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Tales from Two Neighbors: Productivity Growth in Canada and the United States

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Tales from Two Neighbors: Productivity Growth In Canada and the United States

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Abstract

This paper assesses productivity trends in Canada vis-a-vis the United States from two perspectives. The first one is based on estimates of total factor productivity. The second one decomposes productivity growth into two sources: investment-specific technical change, associated with improvements in the quality of the capital stock, and neutral technical change, associated with the organization of productive activities. The results indicate that investment-specific technical change is the major underlying cause of the pickup in productivity in Canada and the narrowing of the productivity gap with the United States.

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I. Introduction

The issue of productivity in Canada has received considerable attention and been widely debated over the past few years. In line with other major industrialized economies, Canada experienced a productivity slowdown following the first oil price shock in the early 1970s. Since then, productivity growth has failed to reach its pre-oil price shock levels. For a long time, the conventional wisdom was that productivity growth in Canada had not been positively influenced by the introduction of a number of important macroeconomic stabilization measures and structural reforms in the early 1990s. This dismal state of affairs was noted by the OECD in its 1997 Economic Survey of Canada:

"...over the last ten years, total factor productivity in Canada has continued to decline relative to historical achievements, and compared with other OECD countries. There is no consensus on why productivity has performed so dismally, although resistance to change and the difficult past macroeconomic environment probably offer some of the possible explanations..."

Such a pessimistic view on Canadian productivity raised concerns that there was "something flawed" in the Canadian economy. Some of these concerns have been focused on whether the country's competitiveness will lag relative to that of other industrial countries, particularly with respect to the United States, as both economies continue to integrate following the free trade agreements. Notwithstanding more recent evidence that productivity growth has not been as weak as previously thought in Canada—but that in fact, it has not only accelerated during the 1990s but also outpaced that of the United States in most of that decade[2]—many doubts still remain about the prospects for strong and sustained productivity growth in Canada. In particular, some of the pending questions relate to which underlying factors have contributed to the relatively modest recovery in productivity growth in Canada, the extent to which productivity growth has lagged the strong comeback in the United States that has occurred since 1995, and whether it is realistic to expect that productivity growth in Canada should eventually benefit in the years to come from the production and use of information technology and the associated surge in productivity growth in the United States.[3]

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[2] Statistics Canada (1999).

[3] As noted by DeMasi (2000), a pickup in labor productivity growth, and the adoption of new technologies has contributed to the belief that the underlying economic conditions are changing in a way that strong economic growth and low inflation could persist indefinitely. This belief in technology as the source of future prosperity has contributed to fuel the boom in the technology sector and driven equity market valuations well above their historical values. See Cerisola and Ramírez (2000) and International Monetary Fund (2000) among others.

This paper delivers a more optimistic message about the recent and expected development of productivity in Canada. Our message is based on the analysis of the trends followed by the two major components of productivity, investment-specific productivity change and technical neutral productivity.[4] Investment-specific productivity change (ISP) captures changes in productivity due to improvements in the quality of the capital stock. These improvements become available to society when investment takes place. Technical neutral productivity (TNP), captures changes in productivity due to changes in the organization of production activities. The introduction of new technologies or structural reforms has a negative impact on TNP initially, since companies need some time to adapt to the new business conditions. Once companies learn how to operate under the new conditions, TNP recovers over time.

We find that ISP is largely responsible for the productivity recovery in Canada. In fact, the strong growth of ISP offset the large decline in TNP growth caused by the introduction of new technologies and structural reforms during the last two decades. We argue that productivity in Canada may experience strong growth in the coming years based on the recent behavior of TNP, as the economy continues to adapt and diffuse across sectors the new technologies that are being adopted. During the last few years, TNP has stabilized markedly, as the sharp deterioration experienced before seems to have ceased, a process which may be signaling the likely end of the adaptation period. In this case, Canada will likely experience a productivity boom which may be similar to the one currently enjoyed by the United States.

The rest of the paper is organized as follows. Section II reviews recent official estimates of TFP in Canada and the United States. Section III estimates ISP and TNP in Canada, and compares it to similar productivity measures in the United States. Section IV concludes.

II. Total Factor Productivity in Canada and the United States

A. Aggregate Total Factor Productivity

The most common measure of productivity is total factor productivity (TFP). TFP is defined as output per unit of total factor input, where total factor input is a weighted average of inputs with weights determined by the choice of an aggregate production function for the sector or country analyzed. Usually, the chosen production function is Cobb-Douglas with constant returns to scale. Hence, TFP growth is equal to output growth net of the weighted average input growth, and by definition, TFP accounts for those factors not related to the accumulation of capital and labor that contribute to output growth. This method to estimate productivity growth is known as growth accounting (Solow, 1957).

