	0.07	0.21	0.09	0.45	0.12	0.11	0.82
ICT-producing services	0.20	0.14	0.46	0.16	0.24	0.13	0.36
ICT-using services	0.46	–0.17	0.12	1.29	0.85	0.51	0.22
Other activities	0.79	0.82	0.71	–0.15	–0.12	0.98	0.62
Total	1.52	1.00	1.38	1.74	1.08	1.73	2.02

Source: OECD (2004)

Table 9
Productivity Growth Developments by Industry, Canada

	1998–2000	2001–02	2003–05	1998–2005	2001–05
Business sector	2.9	1.4	0.9	1.8	1.0
Goods	3.4	0.9	1.7	2.1	1.4
Agriculture	8.0	–1.3	3.3	3.9	1.4
Construction	2.5	3.4	1.5	2.4	2.2
Manufacturing	3.6	0.3	3.0	2.5	1.9
Services	2.9	2.2	0.5	1.8	1.1
Wholesale trade	6.1	0.3	2.5	3.3	1.6
Retail trade	8.1	1.6	–0.5	3.3	0.4
Transportation and warehousing	1.9	0.7	1.6	1.5	1.3
Information and culture	–0.7	6.2	0.0	1.3	2.5
FIRE	2.3	1.0	0.4	1.2	0.6
Professional services	1.7	4.1	–0.1	1.6	1.6
Administrative services	–3.8	1.5	–0.2	–1.1	0.5
Accommodation and food	1.0	1.7	–1.5	0.3	–0.2
Other services	1.7	5.7	–0.5	1.9	2.0

Source: Statistics Canada

Table 10
Labour Productivity Level Comparisons (percentage of U.S. level)

	Baldwin et al. (2005)	Rao, Tang, and Wang (2006)			Inklaar, Timmer, and van Ark (2007)	
	1999	1995	2000	2004	1997	2003
Business sector		72	70	63	88	83
Engineering						
Goods		881	74	58		
Services		62	61	55		
Non-business sector						
Total economy	86.9				98	95

Table 11
Productivity Level Comparisons: Selected Industries, Canada
(share of U.S. level, GDP per worker)

	Labour productivity		TFP	
	1995	2004	1995	2004
Primary	81	98	72	66
Mining	109	142	109	113
Construction	107	150	107	155
Manufacturing	88	58	93	66
Primary metal	116	112	120	118
Computers	128	21	185	23
Transportation	108	100	107	108
Services	62	55	65	61
Wholesale	77	62	107	90
Retail	64	60	79	73
FIRE	62	59	65	67
Total business	72	63	72	66

Source: Rao, Tang, and Wang (2006)

Chart 1
Percentage Share of ICT Investment in Total Non-Residential Investments ($C)*

