Does Under-Investment Contribute to the Canada-U.S. Productivity Gap?

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Abstract

Many commentators have pointed to the productivity gap between Canada and the U.S. as evidence of a Canada–U.S. investment gap. In this paper we examine whether this hypothesis is plausible using a variety of different models of growth, and a variety of different data sources. We find, as other have done before us, that Canada does indeed lag behind the U.S. in investment in machinery and equipment, and investment in R&D, although not in investment in overall physical capital or in human capital. However, it is by no means clear that the investment gaps we have found could be responsible for much of the Canada–U.S. productivity gap. The gap in machinery and equipment investment appears to be largely offset by the greater quality of the Canadian machinery and equipment capital stock. On the other hand, the R&D investment gap appears to be too small to be responsible for much of the productivity gap, unless R&D spillovers are both implausibly large, and largely confined within national boundaries.

Introduction

In a widely quoted address, Professor Pierre Fortin (1999) has argued that productivity levels in Canada are significantly below those in the United States, and that the gap has actually widened slightly over the last twenty years. Fortin argues that we would normally expect Canadian productivity levels to be catching up to U.S. levels, and so the persistence of the productivity gap should be a particular concern for public policy.

What might be behind this productivity gap? Fortin argues that the principal culprit is under-investment: in particular, under-investment in machinery and equipment, and in research and development. This diagnosis has been echoed by other commentators, including Fairholm (1999), who places particular emphasis on Canada’s low investment in machinery and equipment.

In this paper we will take a closer look at whether under-investment can explain why productivity in Canada is lower than in the United States. We shall focus on three questions: what measures of investment matter most for productivity; whether Canada has an investment gap; and whether the investment gap is wide enough to explain lower level of productivity in Canada.

The first question is conceptual in nature, as the answer depends very much on the underlying growth model that one assumes. Rather than arguing for one particular model of growth, Part I of the paper examines a variety of different growth models to establish under what circumstances an investment gap might lead to gap in labour productivity. We then go on in Part II to examine the second, more empirical question—whether or not Canada actually has an investment gap—by comparing a variety of investment and capital stock measures for both the U.S. and Canada in recent years. Part III of the paper concludes by examining the third question: whether the data support the hypothesis that under-investment is responsible for Canada’s productivity gap with the United States.

Part I: Conceptual Issues – How Does Investment Affect Productivity Levels?

We start by outlining the relationship between investment and productivity in three different classes of model: the basic neoclassical growth model; an augmented neoclassical growth model in which technological change is partly embodied in capital; and endogenous growth models, in which technological change is explicitly modelled rather than being assumed exogenous.

1. Basic Neoclassical Growth Model

We begin with a simple neoclassical growth model in which long-term growth is driven by exogenous, disembodied technical change. Let an economy's production function be given by

$$Y = A \cdot K^{\alpha} \cdot L^{1-\alpha}, \qquad (1)$$

where Y is output, K is capital input, L is labour input and A is total factor productivity (TFP). Define labour productivity Y/L as y and capital intensity (the capital–labour ratio) K/L as k. Assume for simplicity that elasticity of output with respect to capital α is the same in both countries. Then labour productivity in Canada relative to the U.S. can be written as

$$\frac{y_{Can}}{y_{US}} = \frac{A_{Can}}{A_{US}} \left(\frac{k_{Can}}{k_{US}} \right)^{\alpha}. \qquad (2)$$

In this model, a U.S.–Canada productivity gap could come from either a difference in TFP levels or a difference in capital intensity (or both). The importance of capital intensity will depend crucially on the output elasticity of capital parameter α, which one would expect to be fairly similar in Canada and the U.S. (around one-third, if proxied by the share of capital in national income) If this elasticity is small then it will take a large difference in capital intensity to affect relative labour productivity between the two countries.

Interpreting the Model in the Long Run

An important factor to bear in mind when interpreting an expression such as (2) is that in the basic neoclassical model, capital intensity is not an exogenous variable. On the contrary, it is an endogenous variable that is partially determined by the level of TFP in long-run equilibrium. In a simple model[1], equilibrium capital intensity is reached when the marginal product of capital is equal to the real after-tax interest rate *r*, so that

$$MP_K = \alpha \cdot \frac{y}{k} = \alpha \cdot \frac{A \cdot k^{\alpha}}{k} = r. \tag{3}$$

In a closed economy, *r* will depend on consumers' discount rates and the rate of taxation on capital. Solving (3) for equilibrium capital intensity gives us

$$k = \left(\frac{\alpha}{r}\right)^{\frac{1}{1-\alpha}} \cdot A^{\frac{1}{1-\alpha}}. \tag{4}$$

Putting (4) into (2) gives us

$$\frac{y_{Can}}{y_{US}} = \left(\frac{A_{Can}}{A_{US}}\right)^{\frac{1}{1-\alpha}} \cdot \left(\frac{r_{US}}{r_{Can}}\right)^{\frac{a}{1-\alpha}}. \tag{5}$$

Thus, in long-run equilibrium, equation (5) indicates that a greater share of any Canada-U.S. productivity gap is explained by TFP differences than would be apparent from an expression such as equation (2). Indeed, if real interest rates in the two countries were equal, such as would occur if Canada were a small open economy *vis-à-vis* the U.S. and capital taxes were the same in the two countries, then *all* of the *long-run* productivity differences in this simple model would be due to technology differences.

Issue: Investment Share or Capital Stock?

Discussions of under-investment often focus on investment shares rather than the capital stock. For example Fortin (1999, p.85, Figure 19) presents a chart of investment to (trend) GDP showing that investment as a percentage of GDP is lower in Canada than in the United States. A similar approach is adopted in Kirova and Lipsey (1998). This choice is usually made on empirical grounds, because investment shares are often easier to construct than measures of the capital stock. Nevertheless, from a conceptual standpoint, capital stock measures are preferable, because in a production function such

[1] We are abstracting from factors such as depreciation and changes in the relative price of capital goods that would cause the rental price of capital to deviate from the real rate of interest.

as (1) it is differences in the capital stock that produce differences in productivity. Although a lower investment rate may well portend a lower capital stock in the future, it is not as relevant as the current capital stock for examining current differences in output per worker. However, other factors may explain why output per worker varies so enormously across countries. Besides differences in physical capital, differences in institutions, regulations or government policies could also affect output per worker[2]. Furthermore, investment shares may be a misleading indicator even of the growth in the capital stock. If we define investment as *I*, then the rate of growth of the capital stock is given by:

$$\dot{k} = \frac{I}{Y}\frac{Y}{K} - \dot{L}\,. \qquad (6)$$

It is quite clear from (6) that two countries could have the same investment share *I*/*Y*, but different growth rates of the capital–labour ratio and therefore of productivity if either employment growth or the output–capital ratio differs across countries.

Issue: How Broadly Should One Define Capital?