[4] The academic literature also refers to investment-specific productivity change as the "vintage effect" or "capital-embodied technical change."

Total factor productivity estimates for the business sector and manufacturing industries in the United States and Canada are produced by the Bureau of Labor Statistics and Statistics Canada respectively. Although the estimates of TFP in both countries are not strictly comparable, because of methodological differences, they are useful to assess productivity trends especially if productivity growth is not significantly affected by the methodology used.

According to Statistics Canada, TFP growth averaged 2¼ percent a year during the 1960s, but following the first oil price shock in 1973, the average annual growth rate of TFP dropped to about ½ percent through 1988.[5] Subsequently, TFP growth has picked up modestly to ¾ percent per year through 1997. Evidently, the weakening of TFP growth has not been an "all Canadian" phenomena, as it has been manifested in most of the advanced economies. Nevertheless, productivity growth remains relatively weak, especially since most of the stronger average productivity growth during the 1990s was primarily accounted for by high growth in 1997, when TFP increased by almost 3 percent. Excluding 1997, the average annual growth in TFP was 0.4 percent.

Between 1961 and 1997, total factor productivity in Canada has evolved at roughly the same pace as in the United States (Figure 1). Even though TFP growth in Canada has tended to outpace somewhat that of the United States since 1985, the differences in accumulated growth rates remain small and may be explained by methodological differences.[6] Nevertheless, the slightly faster average growth of TFP in Canada during the previous decade has helped close somewhat the gap in productivity levels vis-a-vis the United States.

B. Total Factor Productivity Across Industries

TFP growth at the industry level has varied significantly between the two countries. One important sector, whose relative performance stands out, is manufacturing. TFP growth in U.S. manufacturing has significantly outpaced that in Canada. Between 1961 and 1985, TFP growth in the manufacturing sectors in Canada and the United States was similar,

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[5] The data for TFP in Canada, which covers the business sector, were published by Statistics Canada in March 1999. The data reflect revisions to national account figures that led to an upward revision of output growth and a downward revision to the capital stock.

[6] TFP estimates in the United States and Canada are based on different quality-adjusted labor inputs and different methods to estimate the net capital stock. The data for TFP in the United States are compiled on the basis of 1987 as the base period for the capital stock and do not reflect revisions to the national income and product accounts statistics released in November 1999.

averaging about 1¼ percent per year. However, between 1986 and 1996, TFP growth in U.S. manufacturing has averaged about 1½ percent per year compared with 0.6 percent in Canada.

Analysis from Statistics Canada shows that the gap in manufacturing productivity growth between Canada and the United States originates mostly in the strong performance of specific U.S. industries such as electrical products and commercial and industrial machinery—which include computers and computer parts—and where multifactor productivity growth has significantly outperformed that of similar Canadians firms. The larger share of those industries in manufacturing output in the United States accounts for the differential productivity growth between these two countries. In fact, when comparing the performance of other Canadian manufacturing industries vis-a-vis the United States during 1990-95, the differences are significantly smaller, or even show that TFP growth in certain Canadian industries—such as pulp and paper, transportation, and chemicals—has outperformed that in the United States.

A recent study by Gu and Ho (2000) compared the performance between 33 industries in Canada and the United States. Their results show that "quality-adjusted" TFP growth in Canadian industries outpaced on average that in the United States between 1961 and 1988, but since then, "quality-adjusted' TFP growth in Canadian industries has grown at a slower rate than in the United States.[7] In this recent period, about half of the Canadian industries experienced faster "quality-adjusted" TFP growth than in the United States, notably in sectors such as chemicals, petroleum, and communications. Their results also show "quality-adjusted" TFP growth in the Canadian machinery industry significantly lagging that of the United States.

III. Investment-Specific and Technical Neutral Productivity in Canada and the United States

The estimates of TFP cited above, as well as earlier studies on cross-country comparisons of productivity in Canada and the United States, such as Bernstein (1998), Daly and Rao (1985), Denny et al (1992), Fuess and van den Berg (1992), Morrison (1992), and Mullen and Williams (1994) among others, are based on modifications to the growth accounting framework. These studies propose a number of explanations for the productivity slowdown experienced by Canada since the 1970s including: slow growth in domestic research and development activities, reduced spillovers from the United States research and

[7] The authors, following the methodology used by Jorgenson and Yip (1999), calculate constant-quality indices for capital and labor inputs based on a disaggregation of the capital stock and labor force weighted by rental prices and wages, respectively. These weights are expected to capture the impact of the differential effects of investment in tangible and human capital. The quality of capital is calculated as the ratio of capital input to the capital stock, while the quality of labor is the ratio of the labor input index to total hours worked.

development sector, the slowdown in infrastructure spending, the productivity slowdown in mature industries, and sectoral shifts towards low productivity sectors as services.

