The Effect of Adjustment Costs and Organizational Change on Productivity in Canada: Evidence from Aggregate Data

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THE CONTEMPORANEOUS EFFECTS OF investment on output and productivity growth have been examined in many studies.[2] Fewer papers have investigated the effects of investment in new capital on productivity growth over a longer period of time. Investment raises the stock of capital and hence output, but adjustment or adoption costs may initially obscure these gains. To fully exploit the productive capacity embodied in the new capital, firms must devote resources to integrate the new technology into their production processes. These costs may be direct, in the form of installation and training costs. On the other hand, they may be more subtle, involving expenses to develop ways of using the new technology, or costs associated with implementing organizational change that complements the installation of new technologies.

Lichtenberg (1988) has provided evidence of non-negligible adjustment costs at the level of the firm. More recently, Basu, Fernald, and Shapiro (2001), Bessen (2002), and Kiley (1999) have found that capital adjustment costs lowered measured multifactor productivity (MFP) growth by 0.3 to 0.5 percentage points per year in the U.S. manufacturing industry and the U.S. non-farm business sector.[3] The payment of these adjustment costs, however, does lead to benefits. Brynjolfsson and Hitt (2000a, 2000b) and Stiroh (2002) argue that organizational coinvestments complementary to investments in information and communications technology (ICT) lead to output growth above and beyond that of growth due to the accumulation of capital in constant quality units alone. Since the restructuring process may not be immediate, the

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2 For example, Kiley (1999) and Oliner and Sichel (2000, 2002) use the neoclassical growth accounting framework to analyze the impacts of investment in different types of capital stock on U.S. labour productivity growth and the sectoral contributions to multifactor productivity growth in the U.S. non-farm business sector. Studies that use similar techniques and Canadian data include Armstrong et al. (2002) and Khan and Santos (2002).

3 Kiley estimates the magnitude of adjustment costs on the aggregate economy. He finds that adjustment costs have lowered measured MFP growth since 1974 by 0.5 percentage points per year. Using industry-level data, Basu, Fernald and Shapiro (2001) find that adjustment costs have lowered the average measured MFP growth rate by 0.3 percentage points per year during the 1987-1999 period. Using data from U.S. manufacturing industries, Bessen (2002) finds that adjustment costs lowered MFP growth by 0.4 percentage points per year in the 1970s and early 1980s.

full impact of investment in new technologies may not be felt until years after the initial investment. As a result of both adjustment costs and complementary organizational change, investment in ICT equipment or any other kind of capital that embodies new technology does not necessarily have a simple one-period effect on output growth and productivity.

Empirical support for the need to consider the lagged effects of investment can be found in Brynjolfsson and Hitt (2000a) and Basu et al. (2003). Brynjolfsson and Hitt find that the effects of computer capital growth on MFP growth are two to five times greater over periods of five to seven years than over a one-year period, while Basu et al. find that U.S. industries that had high ICT capital growth rates in the early 1990s had high MFP growth rates in the late 1990s.[4]

To capture the full effect of the investment in new technologies, this article studies the lagged impact of various types of capital investments on Canadian MFP. Using a method based on production function estimation, the net effect of capital adjustment costs and complementary coinvestments on MFP growth is estimated. The first section discusses the relationship between adjustment costs, organizational change, and MFP. The second section describes the data and the empirical framework used to identify the effect of investment in new technologies. The third section presents the results. Using aggregate data for Canada between 1961 and 2001, it is found that the effects of adjustment costs on aggregate MFP growth are negligible for all types of capital investment. The effects of complementary investments or innovations, however, are significant and are found to occur most strongly three years after the initial investment in computer hardware. There is also evidence that the effects of complementary investments have grown stronger over time, and that this growth can explain approximately one third of the average annual growth rate of MFP since 1992. The final section provides a summary and conclusion.