Pierre Fortin in his above-mentioned address concentrates on non-residential business investment. However, there is no reason in principal why one should not broaden the definition to include other forms of investment, such as public infrastructure investment, investment by consumers in housing, and even investments in land and inventories. All of these activities increase an appropriately defined capital stock and lead to an increased flow of output over time. Also, it is important to broaden the definition of investment to include the stock of human capital. Even in a neoclassical model, investment in human capital will lead to an increase in the level of output, and the stock of human capital should, in principle, be included in capital stock measures. Whether one includes other forms of physical or human capital, broadening the definition of capital should also affect the way one defines output. So, for instance, if one includes investment in consumer durables as part of the aggregate investment, services from consumer durables should also be considered part of the output[3].

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[2] See Hall and Jones (1999) and Bassanini et al. (2000) .

[3] Kirova and Lipsey (1998) follow this approach.

Note that there is no reason, in a neoclassical model, to privilege investment in machinery and equipment as somehow being more important for productivity than any of the other form of investment mentioned above. Perfect competition in the market for capital should ensure that the marginal products of all types of capital good are equalised at the margin, provided they face the same tax and depreciation rates[4].

Issue: Cyclical Adjustments

One problem with official measures of the capital stock is that they measure installed capital, not the portion of the capital stock that is actually in use[5]. Properly speaking, unemployed capital should not be counted in the production function, just as unemployed workers are not included in the measure of labour input. This becomes especially relevant for U.S.–Canada comparisons if the U.S. is closer to full capacity than is Canada. If this is the case, then the effective capital stock in Canada is over-estimated relative to that in the United States. However, given that investment is quite cyclical, it may also be that investment rates are relatively lower in Canada than they would be in the long run, and so long-run capital intensity may be understated relative to the United States.

Conclusions

- The main conclusion to be drawn from this section is that in attempting to measure an investment gap in the context of the standard neoclassical growth model, one should focus on capital intensity, and use the broadest possible measure of the capital stock (assuming that the definition of output is broad enough to capture the contribution of the investment to GDP).

- The importance of differences capital intensity in explaining productivity differences will be overstated in the long run if allowance is not made for the partial dependence of capital on technology.

[4] In equilibrium, the marginal product of each type of capital should equal its own marginal cost, estimated by rental or user costs, which varies by asset type because of differences in taxes, depreciation and changes in acquisition prices.

[5] Basu (1996) exploits the intuition that materials inputs do not have variable utilization rates, and materials are likely to be used in fixed proportions with value added, so that growth in materials becomes a good measure of unobserved changes in capital and labor utilization.

2. Neoclassical Model with Capital-Embodied Technical Change

A common criticism of the simple neoclassical model presented above is that growth can occur without any investment in new capital goods. However, as Solow (1960) famously argued, 'Many, if not most innovations need to be embodied in new kinds of durable equipment before they can be made effective'. If technological change manifests itself through the introduction of new capital goods, does that mean that we should more concerned about any investment gap that might exist?

To model this idea formally, suppose that stock of capital (K^*) is adjusted for quality as follows:

$$K_t^* = \int_{-\infty}^{t} e^{\lambda t} I(v) dv \ , \tag{7}$$

where $I(v)$ is investment of a given vintage v, and λ is the rate of capital-embodied technical change—that is, the rate at which capital goods become more productive over time. Equation (8) shows the adjusted K^* in terms of the unadjusted gross capital stock K

$$K^* \cong K \cdot \exp\left(\lambda - \lambda \cdot \overline{A}\right), \tag{8}$$

where $\overline{A}$ is the average age of the capital stock. This specification, introduced by Nelson (1964), indicates that older capital stock will have a slower rate of technical change embodied in the adjusted capital stock. Using Equation (8), we can write the U.S.–Canada capital intensity gap as?

$$K_{US}^* \,/\, K_{Can}^* = (K_{US} \,/\, K_{Can}) \exp\left\{\left(\lambda_{US} - \lambda_{Can}\right)\left(\lambda_{US} \overline{A}_{US} - \lambda_{Can} \overline{A}_{Can}\right)\right\}. \tag{9}$$

Hence, in the capital-embodied technical change model, a U.S.–Canada productivity gap could exist because of differences in disembodied TFP and the conventionally measured capital stock (as shown in Equation (2)). Now the productivity gap could also exist because of differences in the rate of capital-embodied technical change, and in the age of the capital stock. Note that, as in the basic model, capital is an endogenous variable that depends partly on the level of technology[6]. Equation (9) will therefore tend to overstate the long-run importance of capital accumulation in explaining productivity differences.

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[6] See discussion in Hulten (1979).

Issue: Interpreting Measures of the Capital Stock

In order to arrive at a measure of the effective capital stock K^* one needs to take two steps. First, investment needs to be scaled upwards by the rate of embodied technological change λ—this corresponds to the term $\exp(\lambda)$ in Equation (8). Second, the capital stock must be adjusted for the fact that embodied technological change renders older vintages of capital goods relatively less productive—this corresponds to the term $\exp(-\lambda \cdot \overline{A})$ in Equation (8).

Statistical agencies in both the U.S. and Canada have now implemented both these steps. Both Statistics Canada and the Bureau of Economic Analysis now adjust their capital stock measures for quality change in certain investment goods, principally computers, using hedonic price indices[7]. By reducing the price of investment goods, the real stock of capital is essentially revalued at the rate of technological change λ. This corresponds to step one above. The second step is achieved by using these hedonic prices when calculating depreciation rates, which will reduce the value of older vintages of capital[8]. Thus the net capital stock measures published by the two statistical agencies are, in principle, equivalent to the adjusted capital stocks K^*[9].

Issue: What is the Relevant Measure of Capital?

The use of measures of the effective capital stock allows one to distinguish between the proportion of the productivity gap that is due to disembodied technological change, and

[7] The use of hedonic prices to measure increasing quality in capital goods raises some difficult issues in the measurement of output, as emphasized by Greenwood *et al.* (1997) and Hercowitz (1998). Their argument is that such measures should *not* be used to calculate national income, as opposed to measures of the capital stock, and that the correct measure of I in the formula $Y=C+I+G+NX$ is investment in *consumption units*. Incorporating capital-embodied technical change in prices of capital goods will mean that the price of investment goods will fall indefinitely relative to the price of consumption goods, and so I will be progressively overstated in real (consumption unit) terms. In the limit, the ratio of quality-adjusted investment to national income will go to one (Greenwood *et al*. 1997, p.356). Although period re-basing of the national accounts will prevent this from actually occurring, it is nonetheless true that quality-adjusted investment shares will become progressively larger over any given time period. In a world of chain-weighted series, ratios of real series start losing some of its original meaning. While investment shares should be then calculated in nominal dollars to avoid the problem, it may also be reasonable to avoid the use of investment shares altogether as a measure of capital accumulation wherever possible.

[8] Nelson (1960) shows that adjusting the capital stock for economic as well as physical depreciation is equivalent to adjusting the capital stock for the age of the capital stock. This is because the impact of capital-embodied technical change on the existing capital stock is precisely the process of economic depreciation described above: as newer, better, capital goods become available, the replacement cost of existing capital goods drops, and thus so does their economic value. This process is independent of whether the existing capital goods are physically less productive.