However, estimates of TFP neglect to account for the role of quality improvements in the capital stock. It is clear, from casual observation and empirical studies, that new vintages of equipment are more productive than those vintages they replace. Therefore, part of the technological progress enjoyed by society is embodied in new machines, and become available when firms and individuals invest in new equipment (Johansen, 1959, and Solow, 1960). Using the new equipment efficiently cannot be achieved overnight, though. Firms and individuals require some time to adapt the new equipment to their current production processes and viceversa. The costs associated with these adjustments can be substantial, in terms of productivity.[8]

A better approach to study productivity, then, should differentiate between two productivity components: investment-specific productivity change (ISP) and technical neutral productivity change (TNP). ISP accounts for improvements in the quality of capital, as it captures technological change embodied in new machinery and equipment. TNP largely captures changes in productivity associated with the organization of capital and labor in productive activities, which is affected by non-technological factors such as business regulations and tax regimes, as well as the adjustment costs associated with the adoption of new technologies.[9] Some recent studies, Wolff (1996) and Gera et al (1998), made progress along these lines by modeling explicitly the effects of quality improvements in the capital stock on productivity in an otherwise standard growth accounting framework.

This section analyzes the trends in investment-specific productivity and technical neutral productivity in Canada, and compares them with those in the United States. The analysis is based on the dynamic general equilibrium model of Greenwood, Hercowitz, and Krusell (1997), and builds on previous work by the authors.[10] This approach improves on the work by Wolff and Gera et al in two aspects. First, changes in the quality of the capital stock should be related to its relative price compared to consumption goods. Second, the investment decision is endogenous and responds to changes in the quality of the capital stock and the taxation regime.

The importance of the general equilibrium framework and its emphasis on relative prices and endogenous investment is illustrated dramatically by two salient features in

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[8] Kiley (1999) found that the introduction of computers in the United States lowered growth by about ½ percentage points.

[9] Improvements in the quality of labor would also be captured in TNP to the extent that adjustments to measures of labor input do not adequately capture changes in labor quality.

[10] Chan-Lau (1999) and Cerisola, Chan-Lau, and Matzen (2000).

Canada: the trend decline in the relative price of equipment and the increasing share of equipment investment in total GDP. Between 1961 and mid-1999, the relative price of equipment declined by roughly 3½ percent on an annual basis while the share of investment in equipment in GDP rose from less than 2 percent to about 9 percent (Figure 2). This negative comovement between the price and quantity of investment in equipment can be interpreted as evidence of significant technological changes, and the investment response of firms to falling equipment prices.

A. The Model

The deterministic economy is populated by a representative household, a representative firm, and a government. The infinitely-lived representative household maximizes its discounted utility over consumption and leisure,

$$\sum_{t=0}^{\infty} \beta^t \left(\theta \ln(c_t) + (1-\theta)\ln(1-l_t)\right),$$

where c and l represent consumption and leisure respectively, β is the subjective discount rate, and $0 < \theta < 1$ is the share of consumption in the utility function. The household rents structures and equipment, and provides labor in a competitive market, and uses the income so generated to pay taxes on capital and labor, consume, and invest in structures and equipment. Therefore, the budget constraint of the household is given by:

$$c_t + i_{e,t} + i_{s,t} \leq (1-\tau_k)(r_{s,t}k_{s,t} + r_{e,t}k_{e,t}) + (1-\tau_l)w_t l_t,$$

where i_s and i_e are investment in structures and equipment respectively, k_s and k_e are the household's stocks of structures and equipment respectively, r_s and r_e are the rental rate of structures and equipment respectively, τ_k is the tax rate on capital income, τ_l is the tax rate on labor income, and w is the wage rate.

The stock of structures, k_s, evolves according to:

$$k_{s,t+1} = k_{s,t}(1-\delta_s) + i_{s,t}, \tag{1}$$

where δ_s is the depreciation rate of structures. Similarly, the stock of equipment, k_e, evolves according to:

$$k_{e,t+1} = k_{e,t}(1-\delta_e) + q_t i_{e,t}, \tag{2}$$

where δ_e is the depreciation rate of equipment, and q is the index of investment-specific productivity (ISP) that measures the quality of new equipment. Basically, the accumulation equation of equipment indicates that one unit of new equipment is equivalent to q units of the old equipment it replaces.

Final output is produced by a representative firm that operates a constant-returns to scale Cobb-Douglas production function:

$$y_t = z_t K_{e,t}^{\alpha_e} K_{s,t}^{\alpha_s} h_t^{1-\alpha_e-\alpha_s}, \tag{3}$$

where z is technical neutral productivity (TNP), K_e and K_s are the stock of structures and equipment rented from the household respectively, and h is labor hired by the firm. The shares of equipment and structures in the production function, alfa e and alfa s respectively, satisfy α_e, $\alpha_s > 0$ and $\alpha_e + \alpha_s < 1$. Notice that TNP, by definition, affects only how equipment, structures, and labor are combined to produce the final goods. Structures, equipment, and labor are hired at market prices, and the main objective of the firm is to maximize its profits net of input payments.

