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TECHNOLOGY AND PRODUCTIVITY: A SUMMARY OF THE RELATIONSHIP AND A REVIEW OF RELEVANT RESEARCH

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Contents

Introduction

This information bulletin is presented in two sections, which follow a summary of the key findings.

The first section addresses the important contribution of productivity to economic growth and explores the relationship between adopting advanced technology and improving productivity. Drawing from the findings of productivity research, the section begins by defining productivity and explains why labour factor productivity is the best measure of, and the key to, productivity enhancement. It then explains how increasing productivity leads to economic growth and a higher standard of living. The section concludes by examining the relationship between adopting advanced technologies and productivity enhancement as shown through a review of relevant research papers.

The second section summarizes the individual findings from 16 research papers, which explore the relationship between adopting advanced technologies and enhancing productivity.

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Key Findings from Literature Review

- Labour productivity, as opposed to total factor productivity (TFP), is the most accurate and meaningful measure of productivity.
- Labour productivity is positively associated with worker skill, firm organization, capital intensity, R&D, innovation, and technology, only the last of which can improve productivity in the long run. While technology adoption is *correlated* with labour productivity improvements, the exact channel through which it influences productivity is still unclear, although capital deepening is likely the largest factor.
- Improvements in labour productivity are tied to similar changes in the wages workers receive. Increased labour productivity, by increasing wages and the amount of output for a given set of inputs, simultaneously increases demand and output, resulting in a higher standard of living as measured by GDP or income per capita.
- Productivity, often due to public misconception, is a difficult concept to rally public support around. Productivity growth does *not* imply working harder, longer, for less, or a contraction of the labour force.
- From 1961-2008, the average annual growth rates of labour productivity (2.0%) and the real wage (1.8%) have been similar.
- Canada still lags behind American productivity performance. In 2008, labour productivity in Canada was only three-quarters of that in the U.S., whereas relative GDP/capita was only 84%.
- Labour productivity will be one of the most important determinants of Canadian's, and Albertan's future standard of living.

Economics is the study of the choices people make and the actions they take when faced with scarcity. The world has endowed us with limited resources and the efficiency, determined by productivity, by which we transform these resources into usable products is a key determinant of economic progress and social well being. Consequently, productivity, and the enhancement of it, has been a focal point of economic studies for decades but has been a challenging public policy issue because it is often misunderstood by the public. Therefore, a brief discussion on what productivity is, how it is measured, and how it can be improved by adopting advanced technologies is warranted.

Productivity is defined as the efficiency through which a given set of inputs is transformed into outputs. It can be measured in three ways: capital, labour and total factor productivity (TFP).[1] The first of these relates output to the amount of capital, or equipment, used in production; the second, relates output to the amount of labour used; and the third relates output to a bundle of all inputs. While all three are useful measures, labour productivity is the most accurate and meaningful metric because it is the one most closely tied to worker wages, income, and thus standard of living.[2]

Simple economic theory posits that the wage workers receive is equal to the marginal product of labour, i.e. the amount of output produced by one additional worker. In reality this relationship is not one-to-one, but is very close in the long run. In Canada, over the period 1961-2008, the average annual growth rates of wages and labour productivity were 2.0% and 1.8%, respectively.[3] By increasing worker productivity, more output can be created using the same inputs, simultaneously driving up wages and aggregate output. Higher output per capita implies a higher level of GDP/capita, while higher wages imply a higher level of income per capita, both of which increase consumption potential and result in a higher standard of living.

So if productivity is so important, how can it be improved? Labour productivity is determined by several factors, which include capital intensity (the amount of capital per worker), worker skill, firm organization, scale, innovation, and technology levels. But research has shown that technology level is the most important factor for increasing productivity in the long run. The other factors are limited in that they can only increase so much before all possible gains are exhausted, whereas technology levels, as witnessed since the industrial revolution, are unbounded and grow at an exponential rate.