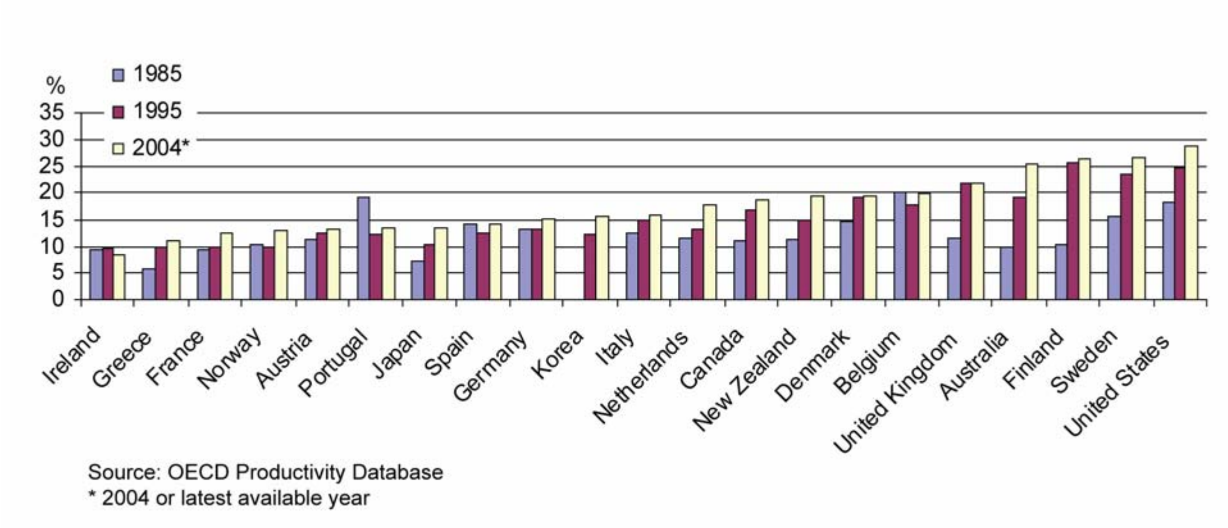


Chart 2
Investment in Hardware, 2004
(as a share of total-residential investment)

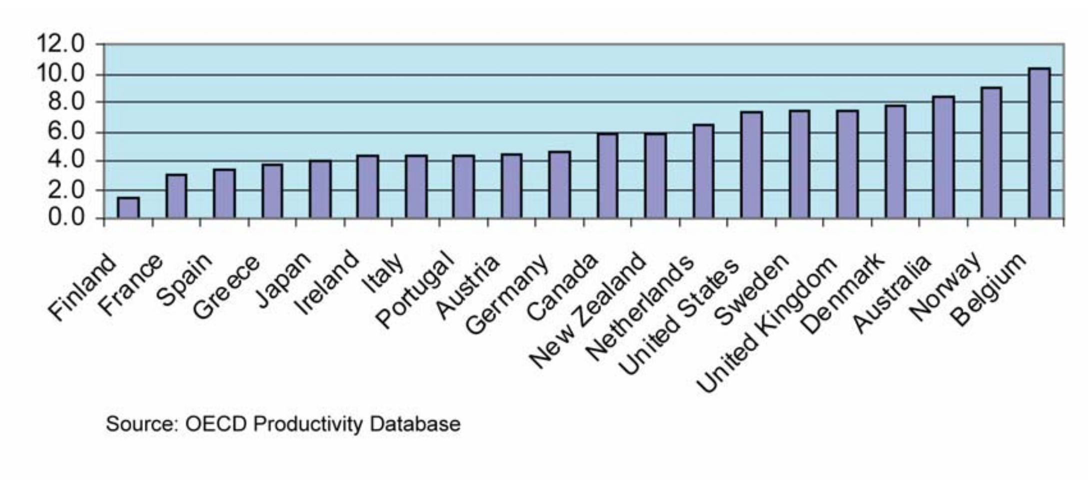


Chart 3
Investment in Telecom, 2004
(as a share of total non-residential investment)