The government runs a balanced budget every period, implying that government consumption, G, in every period is given by:

$$G_t = \tau_k (r_{s,t} k_{s,t} + r_{e,t} k_{e,t}) + \tau_l w_t l_t .$$

The market clearing condition in the goods market requires that total output should be used for consumption, investment in structures, i_s, and investment in equipment, i_e:

$$y_t = c_t + i_{s,t} + i_{e,t} .$$

Similarly, the market for structures, equipment, and labor should clear:

$$K_{s,t} = k_{s,t},$$
$$K_{e,t} = k_{e,t},$$
$$h_t = l_t .$$

The competitive equilibrium in this model along a balanced growth path is completely characterized by the following equations, which are derived from the first order conditions corresponding to the maximization problems faced by the household and the firm, and the market clearing equations:

$$\gamma_q = (\beta / g) \cdot [(1-\tau_k)\alpha_e y / k_e + (1-\delta_e)], \tag{4}$$

$$1 = (\beta / g) \cdot [(1-\tau_k)\alpha_s y / k_s + (1-\delta_s)], \tag{5}$$

$$i_e / y = (k_e / y) \cdot [g\gamma_q - (1-\delta_e)], \tag{6}$$

$$i_s / y = (k_s / y) \cdot [g - (1-\delta_s)], \tag{7}$$

$$(1-\tau_l)(1-\alpha_e-\alpha_s)\frac{\theta(1-l)}{(1-\theta)\left(\frac{c}{y}\right)}=l, \tag{8}$$

$$\frac{c}{y}+\frac{i_e}{y}+\frac{i_s}{y}=1, \tag{9}$$

where g is the growth rate of the economy and γ_q is the growth rate of ISP. The first two equations are the Euler equations for equipment and structures, derived from the intertemporal optimization problem faced by the household. Equations (6) and (7) define the investment-to-output ratios for equipment and structures, respectively. Equation (8) is the efficiency condition for labor, while equation (9) is the resource constraint for the economy.

B. Model Solution

The solution of the system of six equations above requires calibrating some parameters using long-run restrictions imposed by the Canadian data during the period from 1960 to 1999.[11] These parameters include the growth rate of the economy, g, the growth rate of ISP, γ_q, the share of both equipment and structures in the aggregate production function, $\alpha_e + \alpha_s$, the depreciation rate of equipment and structures, δ_e and δ_s, the share of equipment investment and structure investment in GDP, i_s/y and i_e/y, the fraction of time spent at work, l, the marginal tax rate on labor, and the after tax return on capital, r_K, which by definition is equal to β/g.

The calibration of the parameters above is straightforward, with the exception of the growth rate of ISP. From the definition of ISP (or q in the model), an index of ISP should measure how valuable a new unit of equipment is in terms of final output. A useful proxy for this index is the ratio of the implicit price deflator for personal consumption expenditures on nondurable goods and services (excluding housing) and the implicit price deflator for equipment and machinery. This ratio indicates how valuable a unit of equipment is in terms of consumption goods, and matches quite well the definition of ISP. Therefore, the long-run growth rate of ISP is determined from the growth rate of the ratio described above.

With some of the parameters calibrated, the other parameters are determined from the solution of the balanced growth path equations (1) to (6). These parameters include the share of consumption in the utility function, θ, the subjective discount rate, β, the capital output ratios of structures and equipment, k_s/y and k_e/y, the shares of structures and equipment in the aggregate production function, α_e and α_s, and the effective tax rate on capital income, τ_k. The most relevant calibration parameters are presented in Table 1, together with the figures reported by Greenwood, Hercowitz, and Krusell (1997) for the United States, which are used to update estimates of ISP and TNP in the United States.

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[11] Appendix I describes the data used in the estimation of ISP and TNP.