Unfortunately, as mentioned above, productivity is often misunderstood by the public and therefore poses a challenge to public policy makers. It must be noted that productivity improvements do *not* imply working harder, longer, for less pay, or being laid off. In fact, enhanced productivity results in a decrease in the required amount of work to produce a given product. While increasing other factors such as labour force participation, employment rates, and hours worked can raise output, such growth is unsustainable as these factors, similar to those discussed above, are also are limited.[4]

Researchers agree that technology plays a role in enhancing productivity, and that process is the topic of numerous studies - many of which have been performed by Statistics Canada.[5] Investment in technology can take a variety of forms (i.e. replacement, retooling, and expansion), not all of which would be expected to increase productivity.[6] Furthermore, the effects of technology adoption on productivity are likely to vary from firm to firm. For example, where technology-specific human capital is lost and/or a transitional period of experimentation and learning-by-doing exists, a lagged effect of technology adoption on productivity is likely to be observed.

In light of this, some studies examine the effects of advanced technology adoption on firm performance over a period of time. In these studies other factors that influence labour productivity are controlled in order to separate their effects from those caused by technology adoption. While the extent of the impact of technology on productivity varies, a common theme emerges indicating that a robust link between technology use and productivity exists, with the two standing in positive correlation to one another. The research also indicates that the former likely influences the latter most significantly through capital deepening. Thus by investing in, and adopting new and advanced technologies, firms can improve performance, productivity, economic growth, and the standard of living.

To summarize, technology is the key to productivity growth, which is one of, if not the single most important determinant of the future standard of living. In 2008, labour productivity in Canada was only three-quarters of that of the U.S., whereas Canada's GDP/capita stood at 84% that of the U.S.[7] Furthermore, Alberta's productivity growth rate has been the lowest in Canada over the long run.[8] It is estimated that between 2006 and 2020 labour productivity will contribute 82.8% of total economic growth in Canada, whereas over the period 1973-2006, this figure was only 44.9%.[9] Hence, this topic deserves critical attention and cooperation between the public and private sectors if future prosperity is to be achieved.

In the words of former U.S. Secretary of the Treasury William E. Simon: "Productivity and the growth of productivity must be the first economic consideration at all times, not the last. That is the source of technological innovation, jobs, and wealth."

Endnotes

[1,3,7] Baldwin, J. R., & Gu, W. (2009). Productivity Performance in Canada, 1961 to 2008: An Update on Long Term Trends. Economic Analysis Division. Catalogue no. 15-206-x2009025. Ottawa: Statistics Canada.

[2] Carlaw, K. I., & Lipsey, R. G. (2003). Productivity, Technology and Economic Growth: What is the Relationship? Journal of Economic Surveys (17) 3. pp.457-486.

[4,9] Sharpe, A. (2007). Three Policies to Improve Productivity Growth in Canada. CSLS Research Report 2007-05.

[5] Baldwin, J. R., Diverty, B., & Sabourin, D. (1995). *Technology Use and Industrial Transformation: Empirical Perspectives*. Analytical Studies Branch Research Paper Series. Catalgoue no. 11F0019MIE1995075. Ottawa: Statistics Canada.

[6] Power, L. (1998). The Missing Link: Technology, Investment, and Productivity. *The Review of Economics and Statistics (80)* 2. pp. 300-313.

[8] Productivity Alberta's website <http://www.albertacanada.com/productivity/about/index.html>

Summaries of Research Papers

Baldwin, R. J., & Gellanty, G. (2007).
Innovation Capabilities: Technology Use, Productivity Growth and Business Performance: Evidence from Canadian Technology Surveys. Statistics Canada. Micro-Economic Analysis Division. Catalogue no. 11-622-MIE2007016. Ottawa: Statistics Canada.

This publication summarizes the results of the following studies:

- Baldwin, J. R., & Brown, M. W. (2004). *Four Decades of Creative Destruction: Renewing Canada's Manufacturing Base from 1961-99.* Insights into the Canadian Economy Research Paper Series. Catalogue no. 11-624-MIE2004008. Ottawa: Statistics Canada.
- Baldwin, J. R., Diverty, B., & Sabourin, D. (1995). *Technology Use and Industrial Transformation: Empirical Perspectives*. Analytical Studies Branch Research Paper Series. Catalgoue no. 11F0019MIE1995075. Ottawa: Statistics Canada.
- Baldwin, J. R. & Sabourin, D. (2004). *The Effect of Changing Technology Use on Plant Performance in the Canadian Manufacturing Sector*. Analytical Studies Branch. Catalogue no. 88-514-XPE1993001. Ottawa: Statistics Canada.
- Baldwin J. R., Sabourin, D., & Smith, D. (2003). *Impact of Advanced Technology Use of Firm Performance in the Canadian Food Processing Sector*. Economic Analysis Research paper Series. Catalogue no. 11F0027MIE200312. Ottawa: Statistics Canada.