[9] See however Whelan (2000), who argues that current depreciation methods overstate depreciation rates when prices are adjusted for quality change.

the proportion that is due to differences in effective capital per worker. However, from our perspective we are more concerned with separating the total contribution of both embodied and disembodied technological change, both of which are invariant to the rate of investment in the neoclassical framework, from the contribution of capital accumulation.

Thus what is required is a measure that approximates the theoretical quantity $K \cdot \exp\left(-\lambda \cdot \overline{A}\right) = K^* / \exp(\lambda)$, the portion of the effective capital stock that depends on the rate of investment. In order to implement this approach one requires a separate index of embodied technological change. One way to do this is to examine the quality-adjusted price of investment goods relative to consumption goods, which, as Greenwood *et al.* (1997) show, is a good proxy for the rate of capital-embodied technical change λ.

Issue: Adjusting for Depreciation

As noted above, the net stock of capital should provide a good measure of the effective capital stock. However, if depreciation methods differ significantly across countries, then net stocks will not be comparable. Coulombe (2000) argues that such measurement differences do indeed exist between the U.S. and Canada, and that they are significant, with depreciation rates being much higher in Canada. This would imply that the Canadian capital stock is underestimated relative to the U.S. capital stock. An alternative approach is to measure directly the age of the capital stock. If the average age of the capital stock is higher in one country, then this will be an indication the capital stock is less advanced and therefore less productive.

Conclusions

- The most appropriate measure of capital intensity in a neoclassical model with capital-embodied technical change is the effective net capital stock, adjusted to remove the pure impact of embodied technological change (as opposed to the interaction of capital-embodied technical change with the age of the capital stock)

- The degree of capital-embodied technical change can be proxied by the price of investment goods relative to consumer goods

- Independent information on the age of the capital stock will also give a useful indication of the quality of the capital stock in situations where depreciation rates are not comparable.

3. Endogenous Growth Models

Endogenous growth models provide a perspective on the growth process that is quite different from the neoclassical model. As the name suggests, endogenous growth models attempt to explain all of the growth process as the result of the decisions of optimising agents, rather than leaving a portion of the growth process essentially unexplained, as in neoclassical models. This has important implications for how we think about the links between investment and productivity.

There is a wide variety of endogenous growth models: the main differences between them stem from whether it is physical capital, human capital or R&D spending which is the engine of growth. In this section we survey examples of each of these three major categories, which simply provide different mechanisms for determining *A*, either through physical capital, human capital or R&D.

Physical Capital-Based Models

The canonical model of this class of endogenous growth models is due to Romer (1987) Output *Y* is given by the production function:

$$Y = A \cdot L^{1-\alpha} \cdot \sum_{i=1}^{M} X_i^{\alpha} \qquad (10)$$

where *M* is the number of different types of capital good. Altering the number of capital goods involves a resource cost for firms. Each distinct type of capital good is produced according to the cost function[10] $C(X_i) = c_0 + c_1 \cdot X_i$. The total amount of capital goods that can be produced at any point in time is limited by the amount of 'primary' capital, *Z*, which is the amount of resources devoted to the production of capital goods. As the economy grows, the extent of specialisation will increase and new capital goods can be produced.

In equilibrium, the same amount of each kind of capital good will be produced. This gives

[10] This slightly simplified version of the cost function in the Romer model is taken from Aziz (1996).

$$X_i = \frac{K}{M}, \tag{11}$$

where K is the unweighted sum of all the X_is—the capital stock as conventionally defined. Substituting this expression into the production function (10) gives

$$Y = A \cdot L^{1-\alpha} \cdot M \cdot K^{\alpha}. \tag{12}$$

The essential feature of (12) is that while there is diminishing returns to the accumulation of a given kind of capital good, as in the standard neoclassical model, there is no such presumption for new types of capital good. Thus with M fixed, equation (12) acts just like a standard neoclassical production function: the elasticity of output with respect to any of the M existing capital inputs is α. However, the elasticity of output with respect to an increase in M is unity. Thus long-term growth, in this model, comes from increases in the variety of new capital goods.

What are the implications of this model for a Canada-U.S. productivity gap? From equation (10) we obtain

$$\frac{y_{Can}}{y_{US}} = \frac{A_{Can}}{A_{US}} \cdot \left(\frac{k_{Can}}{k_{US}}\right)^{\alpha} \cdot \frac{M_{Can}}{M_{US}} \tag{13}$$

Thus it is the relative variety of capital M_{Can} / M_{US} in the two countries that is important, not simply the relative stock of capital.

One approach to measuring M_{Can} / M_{US} would be to use a measure of capital-embodied technical change. This is because increases in variety, which are what drive growth in this model, are embodied in new capital goods, and act to push out the production function in the same way as capital-embodied technical change. As explained in the previous section, one approach to measuring the quality of new capital goods is to compare the quality-adjusted price of new investment goods. If prices are falling faster in one country, then this is an indication that the quality of capital is growing more quickly.

Some researchers, such as Delong and Summers (1991), have used the investment share of machinery and equipment as a proxy for increases in capital quality, because machinery and equipment, and especially information technology, are thought to be the types of capital goods where new technologies are being adopted most quickly. However, as (13) makes clear, it is quite possible to have a greater volume of physical capital and yet have the same degree of variety. What matters is the quality of investment, not the volume.

Human Capital-Based Models

Physical capital is not the only possible engine of growth in endogenous growth models. Starting with Lucas (1988), a large amount of work has been done on models in which investment in human capital—both in education and on-the-job learning—leads to the generation of new ideas and therefore sustainable increases in TFP. A typical growth model incorporating human capital would take the form

$$Y = A \cdot K^{\alpha} \cdot (h \cdot L)^{1-\alpha}, \quad (14)$$

where h is average human capital per worker. h would include years of schooling and years of relevant experience. As with the basic neoclassical model, physical capital accumulation is an endogenous variable in the long run, and so part of any long run difference in physical capital intensity will be partly attributable to differences in *human* capital intensity.

R&D-Based Models

In R&D-based models of economic growth, such as Romer (1990), investment in R&D is the main engine of growth. Unlike investment in physical capital, investments by firms in R&D do not face diminishing returns because new ideas and designs are non-rival, and so can be used by more than one person at a time at no additional resource cost. A simple growth model based on R&D might take the form

$$Y = A \cdot D^{\varepsilon+\delta} K^{\alpha} \cdot L^{1-\alpha-\varepsilon}, \quad (15)$$

where D is the stock of R&D capital, ε is a parameter measuring the private returns to R&D, and δ is a parameter measuring the social returns over and above the private returns (i.e. spillovers). In this model R&D is accumulated just like conventional physical capital, and its level is determined by the private rate of return that investors receive. Given perfect competition, the share of national income accruing to owners of R&D capital will be equal to ε. However, private investment in R&D also generates spillovers, the returns to which cannot be completely captured by the original investor.