Once all the parameters are determined, either by calibration or from the solution of the model, it is possible to construct the series for technical neutral productivity (TNP), or z in the model, by taking log-differences in equation (3) if the equipment and structures series are known. We construct the stock of structures from the structures investment series using equation (1) and assuming that the initial value of the stock of structures satisfies the ratio of the capital stock of structures to GDP implied by the balanced growth condition. We follow the same procedure for the stock of equipment using equation (2), assuming that the equipment stock initially satisfies the ratio of the capital stock of equipment to GDP also implied by the balanced growth conditions.[12]

C. Results

The results suggest that ISP growth accelerated sharply in Canada during the 1980s relative to the growth experienced in the 1960s and 1970s, but it slowed somewhat in the 1990s (Figure 3). In contrast, after experiencing strong growth during the 1960s and 1970s, TNP growth has been negative since 1980. However, in more recent years, it has tended to decline only slightly and appears to have stabilized. These results also suggest that most of the productivity growth since 1980 was more than accounted for by ISP, as TNP growth declined. To some extent, it is not surprising that faster growth in ISP have been accompanied by losses in TNP growth in Canada. This divergent trend is consistent with the view that, historically, the efficient utilization of new technology has been preceded by a period of adoption and learning during which TNP may decrease due to changes in the organizational structure of production. The recent leveling-off in TNP growth perhaps suggests that the negative effects stemming from ISP growth could be close to an end and may begin to show some signs of recovery given the sound macroeconomic environment in place in Canada.

How well does Canada compares to the United States? In comparing ISP and TNP growth between Canada and the United States, the results from the model show that, between 1988 and 1997, ISP has grown faster and TNP declined faster in Canada than in the United States.[13] ISP growth has averaged about 4½ percent in Canada, compared with 3½ percent in

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[12] The results are robust to the choice of initial values for the capital stock series. In fact, we used the figures reported by Statistics Canada for 1961 as initial values and found no major differences in the simulated path for TNP. In addition, the results are also robust to using the capital stock series for structures from Statistics Canada.

[13] Some caution is needed when comparing ISP growth between Canada and the United States due to differences in the way deflators for equipment and machinery are constructed, particularly regarding the electronics and electrical parts. While the U.S. Bureau of Labor Statistics applies hedonic price adjustment to some products, such as prepackaged software (although not to business own-account software), Statistics Canada maintains the traditional matching method that uses the change in the cost of production as an indicator of the change

(continued...)

the United States (Figure 4), while TNP growth has been negative in both countries, averaging 1¼ percent and 0.1 percent, respectively (Figure 5). However, in the past few years, ISP in the United States has been buoyant, growing at 5 percent per year since 1996, in contrast to an average growth rate of 3½ percent in Canada. TNP growth in the United States has been better than in Canada since 1990, although TNP growth rates have converged markedly since 1996 (-½ percent per year in Canada in comparison with –0.1 percent in the United States). Given the high integration between both countries, the recent buoyant ISP growth in the United States could help accelerate the diffusion of new technologies into Canada, and therefore help accelerate ISP and boost TNP growth in Canada in the period ahead.

IV. Conclusions

The evidence presented in this paper suggests that the Canadian economy may be poised for a period of strong and sustained productivity growth, provided that the macroeconomic framework and structural reforms that have been put in place over the past decade remain in place.

Our message is based on the analysis of the trends followed by the two major components of productivity, investment-specific productivity change and technical neutral productivity. Investment-specific productivity change in Canada has been very robust for more than ten years, and particularly in comparison with the United States. One possible explanation is that Canadian firms may have benefited from choosing the best technologies that have been derived from U.S. firms' research and development. By being followers, Canadian firms may have enjoyed the benefits from incorporating new technologies without having to face the costs of R&D. In contrast, technical neutral productivity growth has been slower in Canada than in the United States. Technical neutral productivity growth requires learning by doing. Organization procedures in other countries do not necessarily work better if adopted because of corporate culture, business regulations, and differences in the macroeconomic environment. In this case, being a follower does not bring many advantages.

Our results also suggest that technical neutral productivity growth has ceased declining and has flattened over the past few years in line with recent trends in the United States. This flattening may be a prelude to a period of high productivity growth in Canada. With a stable macroeconomic framework and structural reforms having been in place for a considerable period of time, the benefits stemming from increased technical neutral productivity growth

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in quality. This difference may bias somewhat the relative movements in the price deflators and, therefore, in ISP.

should be expected to come in time. Evidently, much depends on whether the existing conditions stimulating investment-specific and technical neutral productivity growth persist, and given the increased integration with the United States, on whether the benefits from the increased production and use of information technologies spill over into Canada. Clearly, a macroeconomic framework that promotes price stability, low interest rates, and flexible labor markets, would be most likely favorable to enhance productivity in Canada.