The Measurement of Improvements in Efficiency

MFP is meant to capture the part of growth that cannot be accounted for by increases in capital or labour inputs. It represents technological progress and improvements in the organization of production. The measure of MFP that is produced by statistical agencies such as Statistics Canada or the U.S. Bureau of Labor Statistics captures as well the effects of capacity utilization, returns to scale, and changing market structure. These factors must be considered before attempting to uncover a relationship between adjustment costs, organizational change, and MFP. Paquet and Robidoux (1997) find little evidence of economies of scale and markups for both the Canadian and American business sectors.[5] Therefore, the discussion in the rest of this section and the empirical work that follows proceeds under the assumptions of constant returns to scale and perfect competition. On the other hand, capital utilization is generally acknowledged to have an effect on MFP and is taken into account in the empirical work presented in this paper.[6]

4 Brynjolfsson and Hitt (2000a) use firm-level data from the United States between 1987 and 1994, and Basu et al. (2003) use U.S. industry-level data between 1987 and 1999.

5 Furthermore, Baldwin, Gaudreault, and Harchaoui (2000) estimate MFP growth rates for the Canadian manufacturing sector that allow for markups, scale economies, and capital fixities. They find that relaxing the assumptions of zero markups and constant returns to scale has a relatively small effect on productivity estimates.

6 Paquet and Robidoux (1997) assume that capacity utilization has an effect at the outset and adjust their measure of capital input for utilization before continuing with their analysis.

Adjustment costs at the aggregate level

Adjustment costs can be thought of as arising from the costs related to the direct installation of new equipment, the training of individuals, the use of resources to explore methods to fully utilize the capital, and the reorganization carried out to put those methods into effect. The magnitude of adjustment costs found in empirical studies depends on the methods and data used to obtain the estimates. As stated in the introduction, several papers (Lichtenberg, 1988; Kiley, 1999; Basu, Fernald and Shapiro, 2001; and Bessen, 2002) have studied the magnitude of adjustment costs at the firm, industry, and aggregate levels. They all assume that the production function of a representative firm has a form as follows:[7]

$$Y_{ord} + Y_{adj}\left(\frac{I}{K}\right) = F(A, K, L), \tag{1}$$

where A is disembodied technological change, K is capital input, I is investment, L is labour input, Y_{ord} is the firm's "ordinary" output, and Y_{adj} is the amount of the "adjustment cost" good the firm must produce. The amount of adjustment cost good produced is modeled as an increasing function of investment, I, over capital.[8] Types of capital with high ratios are relatively new types of capital or types of capital with high depreciation rates.[9] Both examples are categories of capital that embody new technology. First, it is natural to believe that wholly new categories of capital would embody the newest technologies. Second, a high depreciation rate may indicate a fast pace of quality improvement in that type of capital. Computers and other ICT equipment would fall into both of these categories, and it is commonly believed that their introduction has been associated with adjustment costs.

In empirical work, neither the technology factor, A, nor the amount of adjustment cost goods produced is observed. However, by moving the adjustment cost term to the right-hand side and regressing gross output on capital, labour, and investment over capital, an estimate of adjustment costs can be obtained using firm- or industry-level data. Adjustment costs lower a firm/industry's measured productivity, because resources are being expended. The firm uses inputs to produce the adjustment cost goods, but there is no corresponding increase in the production of ordinary output. It is important to note that adjustment costs lower measured productivity, leaving the true underlying MFP unchanged. As long as growth in investment in new technology continues to be high, or as long as adjustment costs are incurred because of past investment growth, measured MFP will be lower than true MFP. As soon as investment growth stabilizes, measured MFP growth will rise to its true level, ceteris paribus. As a result of adjustment costs, growth in investment will tend to precede growth in measured MFP by a number of periods.