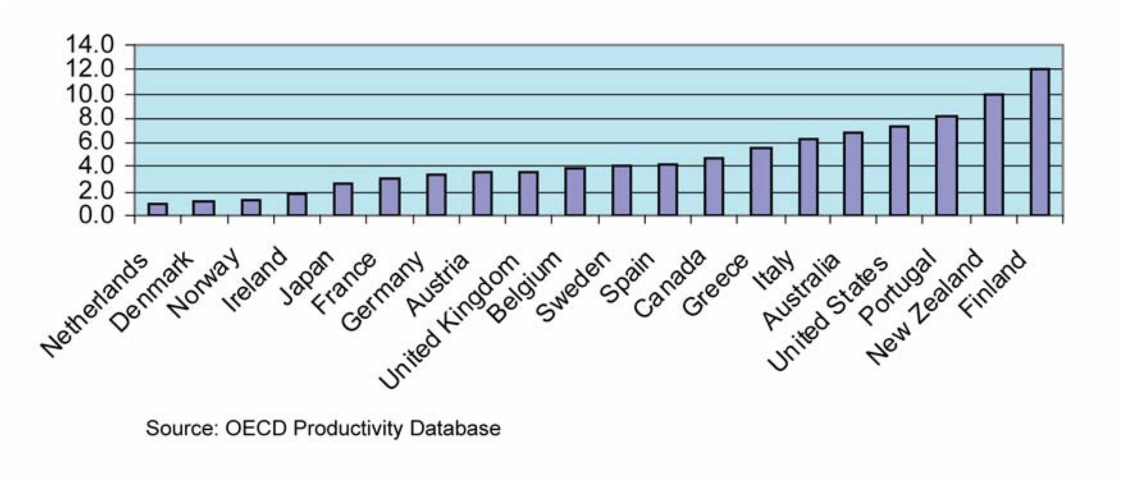
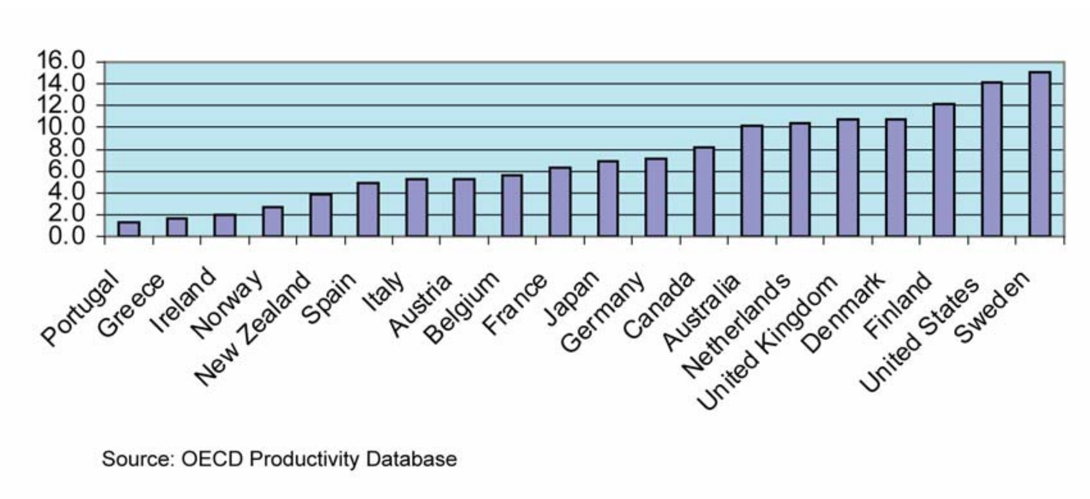


Chart 4
Investment in Software
(as a share of total non-residential investment)



Appendix A: Retail Trade

The sector that has probably attracted the most attention in productivity analysis over the past decade is the retail trade sector. Part of this relates to the strong performance witnessed in the United States, which, according to Triplett and Bosworth (2004), was the single largest contributor to the post-1995 resurgence, and that growth has accelerated over time. In general, retail trade makes up a relatively large share of output and employment in most OECD countries, so how it fares can be important for aggregate productivity growth. It also faces a competitive environment, and therefore should be adopting new technology. Indeed, TFP growth accelerated sharply in the United States, bolstering labour productivity gains in the sector, thereby pointing to an increase in the efficiency of operations.

Studies of retailing in the United States identify a number of factors behind the growth resurgence (Reidy and McGuckin 2005): better information about customers, faster information flow, smaller and more accurate inventories, sharp declines in margins and prices, and increased firm and store size. There has been a sharp contrast between productivity performance in the United States vs. Europe, which has helped to shed light on some of the sources of productivity growth.

Retail firms in the United States have invested heavily in new types of equipment (computers, scanners, and, most recently, radio frequency identification), but not sufficiently to boost productivity growth. The investment must be integrated with changes in business practices and processes. In some cases, productivity gains have been generated via firm turnover; i.e., new firms displacing old firms. In other cases, increasing IT investment has generated productivity gains, although this finding appears to hold only for large firms (Doms, Jarmin, and Klimek 2003; Doms 2004). Other studies suggest that chain stores benefit more than individual stores (Reidy and McGuckin 2005).