These studies are based on past advanced technology surveys (1989, 1993, and 1998) performed by Statistics Canada that have been instrumental in examining the relationship between technology adoption and firm performance. Their main findings are:

- Efficiency is driven by a myriad of factors, including capital deepening, implementation of novel/advanced technologies, firm restructuring/ organization, innovation and research and development. Competition results in relatively inefficient incumbent firms being displaced by more efficient entrants. According to Baldwin & Brown (2004), the resulting rate of firm turnover is quite large. As some plants are shut down and/or downsize, new and growing plants supplant them, and as a result, roughly 40% of jobs are 'renewed,' over a ten year period in the Canadian manufacturing sector, and 65% over a twenty year period. Over the period 1988-1997, Baldwin & Sabourin (2001) find that some 47% of market share is transferred from 'losers' to 'winners', 26% of which went to incumbents gaining market share and 21% of which went to entrants. This turnover is made up of many small changes. Technology adoption works to enhance market share by increasing labour productivity both directly, and by through increases in capital intensity, which in turn affect prices and product quality. Bartelsman et al. (1998) find that advanced technology users are disproportionately represented in the 'winner' category.
- Baldwin et al. (1995) combine data from the *1989 Survey of Manufacturing Technology* with data from the *Annual Survey of Manufactures* longitudinal file to create a panel of

approximately 4200 firms. They find evidence that utilization of advanced technologies is *correlated* with firm performance. In particular, for most technologies studies, technology users in the initial time period (1981) exhibited higher productivity than non-users, and the gap increased over the next decade. This was most marked for firms using inspection and communication technologies.

- Baldwin et al. (2003) study the link between information communication technologies (ICTs) and productivity growth using the *1998 Survey of Advanced Technology in the Canadian Food Processing Industry*, similarly, find that relative productivity is strongly associated with firm technology intensity (ICTs in particular), even after differences in initial productivity and changes in capital intensity, both of which are strong predictors of performance, are included.
- Baldwin & Sabourin (2004) link the *1993 Survey of Innovation and Advanced Technologies* with the *1998 Survey of Advanced Technology in Canadian Manufacturing* to study the effects of technology adoption on productivity and market share. Single-equation and simultaneous equation models were estimated. In both models productivity was found to be positively correlated with technology adoption over the period in question, but unrelated to initial levels of technology. The results of this study, and indeed all of the above studies, are that a "robust link between advanced technology use and plant performance" exists, even after other correlates of productivity are controlled. Certain types of technologies, specifically ICTs displayed the largest impact.

Baldwin, J. R., & Sabourin, D. (2001).
Impact of the Adoption of Advanced Information and Communication Technologies on Firm Performance in the Canadian Manufacturing Sector. Analytical Studies Branch Research Paper. Catalogue no. 11F0019MIE2001174. Ottawa: Statistics Canada.

These authors, using data from the *1998 Survey of Advanced Technology*, regress productivity growth on technology use, initial firm size and productivity, changes in capital intensity, R&D, innovation, and proxies for other business practices in order to separate the effects of technology use from other innovative activities which are often highly correlated, as omitted variable biases could result in overestimation of technology's effect on productivity. Their findings are:

- Productivity growth is positively associated with technology use, even after controlling for changes in capital intensity, which itself is found to have a large significant effect on performance. Conversely, regional location, R&D and other business strategy variables do not display significant effects on performance, suggesting that the fixed effects these variables capture do not bias the estimated impacts of technology on productivity growth. Adoption of network communication technologies and combinations of the three types of technology studied (hardware, software, and communication) resulted in the largest gains. Interestingly, firm level relative productivity displayed a tendency towards mean reversion, with firms that are initially relatively less productive tending to catch up to those with relatively higher initial productivity levels (coefficient on initial productivity negative and highly significant).