Investment in new technology and improvements in efficiency

The discussion above described how investment in new technology leads to adjustment costs and hence mismeasurement of MFP. MFP itself is not affected by investment via this channel. However, Brynjolfsson and Hitt (2000a, 2000b) and Breshnahan, Brynjolfsson, and Hitt (2002) suggest that investment in new technology can bring efficiency gains. They argue that computers, as a

7 The notion of installation costs for new investment goods is not a recent idea. It can be found as far back as Lucas (1967).

8 Adjustment costs may also be allowed to be a function of lags of the investment-to-capital ratio, or the investment-to-capital ratio of different categories of capital.

9 For Canada, the investment-to-capital stock ratio for computers was 0.42 in 2001. In contrast, the ratio for buildings and structures was 0.06.

general purpose technology, facilitate complementary technological and organizational innovations. In turn, these innovations bring increases in output that are above and beyond those resulting from simple accumulation of computer capital. For example, information and communications technology (ICT) is thought to facilitate the flow of information between workers, and between workers and management. Arnal, Ok, and Torres (2001) argue that the strong association between ICT use and the presence of employee involvement schemes, teamwork, and decentralized decision-making is evidence of this relationship. Ichniowski, Shaw, and Gant (2002) suggest that, in contrast to a more traditional hierarchical organization structure, a flatter, involvement-oriented management structure facilitated by ICT allows each individual worker to better access the human capital of other workers, which in turn leads to higher productivity.[10] Since there is likely to be a period between the introduction of ICT and the ensuing organizational changes to exploit advantages of the new technology, the long-run effect of investment in new technology on output should be greater than that of the short run. The effect of investment in technology may even be negative in the short run, as Brynjolfsson and Hitt (2000b) suggest, with firms struggling to maintain the same level of output during the reorganization period.

Stiroh (2002) offers an alternative explanation for improvements in MFP that result from investment in ICT capital. He suggests that the improved communication between firms that results from ICT use generates network externalities that increase the productivity of all parties. Investment in ICT by one firm leads to productivity spillovers to other firms in the network. As Stiroh acknowledges, it is difficult to distinguish between increases in productivity that result from investment-led organizational change and innovation, and improvements that result from network externalities. Improved business-to-business communication due to network externalities facilitates organizational changes, such as outsourcing and just-in-time inventory control, but that does not necessarily mean that improvements in productivity should be attributed to network externalities. Increased outsourcing and better inventory-control systems may not have been possible without improved communication, but the productivity improvements may not have been realized by the development of network externalities alone. This paper attempts to find evidence of links between investment and MFP growth, but does not try to distinguish between the two differing explanations.

Not only is it difficult to distinguish the effects of improved communication links within the firm from those between firms, it is difficult to distinguish the effects of adjustment costs from those of complementary innovations. Both adjustment costs and complementary innovations are argued to be the result of investment in new technology. Thus, any indicator of investment in new technology, such as the investment-to-capital ratio, should lead to both adjustment costs and complementary innovations. Therefore, only the net effect of adjustment costs and complementary innovations can be identified. The only difference is in the timing of the relationships. Based on previous evidence from Bessen (2002), it is expected that the negative effects of adjustment costs should be incurred only in the first one or two years after the initial

10 In Ichniowski, Shaw, and Gant (2002), the amount of human capital an individual worker can access is called the individual's connective capital. The sum of each individual's connective capital is the workplace's connective capital. Increasing the number of links between workers raises the workplace's connective capital and productivity. Ichniowski, Shaw, and Gant (2002) cite other studies that examine the positive effects of innovative human resource management systems, and present some of their own empirical evidence from U.S. steel mills.

investment, whereas evidence from Brynjolfsson and Hitt (2000a) suggests that the positive effects of complementary innovations should be stronger over a longer period of time.

One would also expect that the net effect of adjustment costs and complementary innovations would increase over time as more capital containing the new technology is accumulated. It is likely that productivity increases that result from improved communication linkages between and within firms cannot take place until after some threshold level of capital stock has been passed. One would not expect improvements in productivity to be noticeable if only a handful of employees had access to ICT equipment, nor expect network externalities to develop if only a small number of firms invested in ICT. On the other hand, adjustment costs per unit of investment should be lower after a large stock of capital has been accumulated when the installation and reorganization process has been refined. Consequently, the net effect of adjustment costs and complementary innovations is likely to be an increasing function of the capital stock.