When measuring the importance of R&D capital in a small open economy such as Canada's, it is important to allow for the possibility of spillovers from the R&D

investment of other countries. Although the *private* returns to foreign R&D would not accrue to Canadians, there is no reason in principle why all of the spillovers should stop at national borders.

Conclusions

- In endogenous growth models where physical capital is the engine of growth, the relative variety of capital goods is a key determinant of productivity. This variety will show up as in increase in the quality of the capital stock.

- In endogenous growth models where human capital is the engine of growth, a key determinant of productivity is the relative level of human capital per work in each country.

- In endogenous growth models where R&D spending is the engine of growth, spillovers from investment in R&D, both domestic and external, are key determinants of productivity.

Part II: What Do the Data Say?

We now examine the empirical evidence for a Canada-U.S. investment gap. As practitioners in this field will know, accurately measuring investment and the capital stock poses daunting methodological and empirical challenges. These challenges are compounded when making cross-country comparisons. For this reason, we shall not try to quantify the precise contribution of investment to the productivity gap. Rather, we shall attempt to gain a qualitative sense of Canada-U.S. differences by examining a variety of different measures of capital intensity, both stocks and flows.

1. Physical Capital

Ideally, measures of the capital stock should be deflated by appropriate measures of prices. Statistical agencies in both the U.S. and Canada routinely publish such measures in constant dollar terms, so that variables are measured in terms of the nominal value in an arbitrarily chosen base year. However, as McCabe (2000) points out, it is inappropriate to use such measures when comparing real investment ratios across countries. What is required is measures that allow for inter-country comparisons of price levels across countries. For this reason we rely upon the Penn World Tables (Mark 5.6), which make precisely these kinds of adjustments. Because these data end in 1992, we have updated them using investment data from the OECD.

Investment and Capital Stock per Worker

Figure 1 shows net business sector investment per worker[11] in the U.S. and Canada, for all investment, and for machinery and equipment[12]. The data show that total investment per worker has been very similar in the two countries over the last thirty years, except for the period 1986–1994 when Canada when investment levels were somewhat higher in Canada. This picture is confirmed by Figure 2, which shows that the capital-labour ratio in Canada is currently very similar to that in the U.S., after a period in the 1980s and early 1990s when the capital–labour ratio was higher in Canada than in the United States.

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[11] These data do not count software as investment for either country.

[12] All tables and figures are collected together in the Appendix.

The picture changes when we narrow the focus to machinery and equipment. Investment in this kind of capital is more than 50 per cent greater in the United States than in Canada. Furthermore, the gap is of long standing, as demonstrated by Figure 2, which shows a significantly lower stock of machinery and equipment per worker in Canada. This picture is confirmed by Figure 3, which shows that the computer capital stock per worker in the U.S. almost doubled between 1996 and 1998, whereas in Canada the stock only increased by fifty per cent[13].

Kirova and Lipsey (1998) go further than we do in broadening the definition of the capital stock, by including expenditure on consumer durables, education, defence and R&D. They find that by this broader definition Canada's investment share of GDP is somewhat higher than that of the United States.

Age of the Capital Stock

Table 1 shows data on the average age of the capital stock, for both machinery and equipment and total investment. The data show that over the last twenty years, the average age of the total capital stock was lower for Canada than for the U.S., although the average age of the machinery and equipment stock was quite similar.

Price Indices

Figures 4 shows the implicit price index for investment goods in the United States and Canada, relative to the price of consumption goods. These data are taken from the OECD National Accounts, and intended to be as comparable as possible. Price movements have been quite similar in Canada and the U.S. over the 1990s, with significant declines driven in part by hedonic adjustments designed to capture quality change in new capital goods.

[13] The Canadian computer capital stock data are preliminary unpublished Statistics Canada data.

It may seem strange that the fall in the relative price of investment goods is similar in both countries, given that machinery and equipment is a significantly larger share of investment spending in the United States. The explanation is quite simple: it appears that relative price of machinery and equipment has been falling more rapidly in Canada than in the United States. According to IMF (2000, p.5), the rate of capital-embodied technical change in Canada was one percentage point higher in Canada than in the United States over the period 1988 and 1997.

2. Human Capital

The most common approach to measuring differences in the level of human capital per worker is to use quantity measures such as the average completed years of schooling, or the proportion of the population with higher education. By these measures the average level of human capital in Canada is very slightly below that in the United States. Average completed years of schooling is 13 years in the U.S., compared to 12 years in Canada, and the proportion of the population aged 25+ with higher education is 48 per cent in the U.S. compared to 45 per cent in Canada[14]. Growth rates of these variables over the last 10 years are roughly comparable.

The advantage of these quantity measures is that they are easily available. However, from a theoretical perspective, simply adding up years of schooling is problematic because the marginal benefit of an additional year of high school probably has a impact on productivity that is different from an additional year of graduate school. What is required to construct a proper measure of the human capital stock is a way of weighting the different components of the stock by their marginal productivities. A common approach to this problem is to use information from wage rates in order to estimate the marginal product of each year of schooling, which is not a bad approximation as long as educational wage differentials largely reflect differences in acquired human capital and not innate individual ability[15]. The estimates of marginal productivity are then combined with quantity information to produce a measure of the human capital stock.

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[14] Although we should caution the reader that the definitions of higher education in the two countries are not entirely comparable.

[15] Human capital is sometimes partly reflected in labour inputs. A large growth accounting literature includes estimates of labour quality by weighting heterogenous labour inputs. For instance, the BLS measures labour input for the TFP by estimating an aggregate measure of hours by type of worker. The growth rate of the aggregate is therefore an average of the growth rates of each type of worker where the weight assigned to a type of worker is its share of total labour compensation. The resulting aggregate measure of

Table 2 reports estimates of the human capital stock from two studies: Sala-i-Martin and Mulligan (1994) for the U.S., and Laroche and Mérette (2000) for Canada. Both measures grow at roughly comparable rates over the period 1977-1989. After 1990, the growth rate of the Canadian measure slows considerably. Although there is no data for the U.S. measure after 1990, the fall in the growth rate of average years of schooling would suggest a similar slowdown in the growth rate of the U.S. human capital stock.

3. R&D Capital

Table 3 shows various estimates of the stock and flow of R&D capital in Canada and the United States. It is clear from these data that Canada lags considerably behind the United States. The number of researchers relative to the labour force is significantly higher in the United States (74 per 10,000 compared to 54 per 10,000 in Canada), and domestic expenditure on R&D is 2.8 per cent of GDP in the U.S. compared to 1.6 per cent in Canada. There is some indication that Canada is gradually narrowing the gap in terms of researchers, but this is not true for expenditure on R&D.

One point to bear in mind is that these figures relate to the production of R&D, not to the total stock available to the average Canadian worker. As noted in Part I, if the results of R&D can spillover national borders, then the stock of R&D in Canada will be greater than the figures for domestic production would suggest. The presence of many U.S. multinational companies in Canada would be an obvious channel for the importation of the output of U.S. R&D into Canada. Some evidence on this question is presented in Bernstein (2000): he finds that there are indeed significant spillovers to Canada from R&D performed in the United States.