- The authors note that *how* changes in technology affect performance is outside the scope of this, and similar studies, but posit that a proportion of productivity gains from adoption are likely a result of higher capital intensity.
- In regard to firm performance, it is posited that plants, through either enhancement of their cost structure or the production of higher quality goods can simultaneously improve labour productivity and market share, an idea that is supported by the data. This relationship is likely to work both ways, with higher labour productivity leading market share gains, which in turn foster productivity growth, likely through scale effects.
- Methodologically, the authors contend that economic performance over a given period should be related to initial technology levels and changes in advanced technology utilization over the period. Increases in labour productivity, however, cannot readily be expected after the advanced technology is introduced, but should happen slowly as the firm learns and adapts to the new product/process. Hence, a lagged effect of technology adoption on performance should occur. They further suggest that labour productivity is the appropriate measure as it is "inherently more accurate than measures of total factor productivity (TFP)." These two measures are also very similar if the production function is of Cobb-Douglas is used, in which labour productivity growth is equal to TFP growth plus the growth in the capital labour ratio times the capital share.

Baldwin, J. R., & Gu, W. (2009).
Productivity Performance in Canada, 1961 to 2008: An Update on Long Term Trends. Economic Analysis Division. Catalogue no. 15-206-x2009025. Ottawa: Statistics Canada.

This paper provides a brief discussion of the types of productivity and the factors that influence them, as well as an overview of productivity in Canada. The main points are as follows:

- Productivity typically falls under three categories labour, capital, and total factor (TFP, also known as multifactor productivity, MFP, which measures the increase in output beyond the increase in inputs). Labour productivity is measured as GDP/hour worked; capital productivity is measured as GDP/unit of capital; and TFP is measured as GDP per bundle of labour and capital. TFP is affected by technology, innovation, R&D, firm organization, and scale and capacity utilization effects.
- Labour productivity growth, which is positively associated with rises in capital intensity, worker skill and technology (as possibly imbued in TFP), is of particular interest because it is positively related to worker compensation, and thus income, standard of living, and economic growth. With a Cobb-Douglas production function, wages rise in proportion to increases in labour productivity, but for other functional forms this relation may not hold. Economic theory posits that the real marginal product of labour should equal the real wage (nominal wage/price) in the long run, a relationship that is observed in Canada (average annual growth rates of 2.0% and 1.8% respectively from 1961-2008), although short run deviations exist. Over the

period 2000-2008 average annual real hourly labour compensation grew 0.9% whereas labour productivity grew 0.7%.

- In Canada, over the period 1961-2008, increases in capital intensity contributed to 1.3% of the 2.0% increase in labour productivity, whereas worker skills (0.4%) and TFP (0.3%) contributed the remainder. From 1988-2000, in which labour productivity grew by 1.7%, these figures were 1.0%, 0.4%, and 0.3% respectively. After 2000, TFP turned negative, accounting for almost all of the labour productivity growth slowdown (1.4% growth since 2000). Slow technology growth post 2000, appreciation of the dollar after 2003, and rising commodity prices have adversely affected TFP growth in the mining, oil and gas, and manufacturing industries, which are the primary causes of declining business sector TFP growth rates in Canada.
- Strong relationships between output growth and both TFP and labour productivity growth exist. These relationships work through dual feedback loops. As output increases, specialization and economies of scale are more easily attained, as are monies for investment in advanced technology, and vice versa. In regards to manufacturing, output growth has been the main factor behind the decline in TFP and labour productivity growth.
- Aggregate TFP measures can be derived by summing industry TFPs multiplied by the value added by that industry. Cross country comparisons of productivity are fraught with error due primarily to differences in measurement. Nevertheless, comparisons are made, and small persistent differences in Canada/US labour productivity growth over the period 1961-2008 are attributed mostly to differences in TFP growth. GDP/capita growth rates have been similar to those in the US since 2000, but this has been due to increased labour utilization in Canada (hours worked/capita) which has been offset by falling relative labour productivity. In 2008 Canada's labour productivity was only three-quarters of its US counterparts.

McGuckin, R. H., Streitwieser, M. L., & Doms, M. E. (1996).
The Effect of Technology Use on Productivity Growth. Center for Economic Studies. U.S. Census Bureau. Working Paper.