Empirical Framework and Data

This section describes the data and explains how the effect of capacity utilization, and the net effects of adjustment costs and innovations complementary to investment in new technology on MFP, are identified.

Data

The main analysis for this paper is conducted using annual data for Canada between 1961 and 2001, obtained from CANSIM. Measures of MFP, investment, hyperbolic end year net stock of capital,[11] and annual hours generally pertain to the business sector. The exceptions are the measures of investment and capital for computer hardware, telecommunications equipment and software, measures of current dollar output and labour compensation used to calculate labour's share of output, and the measure of industrial capacity utilization.[12] The measures of investment and capital for computer hardware and for telecommunications equipment and software are for the non-agricultural business sector. Since the agricultural industry likely accounts for only a small fraction of the investment and stocks of these types of capital, the results should not be affected much by this discrepancy. Labour's share of nominal output is for the total economy because GDP in current dollars was available for the business sector only up to 1999 when this empirical work was undertaken. The industrial capacity utilization series is for non-agricultural goods-producing industries. The unabridged version of this paper contains a discussion on why the use of these two series does not affect the main results of the paper.

Empirical framework

As described in the previous section, measurement of MFP is affected by returns to scale, imperfect competition, capacity utilization, adjustment costs and technology. Assuming a simple, aggregate, Cobb-Douglas production function yields the following relationship:

$$\Delta \ln Z_t - (1-\alpha_t)\Delta \ln CU_{Kt} = \Delta \ln A_t - \Delta \Phi_t, \tag{2}$$

where $\Delta \ln Z_t$ is the change in the log of measured MFP in year t from t-1, α_t is labour's share of nominal output, $\Delta \ln CU_{Kt}$ is the change in the log of the capacity utilization rate, $\Delta \ln A_t$ is the

11 The capital stock measure depends crucially on how depreciation is modeled. However, the main conclusion in this paper does not depend on what deprecation profile is assumed. See the unabridged version of the paper for more details on this point. Also, it can be shown that the main finding holds even if gross capital stock is used.

12 The investment and capital stock data for computers and for telecommunications equipment and software were provided by Statistics Canada, but are not available through CANSIM.

change in the log of technology and $\Delta\Phi_t$ is the change in adjustment costs. Variables on the left-hand side of the equation are observed. Together, the left-hand side is measured MFP growth adjusted for capacity utilization, or cyclically adjusted MFP. Variables on the right-hand side of the equation are unobserved. Assuming that innovations and organizational change complementary to investment in new technology are determinants of A, and both complementary activities and adjustments cost are functions of the investment-to-capital stock ratio, an estimating equation can be obtained:

$$\Delta \ln Z_t - (1-\alpha_t)\Delta \ln CU_{Kt} = \beta_0 + \beta_1 \Delta \ln\left(\frac{I_t}{K_t}\right) + \varepsilon_t, \quad (3)$$ [13]

where ε is an error term and β_1 captures the net effect of adjustment costs and complementary innovations on cyclically adjusted MFP. Lags of the investment-to-capital stock ratio, *I/K*, can also be added to control for situations where the effect of adjustment costs and complementary innovations are spread out over a number of periods.