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Table 1: Model Calibration for the Canadian and U.S. Economies

Parameters		Canada	United States
Preferences	β	0.9533	0.9752
	θ	0.4178	0.4023
Technology	α_e	0.1177	0.1852
	α_s	0.2157	0.1148
	δ_e	0.1240	0.1240
	δ_s	0.0560	0.0560
	γ_q	3.42	2.44
Tax rates	τ_k	0.585	0.585
	τ_l	0.40	0.40
Other	g	2.00	3.50
	l	0.24	0.24
	i_e/y	0.0375	0.0673
	i_s/y	0.0534	0.0376
	r_K	0.07	0.07

Figure 1: Total Factor Productivity

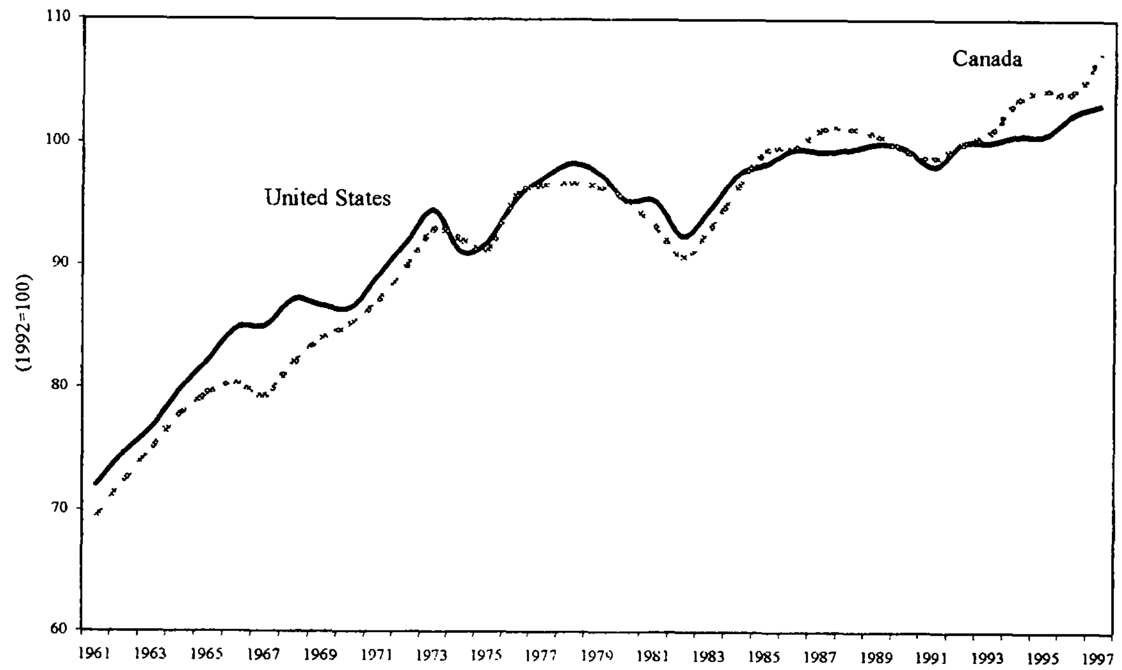
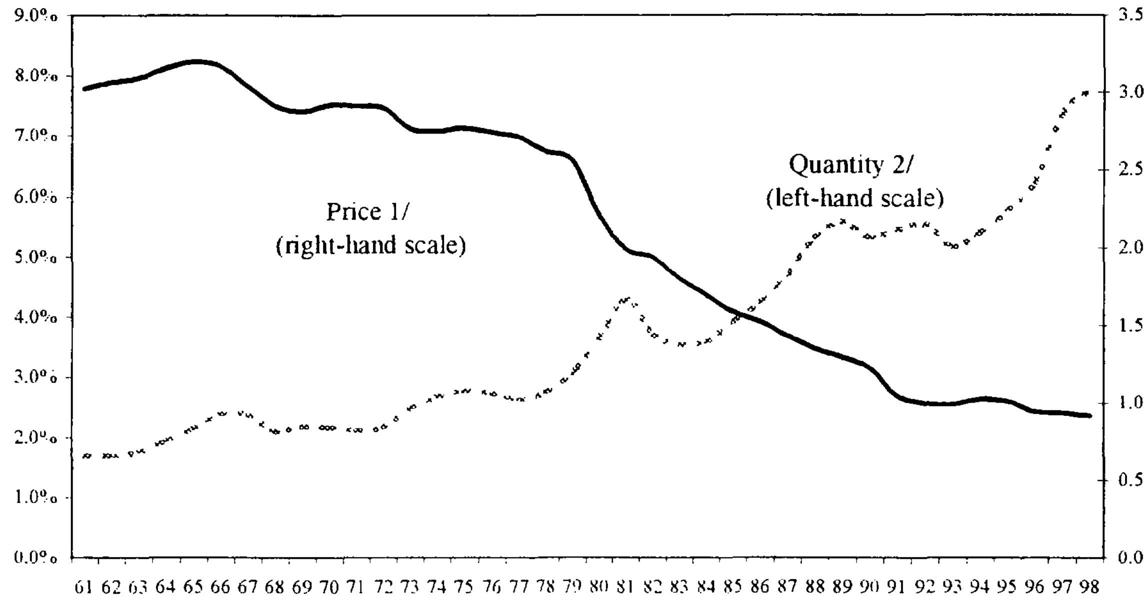
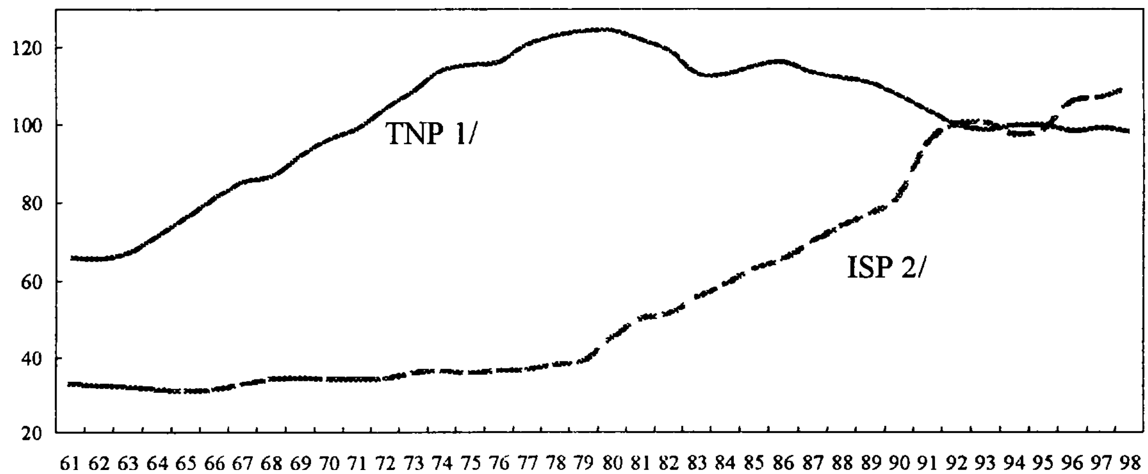