Finally, international trade provides another channel by which Canada can benefit from U.S. R&D. Canadian firms can easily purchase investment goods as technologically advanced as those used by their American counterparts.

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labour input accounts for both the increase in raw hours at work and changes in the skill composition (as measured by education and work experience) of the work force. See the Bureau of Labor Statistics (1997) for details.

4. Summary

As we noted at the outset, any comparison of capital stock data for the U.S. and Canada must be interpreted with great caution. Nevertheless, several broad patterns do emerge, and we feel there is sufficient evidence to conclude the following:

- There is little evidence of a significant gap between the United States and Canada in the overall level of physical capital per worker;

- However, there is robust evidence that the proportion of machinery and equipment, in the U.S. capital stock is significantly higher than in Canada;

- The Canadian capital stock does not appear to be older than that of the United States, nor do the data suggest that capital quality is increasing faster in the U.S. than in Canada;

- There is no evidence of a significant gap between the United States and Canada in the level of human capital per worker;

- There is a large gap between the United States and Canada in the production of R&D, although this may be somewhat attenuated by spillovers from the United States into Canada.

Part III: Conclusions

We shall now assess the empirical evidence of Part II in the context of the growth models described in Part I. In each case we shall wish to know whether the Canada-U.S. investment gaps we have identified above could cause a gap in labour productivity between the two countries.

1. Basic Neoclassical Model

As we have seen, the relevant measure of capital for the basic neoclassical model is the broadest possible measure of the physical capital stock, possibly augmented by the stock of human capital. In either case there is little evidence that differences in capital per worker can explain more than a small fraction of the Canada–U.S. productivity gap. Instead, differences in technology, industrial structure or other such factors must take the blame. This conclusion is all the more true in the long run, because, as we noted in Part I, some part of any difference in capital intensity is ultimately the result of differences in these other factors.

2. Neoclassical Model with Capital-Embodied Technical Change

In this model the relevant variables are the size of the capital stock, as before, and the age of the capital stock. Capital stock of a more recent vintage is more technologically advanced and therefore more effective. However, as far as we can tell, there is little difference in the average age of the capital stock in Canada and the United States. Furthermore, the rate of capital-embodied technical change appears similar in the two countries, and so adjusting the capital stock for the rate of capital-embodied technical change, in order to net out increases in the effective capital stock that are unrelated to investment, will not change the result that overall capital intensity appears similar in the two countries.

3. Endogenous Growth Models

In endogenous growth models in which physical capital is the engine of growth, as in neoclassical models with capital-embodied technological change, the quality of capital is an essential component of the growth process. The difference with the neoclassical model is that capital quality is endogenous rather than exogenous. What evidence is there that the Canadian capital stock lags behind the U.S. in quality? It is undeniable that a greater share of the U.S. capital stock is made up of machinery and equipment. On the other hand, as noted above, data on the average age of the capital stock and the change in the price of capital tend to suggest that there is little difference in *overall* capital quality between Canada and the United States, in part because quality change in machinery and equipment seems to be proceeding somewhat faster in Canada than in the United States.

Because levels of human capital are similar in the U.S. and Canada, endogenous growth models based on human capital would clearly not point to a human capital investment gap as cause of different productivity levels.

However, models in which R&D is the engine of growth could point to an investment gap as the main cause of the Canada–U.S. productivity gap, even allowing for some spillovers of U.S. R&D into Canada. Here the issue is one of magnitude. Table 3 provides information on the size of the U.S. R&D capital stock up to 1990 (a similar argument could be made for Canada[16]). The U.S. figure for 1990 is approximately US$1 trillion in 1987 dollars. Large though this figure is, it is dwarfed by the size of the total U.S. physical capital stock in 1990, which was around US$17 trillion.

Assuming that the *private* rates of return on R&D are of a similar magnitude to the rates of return on other kinds of capital would imply that the share of R&D in national income is much smaller than that of physical capital, around 2 to 3 per cent based on the figures given above. This proportion is too small for a Canada-U.S. R&D capital stock gap to have much impact on productivity differences simply through its impact on the private gains from R&D spending.

Thus, if differences in the R&D capital stock are to affect productivity it must be through the spillover effect, that portion of the gains not captured by the firm incurring the expenditure. Furthermore, the magnitude of this spillover effect must be very large if it is to explain most of the gap. If the Canadian R&D stock is about half that of the U.S. (as suggested by the figures on investment flows), then the spillover parameter δ would have to be around 0.3—ten times the private returns parameter ε—in order to explain a

[16] These U.S. figures are from the Bureau of Economic Analysis (BEA). Statistics Canada does not produce comparable figures for Canada. Table 3 shows our own comparable stock estimates based on R&D expenditures for the U.S. and Canada.

Canada-U.S. productivity gap of 18 per cent. The spillover parameter would have to be even larger if Canada benefits from some R&D spillovers from the United States.

4. Overall Conclusions

We find that Canada significantly under-invests relative to the United States in R&D and in machinery and equipment. This conclusion confirms that of other researchers. However, we differ in the significance that we ascribe to these results. In particular, we do not agree that these investment gaps necessarily explain much of the Canada–U.S. productivity gap.

- For the R&D gap to be the principal contributor to the productivity gap, two conditions must hold: first, the social returns must be an order of magnitude greater than the private returns; and second, a large proportion of these spillovers must stop at national borders.

- For the machinery and equipment gap to be the principal contributor to the productivity gap, it must be that this gap more accurately measures differences in capital quality than the other measures we have looked at.

In both cases it seems to us that the verdict is 'not proven'.

This is not to say that differences in capital quality and innovation do not contribute to the productivity gap. Clearly, something must explain the gap, and that something may be related to under-investment of some kind. However, the gap does not seem to be the result of under-investment at the level of the broad aggregates that we have been looking at here. This has important implications for policy, because it means that policy measures—such as taxes and subsidies—that target these broad aggregates may not be the most efficient means of affecting the underlying causes of the productivity gap.

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Appendix : Tables and Figures

Table 1. Average Age of (Equipment and Total) Capital Stock, the U.S. and Canada, 1961-97

	United States		Canada	
	Equipment	Total	Equipment	Total
	(in years)			
1961-73	6.8	17.3	8.0*	13.8
1974-79	6.6	16.0	7.3*	13.1
1980-89	6.9	15.4	7.0*	13.2
1990-94	7.3	15.7	7.0	13.9
1995-97	7.2	16.1	7.1	14.3
	(in annualized growth rates)			
1961-73	-1.0%	-1.0%	-0.7%	-0.8%
1974-79	0.3%	-0.4%	-1.1%	-0.1%
1980-89	0.7%	0.0%	0.1%	0.4%
1990-94	0.3%	0.9%	0.6%	0.9%
1995-97	-0.9%	0.0%	-0.5%	0.0%

Sources: For Canada, “Fixed Capital Flows and Stocks 1961-1994”, Cat 13-568 Section IV, page 60. Updated to 1999 by Statistics Canada on request. For the U.S., “Fixed Reproducible Tangible Wealth in the US”, Table 1.1. Page 1 Aug-99, US Department of Commerce. 1995-97 figures are preliminary.