Table 1
The Net Effect of Complementary Activities, 1961-2001

	Cyclically adjusted MFP growth	MFP growth	Labour productivity growth
$\Delta ln(K_t/L_t)$	—	—	0.3735 (2.43)
$\Delta ln(CU_{Kt})$	—	0.4230 (5.74)	0.4331 (6.14)
$\Delta ln(I_t/K_t)$	-0.0003 (0.02)	-0.0015 (0.12)	-0.0061 (0.46)
$\Delta ln(I_{t-1}/K_{t-1})$	0.0040 (0.26)	0.0067 (0.32)	-0.0002 (0.01)
$\Delta ln(I_{t-2}/K_{t-2})$	0.0073 (0.32)	0.0086 (0.38)	0.0068 (0.29)
$\Delta ln(I_{t-3}/K_{t-3})$	0.0460 (2.91)	0.0458 (2.73)	0.0407 (2.03)
Constant	0.6812 (1.91)	0.6827 (1.83)	1.034 (2.89)

Notes: Dependent variable is indicated in column heading. Independent variables are the growth rate of the investment-to-capital ratio for computer hardware and its lags. *t*-statistics are in parentheses. Number of lags are chosen using the Akaike information criterion.

Results

The first column of Table 1 shows ordinary least squares (OLS) estimates of equation (3).[14] The dependent variable is MFP growth adjusted for capacity utilization. The independent variables are *I/K* growth and its lags for computer hardware. Regressions using *I/K* growth for total investment, machinery and equipment, and ICT were also attempted, but statistically significant results were not obtained.[15] In fact, only the third lag of *I/K* growth for computer hardware is positive and significant. The fact that *I/K* growth and its lags for total investment and machinery and equipment are insignificant is not surprising. Total investment includes buildings and structures, and machinery and equipment includes office furniture, furnishings, automobiles, trucks, locomotives, and household equipment. Although these types of capital may embody some new technology, they are not usually associated with the creation of networks or complementary innovations that raise MFP. The finding that *I/K* growth for ICT equipment is insignificant is somewhat surprising. However, the strongest evidence of investment in capital affecting MFP, from Lehr and Lichtenberg (1999) and Brynjolfsson and Hitt (2000a), is for computer investment only.

13 See the unabridged paper for details on the derivation of the estimating equation.

14 *t*-statistics that take into account serial correlation in the error term are presented throughout this paper. Furthermore, although capital stock is largely predetermined, investment is an endogenous variable. Therefore, simultaneity bias may be present. Instrumental variable estimates (current Canadian I/K growth is instrumented by its U.S. counterpart), however, are similar to the ones presented here. See the unabridged paper for more details.

15 See unabridged paper for more details.

It is surprising that only the third lag of *I/K* growth for computer hardware is positive and significant. This finding could be a consequence of the modeling strategy, specifically, adjusting MFP growth for capacity utilization and not estimating it, and using MFP growth as a dependent variable instead of labour productivity. To check the robustness of the finding, unadjusted MFP growth is regressed against the growth rate of the capacity utilization rate, and the *I/K* growth for computer hardware and its lags. Also, labour productivity growth is regressed against the growth rate of the capital-labour ratio, the growth rate of the capacity utilization rate, and the *I/K* growth for computer hardware and its lags. Columns two and three of Table 1 present the results for these regressions. In both of the regressions, among the lags of *I/K* growth for computer hardware, only the third is significant.[16] The surprising result is therefore not due to the modeling approach of this paper.

It is possible that only the third lag of *I/K* growth for computer hardware is significant because the negative effects of adjustment costs cancel out the positive effects of any organizational change and complementary innovation. Before making this conclusion, however, other possible explanations are explored.[17] The depreciation profile of computer hardware may be the cause. A computer loses much of its value through depreciation by the third year. If the accounting value of computer capital drops significantly in the third year after a large investment, but the computers themselves are still being used in production, then MFP would rise as output appears to be produced with less capital. Finally, the period of analysis may be too long, given the question at hand. Computers did not experience widespread use until after the early 1980s. It may be the case that there is a structural break in the data, whereby the limited use of computers before 1980 did not lead to levels of adjustment costs or organizational change that can be detected using aggregate level data.