Similar to the studies performed by Statistics Canada, this paper examines the relationship between advanced technology adoption and firm performance in the U.S. Data from the 1988 and 1993 Surveys of Manufacturing Technology are combined with survey data from the Longitudinal Research Database. The author's findings are:

- Diffusion is not congruent amongst the technologies studied, and the adoption process is not smooth as plants utilized and discontinued use of specific technologies over the period 1988-1993 (average gross change of four technologies, net increase of one). Hence, technologies seem to be an experience good, and firms undergo periods of experimentation and learning processes with each.
- Firms that adopt advanced technologies exhibit higher productivity, even after plant size, age, capital intensity, labour skills mix, and other plant characteristic controls, such as industry and region, are included. This relationship holds in regards to both incident and intensity of use.

- The data suggests that relatively 'good' performers are more likely to adopt advanced technology, and this is primarily responsible for the positive relationship between technology and productivity that is found. Therefore, a possible simultaneity bias may exist.

Carlaw, K. I., & Lipsey, R. G. (2003).
Productivity, Technology and Economic Growth: What is the Relationship? *Journal of Economic Surveys (17)* 3. pp. 457-486.

While not conducting any empirical investigation of technology and firm performance, this paper discusses, in-depth, some methodological issues surrounding such studies. In particular, the shortcomings of TFP as a reliable and accurate measure of productivity are advanced. The authors posit that:

- TFP does NOT measure technological change nor long term increases in production potential, but rather contemporary returns in excess of returns available by investing in known technology. Furthermore, TFP is at best an indicator, but not a policy lever.
- No relationship between technology transformation and productivity rates need be necessary.
- Interpretation of TFP falls into three broad categories- technology change, "free-lunches", and the "ignorance" view, all of which can be misleading.
- Growth accounting requires a specific production function that is stable across time, technologies, industries, and levels of aggregation for TFP to be accurately calculated. The authors sugges this is extremely unreasonable.
- Index accounting and distance function approaches to TFP measurement are also fraught with issues.
- TFP can only measure the gains in output in excess of the development costs and cannot therefore indicate the total gains from adoption of a new technology. These returns are also not all "free-lunches," but rather compensation for the risk and uncertainty firms face when adopting novel technologies, while some gains, via externalities, may accrue to factors outside TFP calculations (and in some cases indeed be "free lunches," typically with general purpose technologies). Thus TFP fails to measure all the societal benefits of new technologies and may also misrepresent firm or industry level benefits as well.
- Non-existent TFP growth does not imply zero technology growth, but rather that new technologies have returns congruent to existing technologies at the margin. Technological change exerts its positive influence on economic growth by retarding the diminishing returns process to labour and capital. Therefore, even if TFP growth is zero, productivity (for given rates of labour and capital accumulation) can be increasing.
- The timing of cost-reductions impact TFP measurements, which are larger the more spread out the cost-reduction is. Treatment of R&D as a user of inputs with no discernable same period output results in reduced TFP even though no technological regression has occurred. TFP only incorporates the returns to R&D once new technologies are actually utilized.

- A substantial amount of technological change, even at the plant level, will be embodied in increases in measured inputs and thus not contribute to TFP, when in fact it should.

In conclusion the authors state that:

"Although TFP is easily calculated, it is difficult to interpret. Only under a very specific set of ideal conditions does it measure the super normal benefits associated with technological change. It is, therefore, at best only an indicator of how much measured output growth an economy achieves relative to measured input growth." (pp. 475).

Thus, utilization of labour productivity as a measure of the impact of technology on productivity is the most appropriate. It should be noted that most of the authors of the other papers summarized here acknowledge this as well.

Power, L. (1998).
The Missing Link: Technology, Investment, and Productivity. *The Review of Economics and Statistics (80)* 2. pp. 300-313.