Figure 2. Trends in Equipment Cost and Investment



1/ Defined as the ratio of the price deflator for equipment and machinery to the personal consumption expenditures.
2/ Defined as the ratio of nonresidential investment in machinery and equipment to GDP.

Figure 3. Technologically Neutral
Investment-Specific Productivity Change in



1/ TNP is technologically neutral productivity change, which is defined as the difference between output growth (excluding housing) and ISP.

2/ ISP is investment-specific technological change, which is defined as the ratio of the implicit price deflator for personal consumption expenditures on nondurable goods and services (excluding housing) and the implicit price deflator for equipment machinery.

Both variables are indices based on 1992=100 and do not represent levels.

Source: Statistics Canada and U.S. Department of Labor, Bureau of Labor Statistics.

Figure 4. Investment-Specific Productivity Change, Canada vs. the United States (1992=100)

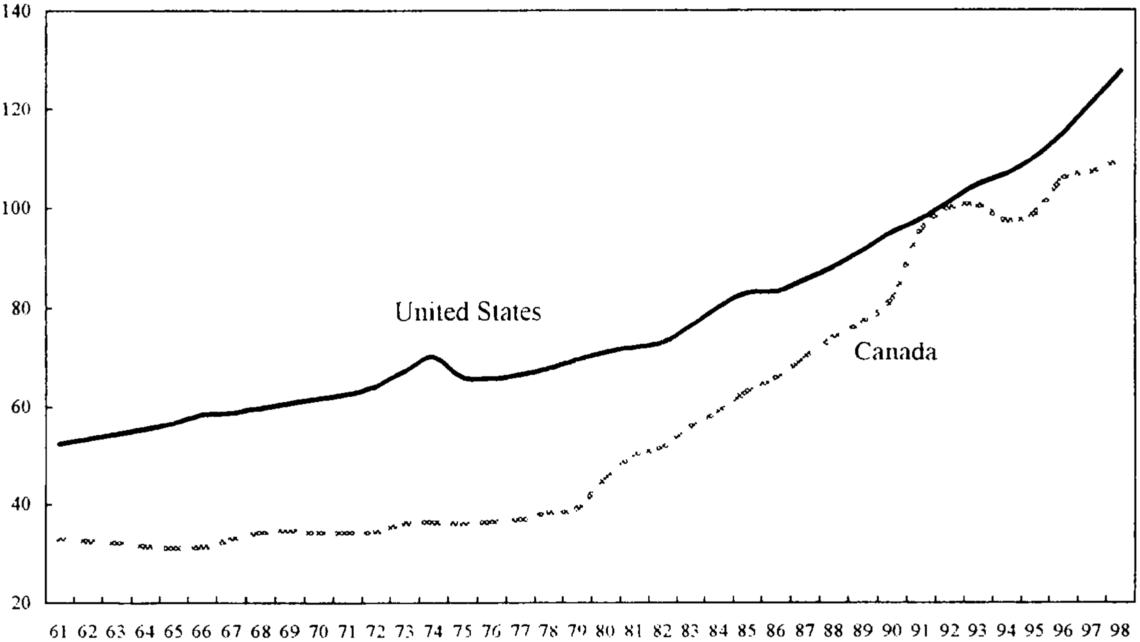
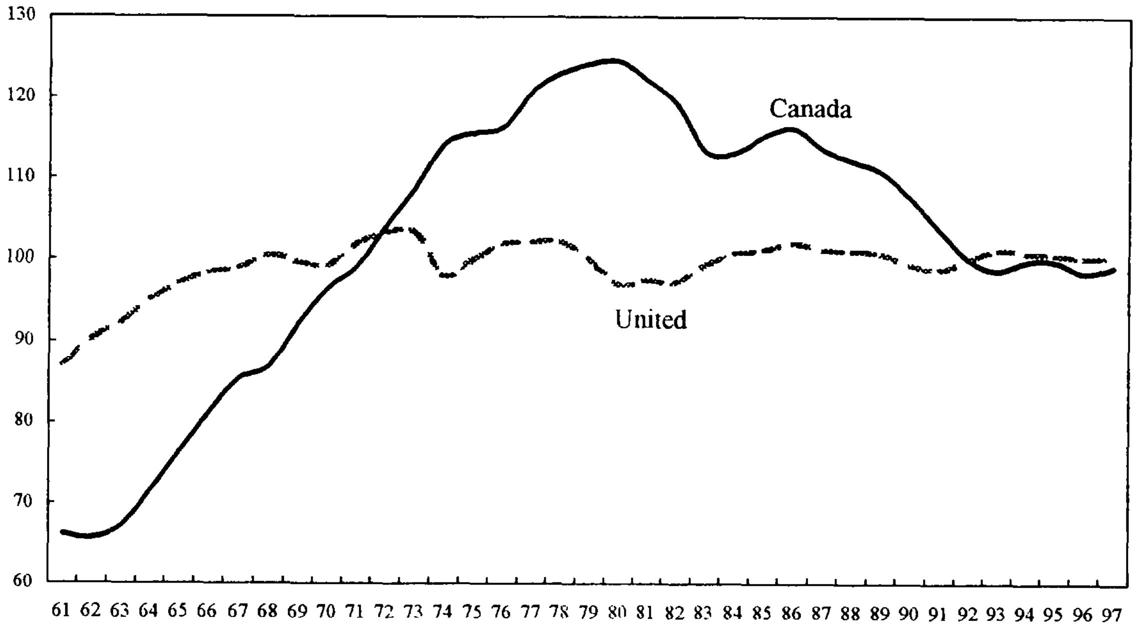


Figure 5. Technologically Neutral Productivity Change, Canada vs. the United States, (1992=100)



Data Definitions and Sources

The parameters used in the model which are presented in Table 1, were calibrated using both the Canadian National Income and Product Accounts and estimates for the United States as in Greenwood et al. In particular, the parameters which were calibrated using Canadian data are the averages for the period between 1961 and the second quarter of 1999, with data available as of end-July 2000.

The variables are defined as follows:

Output (y): Average growth for the 1961-mid-1999 period for real gross domestic product expenditure net of gross housing product (measured by gross inputted rents (D15328) and gross paid rents (D15329)), based on 1992 prices.