To check whether the third lag of *I/K* growth for computer hardware is significant because of the possible rapid depreciation of computer capital in the third year of its life, investment scaled by gross capital stock is used as a regressor in place of investment scaled by capital net of depreciation. It is found that the results using gross capital stock are not significantly different from the ones using net capital stock.[18] Thus, the finding that the third lag of *I/K* growth for computer hardware is significant is not due to the rapid depreciation of computer hardware.

To determine whether there is a structural break in the data, the sample is split into the pre-1982 and post-1981 periods. Regressions are then performed on the subsamples. The break point at 1982 is arbitrary, but it does split the sample exactly in half and it roughly corresponds to the point where widespread use of computers began. The results in Table 2 show that the effect of *I/K* growth for computer hardware on cyclically adjusted MFP growth is quite different across the subsamples.[19] Only the first subsample, 1961-81, shows evidence of adjust-

16 The findings for the other types of capital are not significantly affected by different modeling strategies either.

17 Other possible econometric explanations such as multicollinearity and omitted variable bias are explored in the unabridged paper.

18 See unabridged paper for more details.

19 Regressions on the subsamples using *I/K* ratios for other types of capital, total, machinery and equipment, and ICT do not reveal evidence of a change in the impact of the *I/K* growth on productivity. All the coefficient estimates, other than the constant, remain insignificantly different from zero. A regression using *I/K* growth for software as a regressor in the 1982-2001 period uncovers weak evidence of positive lagged effects. These effects disappear, however, once *I/K* growth for computer hardware is entered into the regression.

ment costs associated with period *t I/K* growth for computer hardware. On the other hand, the positive effects of complementary innovation and organizational change are found only in the 1982-2001 period. In the 1982-2001 regression, period *t* growth of *I/K* for computer hardware is positive and significant at the 10 per cent level, while period *t*-1 and *t*-3 *I/K* growth is positive and significant at the 5 and 1 per cent levels, respectively. Overall, the results in Table 2 support the idea that the negative effects of adjustment costs are canceling out the positive effects of complementary organizational change and innovation, and that the negative effects of adjustment costs are falling and the positive effects of complementary organizational change are growing stronger over time.

The results in Table 2 also support a hypothesis that, before the early 1980s, adding computers to the mix of inputs actually decreased MFP growth; perhaps adjustment costs were high because computers of that era were not as "user-friendly" as the current vintage. Positive gains to MFP did not materialize until after the early 1980s because a critical mass of computer capital had to be accumulated before improvements in networking triggered organizational innovations. To obtain further evidence for this hypothesis, the interaction between *I/K* growth for computer hardware and the computer capital-to-output ratio, *K/Y*, is included as an explanatory variable.[20] The interaction term allows the effect of *I/K* growth to change as *K/Y* increases. If a critical mass of computers is necessary, then the coefficients on *I/K* growth should be negative and the coefficients on the interaction terms should be positive. When the stock of computers is zero or small, the negative effect of the adjustment costs should dominate. As the stock of computers becomes larger, the effect of complementary innovations should become larger. The results are shown in Table 3.[21] In accordance with the hypothesis that a critical mass of computer hardware is needed to support complementary innovations and organizational change, the coefficients on the I/K growth are negative and the coefficients on the interaction terms are positive.

Finally, it would be interesting to see how much of the so-called MFP revival since 1992 can be explained by growth in *I/K* for computer capital. To assess the magnitude of the effect of organizational change and complementary innovations on MFP growth over this period, the average values of the *I/K* ratio for computer hardware and its lags are taken for that period and multiplied by the corresponding coefficients from the second column of Table 2. The one

Table 2
The Net Effect of Complementary Activities, 1961-1981, 1982-2001

	1961-81	1982-2001
$\Delta ln(I_t/K_t)$	-0.0519 (2.51)	0.0376 (1.79)
$\Delta ln(I_{t-1}/K_{t-1})$	-0.0514 (1.53)	0.0475 (2.32)
$\Delta ln(I_{t-2}/K_{t-2})$	—	0.0294 (1.04)
$\Delta ln(I_{t-3}/K_{t-3})$	—	0.0548 (3.45)
Constant	2.4736 (8.53)	0.3182 (1.17)

Notes: Dependent variable is MFP growth adjusted for capacity utilization. The growth rate of investment-to-capital ratio is for computer hardware. Number of lags are chosen using the Akaike information criterion. Lags that are statistically insignificant have been dropped. *t*-statistics are in parentheses.