Using panel data from the Longitudinal Research Database (LRD) on approximately 14,000 large manufacturing plants (accounting for over 60% of investment in the US manufacturing sector) over the period 1972-1988, the author estimates a number of ordinary least squares (OLS) regressions with productivity (levels and growth) as the dependant variables. Plant age, investment age, and other proxies for plant characteristics are included as independent variables. Both pooled and industry level regressions are estimated, with and without plant level fixed-effects (to control for unobserved heterogeneity among plants). The somewhat unintuitive results are as follows:

- "Plant embodied technical change" assumes existing producers face sunk costs as new plants have a relative advantage at adopting new technologies. In contrast, "machine-embodied technical change" assumes that technological progress is embodied in new machinery in incumbent plants. In reality, technological adoption is likely somewhere between the two; with both existing and entrant firms adopting new technology, and competitive advantages could go both ways.
- Many different types of investment exist (replacement, retooling, expansion, etc…), and each should be expected to affect plant productivity, if at all, in different ways. While this study excludes structures as a form of investment, the exact type of investment is not specified. (This could be the primary influence on the results, as potentially productivity neutral investments, such as expansion, could be included in the analysis, which the author acknowledges). Furthermore, technology adoption can result in the loss of technology specific human capital if learning-by-doing exists, and thus productivity levels may decline after the adoption of a new technology.
- In both the pooled and industry level regressions, virtually *no* positive correlation between productivity and high levels of recent investment are observed. This holds across the three definitions of investment utilized (absolute, relative, and combined investment spikes), and is even more pronounced when fixed effects are included. Also, variations in productivity with respect to investment age diminish once fixed effects are included. Size, industry, and plant-specific effects are found to be important

determinants of productivity. Large plants are found to be generally more capital intensive than smaller plants.

- Productivity patterns, with respect to plant and investment age are not constant across industries.

Overall, due to lack of specification, these results cast little doubt on the technology-productivity drive hypothesis.

Bartelsman, E., van Leeuwan, G., and Nieuwehuijsen, H. (1996).
Adoption of Advanced Manufacturing Technology and Firm Performance in the Netherlands. *Economics of Innovation and New Technology (6)*. pp. 291-312.

This paper links data from the 1985 and 1991 Production Statistics with the 1992 Survey of Advanced Manufacturing Technology and the 1982-1993 Survey of Capital Stocks in the Netherlands. The data are split into three groups- firms using advanced manufacturing technology (AMT), those without AMT, and those with AMT excluding the largest five firms. Only computer aided manufacturing equipment is included in the analysis. The authors note this limitation in the study, as well as the fact that the actual date of adoption is not observed. Their results are:

- Productivity growth is found to be higher for firms utilizing AMT, but employment and output are lower. Interestingly, they find that the share of advanced technological equipment in total factor inputs decreases with firm size (even after correcting for possible selection bias), which stands in contrast to most other studies of AMT.
- The AMT usage dummy variable is significant (increases when AMT intensity variable is included) and AMT intensity has a negative but insignificant effect in TFP. The effect of the AMT dummy on labour productivity growth is barely significant, and growth is attributed primarily to the increase in capital-labour ratios. While firms that employed AMT in 1992 displayed higher growth rates of TFP and employment between 1985 and 1991, no clear causal relationship exists between AMT usage and either measure of productivity. Capital deepening is cited as the main channel via which labour productivity is affected by technology adoption.
- The probability a firm uses AMT increases with firm size and its capital-labour ratio. Growth in the capital-labour ratio was higher for AMT users. Conditional on use of AMT, AMT intensity increases with the capital-labour ratio, but declines with respect to the level of labour productivity.
- A significant interaction between AMT adoption and worker compensation is also observed. The authors note, however, that causality could go in both directions. High wages may result in firms adopting labour saving technologies or implementation of AMTs could increase wages through upgrading of the labour force or rent-sharing. Usage of AMT was correlated with relatively higher employment growth, which in turn is inversely related to wage growth.

Beede, D. N., & Young, K. H. (1998).
Patterns of Advanced Technology Adoption and Manufacturing Performance. *Business Economics (33)* 2. pp. 1-11.

The authors of this paper summarize the findings of some of the studies discussed above, noting that often only the number of technologies is used to measure a firm's technological sophistication, a methodology that ignores potential diversity in adoption patterns and the effects of specific combinations of technologies. In light of this, their study (which looked at roughly 10,000 firms from the 1988 Survey of Manufacturing Technology and linked this with the LRD) analyzes various technologies to determine the effects of specific (and combinations of) technologies on firm performance. The findings are:

- Enormous diversity exists in adoption patterns, even within the same industry and the same production process. The most commonly used technologies are computer aided design, numerical control tools, and a combination of these two.
- More than 80% of technology categories adopted are associated with plants with higher levels of productivity and job growth. The relationship between technology adoption and productivity growth is weak, however. These results are similar to most studies on technology and productivity. However, for certain technologies (and combinations thereof), large gaps in productivity existed (20-25%) between those firms that adopted and those that did not. These technologies are intercompany computer networks and computer aided design with programmable logic controllers or numerically controlled machines.