Labor Input (l): measured by persons-hours worked for the total economy (I609001).

Capital Input (k_e and k_s): data for the net capital stock is based on Statistics Canada (D99333). Values for the net capital stock for equipment and structures were constructed by iterating on the law of motion for the capital stock for equipment, which added to the initial capital stock the annual investment in equipment adjusted for q after subtracting the total depreciation. The starting value for k_e was set at its balanced growth level, given the values of output, q, and i_e at the beginning of the sample. The series for structures was estimated by following the same procedure.

Consumption: personal consumption expenditures (PCE) for nondurable (D14845) and semidurable goods (D14844) and services (D14846) net of housing (D15328 and D15329) (based on 1992 prices).

Investment in producer durable equipment (i_e): business investment in nonresidential machinery and equipment, base 1992 (D14855).

Investment in structures (i_s): business investment in nonresidential structures, base 1992 (D14854).

Investment specific technological change (q): defined as the growth in the ratio of the implicit price deflator for personal consumption expenditures (PCE) on nondurable consumption goods and services (excluding housing) and the implicit price deflator for producer durable equipment. The implicit price deflator for expenditures on nondurable goods and services was constructed as the ratio of nominal PCE on nondurable goods and services (excluding housing) to constant PCE (base 1992) on nondurable goods and services. A similar procedure was used for producer durable equipment.