20 To control for the size of the economy, computer capital is scaled by output. A given stock of computers may be large enough to trigger organizational innovations in a small economy, but inadequate in a large economy. Furthermore, since *K/Y* is a smooth series that increases over time, a time trend is also entered into the regression to prevent the interaction term from picking up the downward trend in MFP growth.

21 Table 3 uses gross computer hardware capital in the calculation of *I/K* and *K/Y*. The conclusion drawn from the results in Table 3 does not change when capital net of depreciaiton is used.

Table 3
The Importance of the Size of the Accumulated Stock of Capital

	Cyclically adjusted MFP growth
$\Delta ln(I_t/K_t)$	-0.0128 (1.22)
$\Delta ln(I_{t-1}/K_{t-1})$	-0.0043 (0.29)
$\Delta ln(I_{t-2}/K_{t-2})$	-0.0076 (0.62)
$\Delta ln(I_{t-3}/K_{t-3})$	0.0202 (1.56)
$\Delta ln(I_t/K_t) \times K_t/Y_t$	0.0418 (1.88)
$\Delta ln(I_{t-1}/K_{t-1}) \times K_{t-1}/Y_{t-1}$	0.0536 (2.54)
$\Delta ln(I_{t-2}/K_{t-2}) \times K_{t-2}/Y_{t-2}$	0.1096 (3.27)
$\Delta ln(I_{t-3}/K_{t-3}) \times K_{t-3}/Y_{t-3}$	0.1420 (3.35)
t	-0.0979 (-3.45)
Constant	2.8126 (3.93)

Notes: Dependent variable is MFP growth adjusted for capacity utilization. Investment and capital stock numbers are for computer hardware. *t*-statistics are in parentheses.

exception is that the coefficient for the second lag is set to zero, because it is not statistically significant. The average annual MFP growth rate between 1992 and 2001 is 1.23 per cent. The average cyclically adjusted MFP growth rate is lower, at 1.07 per cent, because the average annual growth in capacity utilization is slightly positive. The amount of cyclically adjusted MFP growth due to *I/K* growth for computer hardware turns out to be 0.37, approximately one third of the average annual MFP growth rate.

Conclusion

This paper has presented evidence that investment in computer hardware leads to growth in output and productivity above that stemming from accumulation of computer capital alone. A large portion of these gains, however, is not obtained immediately. Instead, the impact of computer investment is not fully realized until three years after the initial investment. If one were to interpret these gains as coming from organizational change or other complementary innovations, as they are in this paper, then the findings would suggest that there may be a period of learning before firms realize the full potential of the new technology and begin implementing new processes. It is important to note that these results do not suggest that computer investment does not raise output immediately. Instead, the results imply that computer investment raises output levels more than the amount usually attributed by traditional growth accounting methods. These additional gains, however, take time to be realized.

The results in this paper suggest that despite the current lull in investment, productivity improvements should occur as firms continue to integrate new technologies into their production processes. Indeed, the notion of delayed complementary activities has been put forward to explain the surge in U.S. productivity that has occurred after the ICT investment collapse. This paper finds that the effect of complementary activities in Canada is strongest three years after the initial investment in computer hardware. Thus Canada should be currently receiving benefits from complementary investments. The timing of these complementary investments, however, is likely sensitive to economic conditions. Reorganization of the production process is not costless and firms may be waiting for the right conditions to proceed with changes. Future research exploiting the experience of more disaggregated units should shed light on this timing issue.

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