*Note that before 1984 the average service life in Canada was not based on a regular survey, and so these data are to be treated with caution.

Table 2: Human Capital Stock: Number of University Educated People over 25 years old and Average Years of Schooling, the U.S. and Canada, 1976-98

	United States			Canada		
	People with Higher Education (% of population 25+)	Average Years of Completed Schooling (in years)	Human Capital Stock /a (logs)	People with Higher Education (% of population 25+)	Average Years of Completed Schooling (in years)	Human Capital Stock /a (index 1976=100)
1976-79	29.4%	12	0.4208	21.0% /e	11	107
1980-89	35.1%	12	0.4991	25.3% /e	11	122
1990-94	42.8%	13	0.5481	39.5%	12	130
1995-98	48.3%	13		45.8%	12	133 /b
	(in annualized growth rates)					
1977-79	1.3%	0.5%	0.9%/c	0.2% /e	0.3%	3.0%
1980-89	3.8%	0.5%	1.6%/d	3.2% /e	0.5%	1.0%
1990-94	2.1%	0.5%		3.4%	0.5%	0.5%
1995-98	3.8%	0.2%		2.6%	0.4%	0.2% /b

a/ A labour-income-based measure of human capital. For the U.S., Sala-i-Martin and Mulligan (1994) and, for Canada, Laroche and Mérette (2000).

b/ 1995-96 only. c/ 1970-80. d/ 1980-90.

/e Canadian data before 1990 are not strictly comparable to post-1990 data.

Note: American data from http://www.census.gov/population/socdemo/education/tableA-1.txt. Canadian data from LFS by educational attainment, special tabulation.

Source: U.S. Census Bureau and Statistics Canada, Sala-i-Martin and Mulligan (1994), Laroche and Mérette (2000).

Table 3. R&D Capital Stock, 1970-99

	United States			Canada	
Indicators of R&D capital stock	BEA Estimates (1987 billions of dollars) /a	Estimates based on R&D Expenditure (1996 billions of dollars) /b	Number of Researchers (in 10,000 per labour force) c/	Estimates based on R&D Expenditure (1992 billions of dollars) b/	Number of Researchers (in 10,000 per labour force) c/
1970	581	n.a.	n.a.	n.a.	n.a.
1975	646	63.2	n.a.	2.9	n.a.
1980	686	163.6	62 (1981)	8.4	31 (1981)
1985	797	391.4	68	22.9	40
1990	978	674.8	75 d/	41.7	45 d/
1995	n.a.	972.3	74 (1993)	59.6	54
1999	n.a.	1387.9	n.a.	78.5	n.a.
		(in annual average growth rates)			
1970-75	1.8%	n.a.	n.a.	n.a.	n.a.
1975-80	1.0%	17.2%	n.a.	19.3%	n.a.
1980-85	2.5%	15.7%	5.3%	18.3%	5.3%
1985-90	3.5%	9.5%	3.6%	10.5%	4.8%
1990-95	n.a.	6.3%	0.2%	6.2%	5.1%
1995-99	n.a.	7.4%	n.a.	5.6%	4.2% (1995-8)

a/ BEA estimate of R&D net total capital stock, http://www.bea.doc.gov/bea/an/1194od/boxtab.htm

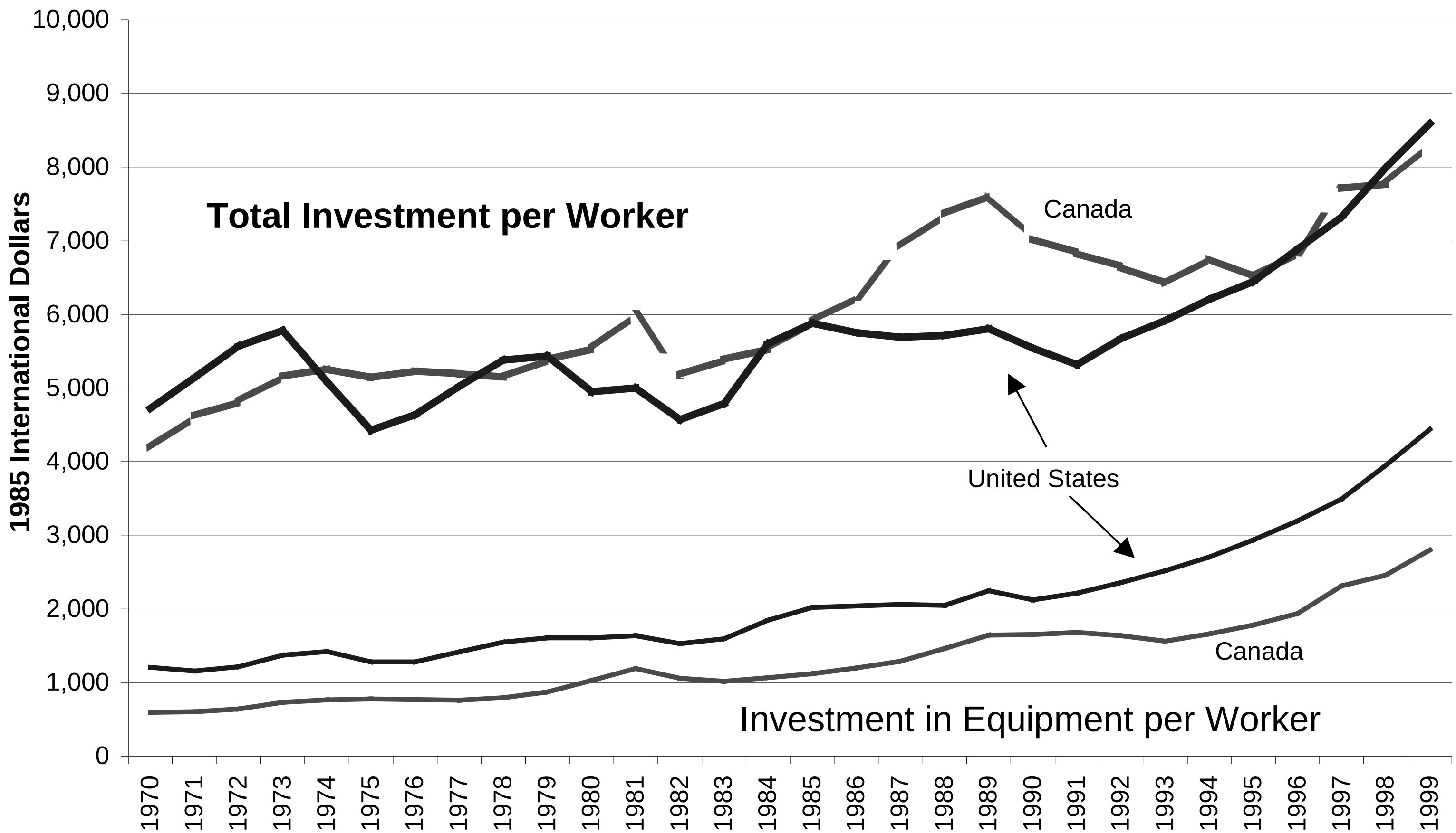
b/ Own calculations using annual expenditures on R&D starting in 1970 and a 11-per-cent rate of depreciation.

c/ OECD Science, Technology and Industry Scoreboard, 1999 (tables 3.1)

d/ Extrapolated from 1989 and 1991 OECD figures.