The United States invested heavily in ICT equipment earlier than in Europe, and this may be one reason why the productivity gains have appeared sooner. The Wal-Mart name is synonymous with the surge in productivity growth in retail trade. In fact, the Wal-Mart effect is used to define the changing retail landscape where relentless competition forces investment and organizational change that drives productivity growth. Reidy and McGuckin (2005) suggest that a combination of regulatory barriers that limit competition as well as slow the adoption of new technology (such as bar codes and radio frequency identification), a smaller scale, slower complementary change (in supporting industries such as transportation), and differences in culture and tastes across Europe that make it more difficult to streamline operations have all played a role in

Europe's lagging productivity growth. Some of the regulatory barriers include restrictions on opening hours and land use, impediments to labour market flexibility via high minimum wages, and strict hiring and firing laws. In a study of the United States vs. the United Kingdom, Basu et al. (2003) hypothesize that one reason behind the differing productivity performance in retail (and wholesale) trade between the United States and the United Kingdom may be competition (in particular, they point to restrictive planning laws in the United Kingdom, which hamper the growth of big-box retailing). Moreover, the U.S. productivity improvement is not the result of a sudden change; rather, it reflects decades of heavy investment, organizational change, and effective management.

Canadian studies suggest that, as in many cases, Canada tends to fall between Europe and the United States. Tarkhani (2005) shows that labour productivity growth surged to 3.9 per cent growth in the 1995–2000 period on the back of a tremendous pickup in TFP growth. Although capital intensity was an important contributing factor, the contribution from TFP was seven times as large. Labour productivity slowed to 2.5 per cent between 2000–03, mainly because the contribution from TFP slowed from 2.9 to 2.2 per cent. Tarkhani (2005) identifies some of the factors behind the surge in TFP, including the use of scanners and UPC codes, better supply-chain management, and improved transportation logistics. Although these show up in increased capital intensity, the way in which they allow retailers to operate better would be consistent with the surge in TFP growth.

Canada's productivity performance, however, has lagged that of the United States. Not only has growth been lower, the gap in productivity levels has opened up markedly between 1987 and 2002, falling from 109 per cent of the U.S. level to 83 per cent. Sharpe and Smith (2004) show that, over this period, output growth was about half that of the United States, while hours growth was similar, implying a substantially lower labour productivity growth, of about 1 per cent for Canada and almost 3 per cent for the United States. The gap narrowed between 2000 and 2002, when it stood at 3.6 per cent for the United States and 1.9 per cent for Canada. To a large extent, this gap can be attributable to much lower TFP growth. Moreover, Canada has had a much lower level of capital intensity, at only about 68 per cent that of the United States in 2002. Such investment, particularly in ICT, may have helped to boost TFP growth in the United States. More fundamentally, the competitive pressures to reform business operations and boost productivity growth seem larger in the United States; and Sharpe and Smith (2004) and the Conference Board (2004) point to this Wal-Mart Effect as the principal reason behind Canada's lagging productivity growth. Although it is reasonable to expect that Canada's retail trade sector will experience some improvement in productivity growth for this reason, Sharpe and Smith (2004) argue that it is unlikely to experience it to the same extent, because of, for example, the lower penetration rate of Wal-Mart, given the more local nature of Canadian markets. In addition, substantial scope remains for Canada's retail, wholesale, and transportation industries to increase their integration and standardization by using improved scanning technologies and other such equipment.

In summary, while there may be some regulatory issues at play in Canada that have hampered productivity growth (e.g., Canada's higher unionization rate), it seems more likely that differences in the Canadian marketplace itself, as noted by Sharpe and Smith (2004), such as its more local nature, are probably the most likely reasons behind lagging productivity growth in this sector. And there is more scope for the retail sector to improve its synergies with other sectors. The precise reasons behind the more recent slowing, however, remain elusive.