Fuentelsaz, L., Gomez, J., & Palomas, S. (2009).
The Effects of New Technologies on Productivity: An Intrafirm Diffusion-Based Assessment. *Research Policy (38).* pp. 1172-1180.

The authors of this paper bring to the foray some interesting methodological issues that are apparent in previous studies examining the relationship between technology and productivity. A summary is as follows:

- Technology is diffused in two ways interfirm and intrafirm. The former measures the extent to which firms in a given industry have acquired at least one unit of a technology. The latter, which is important for divisible technologies, measures the extent to which a single firm has incorporated a specific technology into its operations.
- A common feature of previous studies is to separate the data set into adopters and non-adopters. This can be erroneous. First, the focus on interfirm diffusion ignores the intrafirm diffusion process. In some instances, the point of adoption may not be the time in which the technology is actually used and exerts effects on productivity, but rather an experimental/learning phase. Second, technology diffusion within a firm is a dynamically evolving process (tending to follow a logistic S-shaped path) that begins upon adoption and therefore benefits to new technology are likely to fluctuate over time. This should be explicitly acknowledged. Third, the interfirm diffusion approach ignores the heterogeneity among firms in their level of technology adoption.

- For indivisible technologies whose use throughout an entire organization occurs at the point of adoption and whose use is mandatory, other measures of implementation such as infusion, routinization, and assimilation would be necessary, as diffusion would be instant.

It should be noted that many of the above studies overcome these shortcoming through longitudinal analysis and/or the inclusion of plant level fixed effects. The authors do also note the difficulty in obtaining the requisite data that would allow for a fruitful analysis on intrafirm technology diffusion.

Basu, S., Fernald, J. G., & Shapiro, M. D. (2001).
Productivity Growth in the 1990s: Technology, Utililization, or Adjustment? National Bureau of Economic Research. Working Paper.

After a protracted recovery from the 1990-91 recession, during the second half of the 1990s, productivity growth increased considerably in the United States. Measured productivity levels (MFP) however, according to these authors, were not wholly due to technological change, but rather influenced by three factors: factor utilization rates, adjustment costs, and the distribution of factors among industries with varying degrees of economies of scale. The authors posit that when factor utilization rates are increasing, measured productivity levels will rise even without any increase in technology, and thus will be overestimated. Conversely, when factor adjustment occurs, output will fall, and correspondingly so will measured productivity, even if no technological regression has occurred. During periods of expansion, factor utilization rates will rise and so will adjustment costs (as firms accumulate capital and engage in hiring labour). During a contraction, the opposite tends to occur. In both phases of the business cycle, the effects of either of these cyclical factors could potentially offset the other. The third factor, dealing with economies of scale, can work both ways. If inputs are being shifted to industries that are characterized by economies of scale, measured productivity will be overestimated, and vice versa. Basu et al. (2001) develop a complex model, with the working assumption that technology and productivity are equal in the long-run. They decompose measured productivity into the above three components, plus the proportion due to technology. Using figures from the Bureau of Labor Statistics (BLS's) multifactor productivity data, that assembled by Dale Jorgenson and his associates, and from the Bureau of Economic Analysis' Gross Product Originating dataset, they find that:

- Cyclical factor utilization rates accounted for some of the rate of measured productivity growth in the first half of the 1990s but cannot account for the rapid productivity growth in the second half of the decade.
- Adjustment costs downwardly influenced measured productivity during the initial expansion after the 1990-91 recession, obscuring true technology growth.
- Reallocation of inputs affects baseline growth in technology, but has not significantly contributed to growth rates.
- Evidence of substantial growth in technological change in evident for the second half of the 1990s.

This paper, in conjunction with that by Carlaw & Lipsey (2003), provides both theoretical and empirical evidence that supports the notion that TFP is an inaccurate measure of technology.