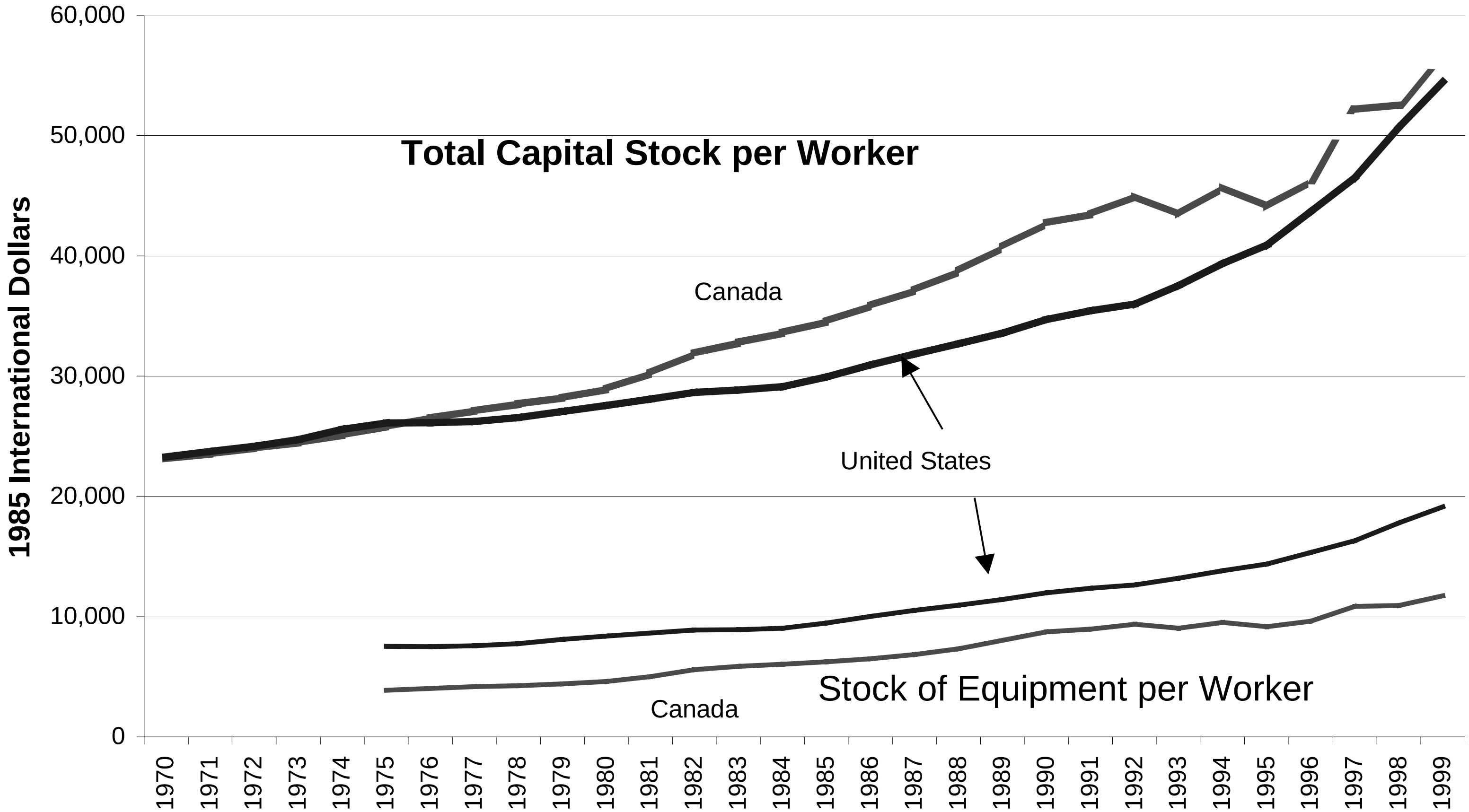
Sources: Bureau of Economic Analysis (U.S.); OECD; and own calculations

Figure 1:
Total Investment (and Investment in Equipment) per Worker, Canada and the U.S., 1970-99



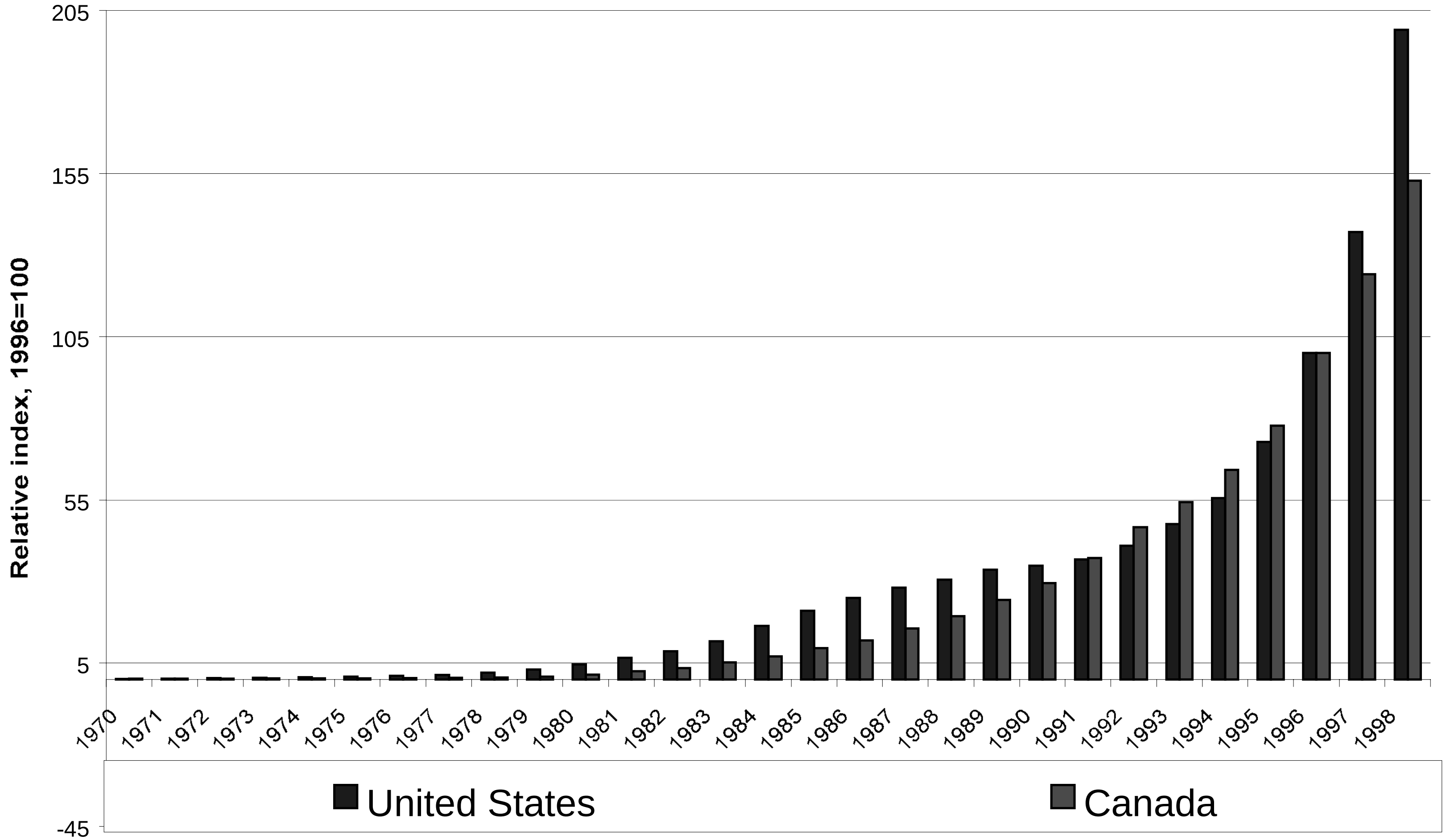
Sources: Investment figures from Penn Tables (1970-92, Mark 5.6a); employment data from "Comparative Civilian Labor Force Statistics, Ten Countries 1959-99", Bureau of Labor Statistics, http://www.bls.gov/flswarn.htm; data updated using growth rates from real investment figures published in the Quarterly National Accounts, OECD (2000, No. 2) and employment data from BLS.