Appendix B: Performance Indicators – Canada versus the United States

Indicators	Canada vs. U.S.	Factors
Business sector TFP	lower	• 19% gap in 2004 versus 12% in 1995, accounting for over two-thirds of 2004 labour productivity gap • significant advantage in mining, resource-based manufacturing, and construction • large gap in services and high-tech manufacturing, especially computers and electronics • factors: mostly lower M&E capital/labour in Canada, but also lower share of hours worked by workers with university degree and above, and lower R&D expenditures to GDP ratio (Rao, Tang, and Wang 2006)
M&E investment/GDP	lower	• industrial structure plays no role • lower intensity pervasive across industries and, within business sector, heavily concentrated in ICT, particularly telecom equipment and software (Fisher and Rodriguez 2006)
ICT investment/GDP	lower	• industrial structure: lower Canadian employment shares in ICT-intensive industries, including telecom services and FIRE • size distribution of employment: larger share of employment in low-ICT small and medium-sized firms • higher relative ICT/labour costs in Canada • lower proportion of Canadian managers with university education (Sharpe 2005)
Business capital/GDP	lower	• the Bureau of Economic Analysis (BEA) uses lower depreciation rates than Canadian productivity program, particularly for engineering structures and buildings • no overall gap when Canadian depreciation rates are applied to U.S. data • positive gap in engineering capital, owing to favourable industrial structure and higher intensity by industry in Canada, offsets deficits in ICT capital (mostly due to lower intensity by industry) and in non-ICT M&E and buildings (since lower intensity by industry more than offsets favourable industrial structure) (Baldwin et al. 2006)
Business capital/worker	lower	• negative gaps to total capital and M&E would be larger if Canada had the same industrial structure as the U.S. Without mining and utilities, however, the differences in industrial structure have no significant effect. • panel regressions suggest that differences in investment prices, real wage rates, the share of hours worked by university-educated workers, R&D-to-GDP ratio, and Hodrick-Prescott measures of the output gap all have a significant impact. (Rao, Tang, and Wang 2007)

Indicators	Canada vs. U.S.	Factors
PCs in use per capita	lower	• 15% lower PC intensity in Canada in 2005, concentrated in business sector, government, and education • lesser PC penetration would explain 30% of the 18% labour productivity gap vs. U.S. in 2000 (Fuss and Waverman 2005)
Business R&D/GDP	lower	• industrial structure is important: relatively small share of R&D-intensive industries in Canada • low R&D intensity in motor vehicle manufacturing, wholesale and retail trade (ab Iorwerth 2005)
Higher education R&D/GDP	higher	• (Institute for Competitiveness and Prosperity 2006)
Patents per worker, per capita, per R&D dollar	all lower	• 19th among the OECD countries in 1999 in terms of triadic patents per million of R&D spending (Jaumotte and Pain 2005) • U.S. patents per worker from Ontario less than half those from U.S. peer states, because of lower patent intensity by industry cluster; unfavourable cluster mix plays little role (Institute for Competitiveness and Prosperity 2004) • 55% of patent applications resulting in patent grants over 1992–97 versus 61% in G-7 • “quality” of Canadian patents as proxied by citations received is about 20% lower than in U.S. • half of Canadian patents may not benefit the Canadian economy, either because they are not commercialized or because they are owned by foreign assignees (Trajtenberg 2002)
Managers’ educational attainment	lower	• lower proportions of managers, 25–64-year-olds, with bachelor’s degree and advanced degree, 2001 (Institute for Competitiveness and Prosperity 2005)
Adult education and training participation	lower	• lower fraction of time an average person spends on learning activities during the year: 3% vs. 4% in the U.S. and 7–10% in Sweden, Finland, Great Britain, and Denmark (OECD 2006)
University degrees/population	lower	• lower proportion of 25–64-year-old population having a university degree (22% vs. 28% in 2003) (OECD 2006) • weaker annual flow of new university degrees, especially at the master’s level, per 1,000 population (5.58 vs. 6.56) in 2002–03 (Institute for Competitiveness and Prosperity 2006)