Sharpe, A. (2007).
Three Policies to Improve Productivity Growth in Canada. Centre for the Study of Living Standards. Research Report 2007-05.

This paper discusses the importance of productivity to long term economic growth, issues that surround the study of productivity and related policy, and three policies by which productivity could be improved are suggested. The main points are:

- Productivity is by far the most important determinant of material living standards for Canadians because real income can only be increased in the long run if more real output is produced. Productivity also positively affects other, broader, concepts of economic and social well being.
- Growth in GDP can be decomposed into labour input growth and labour productivity growth. Growth in GDP per capita can be broken down into labour productivity growth, the average number of hours worked per employed person, and the proportion of the population that is employed. While increases in the number of hours worked, employment rates, and labour force participation rates can increase output, these factors are bounded. Therefore, productivity growth is key to long run growth.
- Canada's aging population makes productivity a critical factor affecting future standards of living.
- A lack of direct measurement of the productivity of the public sector is a severe measurement problem. Incorporating changing qualities of goods in requisite deflators is also an issue. If such corrections are not made, real output and thus real productivity growth will be underestimated.
- While investments in physical and human capital are positively associated with labour productivity increases, technological advancement, which may or may not be embodied in new equipment, is the primary driver of long run business sector growth.
- In 2005, Alberta's GDP/worker was 144.3% of the national average. Between 2006 and 2026, labour productivity is estimated to contribute to 82.8% of total economic growth in Canada. Over the period 1973-2006, this figure was only 44.9%.
- Politically, productivity is a risky word because of common misconceptions of the subject. Many people associate productivity with working longer hours and/or working harder and layoffs. The first two are simply wrong interpretations; the last need not be the case, as increased output results in higher income and thus higher demand, which itself creates employment opportunities. If the labour supply curve is positively sloped (which is questionable), aggregate employment will actually increase.
- "Programs and policies that boost productivity may not have the highest returns for society." However, the authors suggest the diffusion of best-practice technologies,

removal of PST on the purchases of new machinery and capital, and promotion of interprovincial mobility of workers are means by which to achieve efficiency gains.

Sharpe, A., Arsenault, J.F., & Harrison, P. (2008).
The Relationship between Labour Productivity and Real Wage Growth in Canada and OECD Countries.
Centre for the Study of Living Standards. Research paper 2008-8**.**

The authors of this paper present a thorough discussion of the link between labour productivity and real wage growth, which they contend is the key to long run prosperity. A summary is:

- Economic theory posits that the aggregate level of real wage growth is determined by labour productivity growth, a relationship that is mediated by labour's share of output (and hence of compensation) and labour's terms of trade (the price of output, as given by a GDP deflator, divided by the price of consumption, as given by the CPI). The latter two factors operate within narrow bands, and thus productivity growth is the only way to sustain rising living standards.
- The real consumption wage is equal to the nominal wage divided by the CPI, whereas the real product wage is defined as the nominal wage deflated by a GDP deflator. The former is more closely related to real worker compensation as it relates a worker's wage to the price of a basket of typically purchased goods, but the latter is more closely related to labour productivity.
- The change in the real consumption wage is equal to the change in real labour productivity times the change in labour share multiplied by the change in labour's terms of trade. The product of the first two terms equals the real product wage.
- In theory, firms hire workers up to the point where the marginal cost of doing so, the nominal wage, is equal to the marginal revenue product of labour, which is equal to the average revenue product of labour if returns are constant to scale. Thus, an increase in productivity, if not totally offset by declines in share and terms of trade, will raise the real consumption wage, which entails a higher standard of living.
- In the presence of competitive labour and product markets, no relationship between labour productivity and real consumption wage growth need be necessary. Wages are determined at the level of the total economy, and above average labour productivity in one sector results in declining relative prices rather than higher relative wages, which benefits all consumers.
- In Canada, over the period 1961 to 2007, annual growth in both consumption and product wages (1.67% and 1.56% respectively) was generally outpaced by productivity growth (1.73%). From 1980 to 2005, labour productivity rose 37.4%, but the average annual earnings only rose 0.13%. This disparity is due to measurement issues, increased income inequity, and decreases in labour's share of national income and terms of trade.