Figure 2:
Total Capital Stock (and Stock of Equipment) per Worker, Canada and the U.S., 1970-99



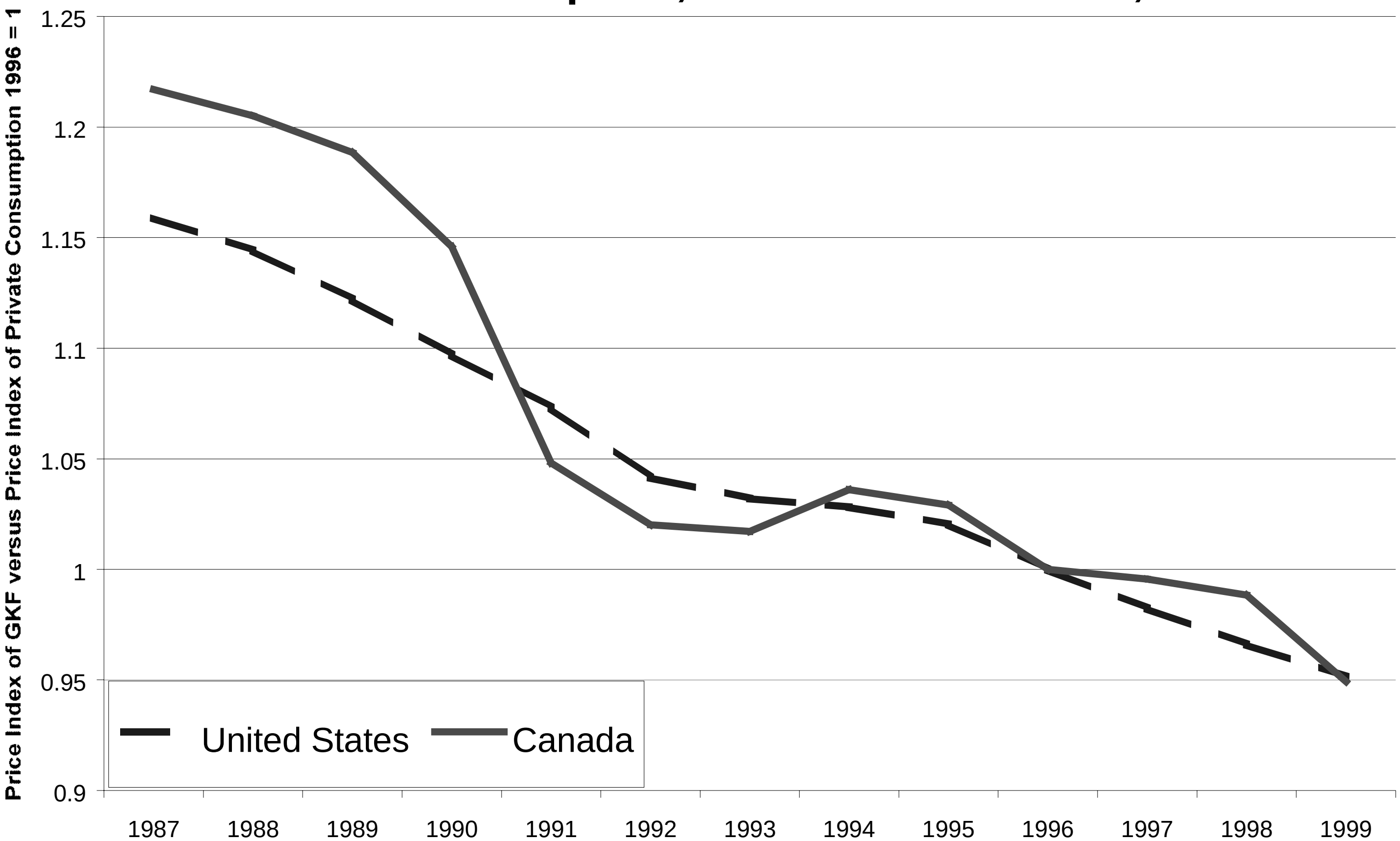
Sources: Capital stock per worker and producers durables from Penn Tables (1970-92, Mark 5.6a). Capital stock figures updated using growth rates in real investment from OECD's Quarterly National Accounts (2000) and in employment from "Comparative Civilian Labor Force Statistics, Ten Countries 1959-99", Bureau of Labor Statistics, http://www.bls.gov/flswarn.htm

Figure 3:
Stock of Computers per Worker, Canada and the U.S., 1970-98



Sources: Estimates of capital stock from Bureau of Economic Analysis (U.S. data) and Statistics Canada (Canadian data). Comparable employment data from “Comparative Civilian Labor Force Statistics, Ten Countries 1959-99”, Bureau of Labor Statistics, http://www.bls.gov/flswarn.htm.

Figure 4: Relative Price of Gross Capital Formation versus Private Consumption, Canada and the U.S., 1987-99



Source: Quarterly National Accounts, OECD (2000, No. 2: Tables 2,).