Indicators	Canada vs. U.S.	Factors
Proportion of small firms/establishments	higher	• as at 2001, average firm size is smaller in Canada than in the U.S., reflecting 25–30% fewer employees per firm in both the smallest (0 to19) and the largest (500+) firm-size categories • as at 1997, Canadian (U.S.) manufacturing plants with less than 100 employees were 64% (74%) as productive as medium-sized plants (100–499 employees), and 46% (50%) as productive as large plants (Baldwin, Jarmin, and Tang 2004)
Net income per self-employed worker relative to paid worker	lower	• contributes to depress business sector labour productivity relative to that for the U.S. in the 1990s (Baldwin and Chowhan 2003)
Share of self-employment in total employment	higher	• higher level and growth rate in the 1990s contribute to depress business sector labour productivity growth relative to that for the U.S. (Baldwin and Chowhan 2003)

Appendix C: Linking Value-Added Labour Productivity Growth at the Aggregate Level to Gross Output Productivity Growth by Industry

Stiroh (2002):

$$d \ln LP^{V} = \sum_i \overline{w}_i d \ln \cdot LP_i^{y} \qquad \text{(industry productivity growth)}$$

$$+ \left(\sum_i \overline{w}_i d \ln L_i - d \ln L \right) \qquad \text{(reallocation of labour)}$$

$$- \left(\sum \overline{m}_i d \ln M_i - d \ln Y_i \right) \qquad \text{(reallocation of intermediate inputs),}$$

where LP^{V} refers to aggregate value-added productivity, LP_i^{y} to gross output labour productivity in industry *i*, *L* to labour input, *M* to intermediate inputs, *Y* to gross output, $\overline{w}_i$ to a 2-period average share of industry value-added in aggregate value-added, and m_i to a 2-period average ratio of nominal industry intermediate inputs to nominal aggregate value-added.

Ho, Rao, and Tang (2004):

$$d \ln LP^{V} = \sum_j \overline{w}_j^{k} d \ln k_j \qquad \text{(capital deepening by asset type)}$$

$$+ \overline{w}_l d \ln l \qquad \text{(labour quality)}$$

$$+ \sum_i \overline{w}_i^{d} d \ln TFP_i^{y} \qquad \text{(gross output TFP by industry),}$$

where $\overline{w}_j^{k}$ is a 2-period average nominal income share of capital asset *j* in nominal aggregate value-added, k_j the ratio of capital asset *j* to labour input, $\overline{w}_l$ a 2-period average income share of labour in aggregate value-added, *l* the ratio of quality-adjusted labour input to raw labour input, $\overline{w}_i^{d}$ a 2-period average of industry *i* nominal gross output in nominal aggregate value-added, and TFP_i^{y} the gross output *TFP* in industry *i*.

Appendix D: Formula for Decomposing Labour Productivity Growth

Faruqui et al. (2003):

Aggregate labour productivity growth ($L\dot{P}_t$) at time t can be written as:

$$L\dot{P}_t = \frac{L_{t-1}}{L_t} \cdot \left[\sum_i \left(\alpha_{i,t-1} \cdot L\dot{P}_{it} \right) \right] \qquad \text{(pure productivity growth effect)}$$

$$+ \frac{L_{t-1}}{L_t} \left[\sum_i \left(\alpha_{i,t-1} - \left(\frac{L_i}{L} \right)_{t-1} \right) \cdot \dot{L}_{i,t} \right] \qquad \text{(labour reallocation effect),}$$

where L_i refers to labour input in industry i, and α_i to nominal output share of industry i.

Tang and Wang (2004):

$$L\dot{P}_t = \cdot \sum_i \alpha_{i,t-1} \cdot L\dot{P}_{it} \qquad \text{(pure productivity growth effect)}$$

$$+ \sum_i \left[\left(\frac{LP_i}{LP} \right)_{t-1} \cdot \Delta \left(\frac{Pi \cdot L_i}{P \quad L} \right)_t \right] \qquad \text{(Denison effect)}$$

$$+ \sum_i \left[\left(\frac{LP_i}{LP} \right)_{t-1} \cdot \Delta \left(\frac{Pi \cdot L_i}{P \quad L} \right)_t \cdot L\dot{P}_{it} \right] \qquad \text{(Baumol effect),}$$

where Pi is output price in industry i.