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ENDOGENOUS INNOVATION AND GROWTH: IMPLICATIONS FOR CANADA

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ENDOGENOUS INNOVATION AND GROWTH: IMPLICATIONS FOR CANADA

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

While Canada enjoys one of the five highest levels of real income in the world today, economic growth in the country has slowed down since 1973. Labour productivity, as a contributing factor to economic growth, accounted for about 60 percent of the overall economic growth in both the 1961-1973 period and in the post-1973 period when overall economic growth slowed. The dominance of labour productivity in Canada will most likely become even stronger. Labour productivity growth, and not demographic trends, will continue to be the dominant determinant of growth in Canada in the future.

If the labour productivity slowdown was the major cause of the decline in the growth rate of real income per capita beginning in the first half of the 1970s, the next logical question is why annual labour productivity gains have been smaller ever since. In an effort to explain why labour productivity gains have slowed, it is suggested that labour productivity growth is derived from two sources: capital accumulation and technological progress, as measured by the growth in total factor productivity (TFP).

Observed labour productivity slowdown in Canada after 1973 was not the result of a decline in the rate of capital accumulation: the trend growth rate of capital per worker did not change significantly between the two periods 1961-73 and 1974-93. The productivity slowdown was rather the result of other developments that have translated into a decline in the growth of TFP.

Looking at human capital accumulation, it is concluded that public policies to encourage investment in human capital can enhance efficiency and speed up the economy's growth rate. The paper also explores the implications of gains made possible through "learning by doing" and demonstrates how investment in R&D is a mechanism through which labour productivity can rise.

The mechanisms through which investment in R&D can influence productivity growth, within models of endogenous growth, are then explored. For privately funded R&D to take place, an economic environment that protects intellectual property rights must exist in a way that allows firms to enjoy the fruits of their R&D efforts. Also, some form of increasing returns and lack of perfect competition (monopoly power) are necessary for R&D investment.

Theoretically, investment in R&D can have positive or negative effects on output growth. Positive spillovers arise when the social benefits to investment exceed the costs. Negative effects are also possible, however, arising from the destruction of products and profits as R&D investment creates new products and processes to replace existing ones. On balance, in Canada, significant R&D spillovers appears to exist across firms and industries. As a result, the social rate of return on R&D is higher that the private rate of return by a factor that varies from two to five.

It follows from the above evidence that Canada does not invest enough in R&D. This is in part due to the existence of positive externalities. But also, Canada is a small open economy where there are plenty of natural resources which are a poor substitute for highly skilled labour. This leads the economy to specialize in resource-intensive sectors and to invest too little in R&D.

Therefore, there is an economic rationale for subsidizing investment in R&D in Canada. Subsidization of R&D, however, must be carefully assessed to reflect the true extent of the spillover effects. Also, while R&D subsidies may be desirable, output subsidies for sectors that invest in R&D may be detrimental.

Investment in R&D can also have an impact on the labour markets. In particular, productivity growth that is driven by inventive activities can raise or reduce the long-run level of unemployment. This important question has received very little attention. More research is required on the impacts of investment in R&D on unemployment and on the types of education and training that would be optimal.

International economic relations can play an important role in shaping a country's economic attributes. Trade and foreign direct investment generate positive spillovers via the flows of knowledge that they cultivate. In addition, trade will lead firms to specialize and reduce the extent to which the same kinds of research are duplicated in different countries. Further, servicing a larger market raises the return to R&D, therefore, raising the level of R&D undertaken. There are, however, potentially negative effects of trade on investment in R&D arising from the increased competition that firms face in international markets and the resulting price discipline that this brings. But on balance, the available empirical evidence supports the view that trade has a favourable impact on productivity.

In conclusion, policies encouraging the accumulation of human capital, directly supporting R&D activity and ensuring access to international knowledge and markets can improve growth prospects. However, in each case, there are possible negative effects that do not guarantee a higher level of welfare. Therefore, both costs and benefits must be considered in the development of economic policies in these areas.

INTRODUCTION

The standard of living of a population is closely related to real national income per capita — an indicator of the quantity of goods and services the average member of society can purchase with his or her income in a given year. It is equal to gross national product (GNP) divided by an index of the average price of goods and services purchased (hence the term "real") and by the total population of the country (hence the term "per capita"). Economic growth is concerned with the growth rate of real national income per capita (or real income per capita for short).

Economic welfare is but one dimension of global human welfare, and it depends, in important ways, on real income per capita. And, while the quality of life encompasses much more than the total quantity of goods and services consumed, real income per capita is universally viewed as a key facet of the well-being of society. For this reason, the analysis of economic growth focuses on real income per capita, and we will follow this practice.

Our paper is in four parts:

- Chapter 1 reviews the evidence of Canada's growth. This leads us to focus on labour productivity.
- Chapter 2 discusses various factors that contribute to labour productivity such as capital accumulation, exogenous technological progress, human capital accumulation and learning by doing. The chapter also contains a preliminary discussion of innovations.
- Chapter 3 is devoted to a detailed discussion of endogenous innovations. After a description of the economic mechanisms that link the incentive to innovate to productivity growth, we discuss welfare implications, the importance of general equilibrium effects and the relationship between growth and unemployment.
- Chapter 4 gives a description of the links between international economic transactions and endogenous innovation and growth.

We do not have a separate section on policy implications. Instead, we discuss policy issues in all chapters as they arise. We point out the policies that might be useful and those that might not work or will be difficult to implement. In any case, we do not take a position on specific policies regarding Canada. Rather, we suggest areas in which policies might be helpful. The design and implementation of such policies require detailed knowledge of the economy, as well as good judgment in cases in which quantitative estimates are not available. Detailed policy recommendations are therefore beyond the scope of this paper.

CHAPTER 1

CANADA: REAL INCOME AND PRODUCTIVITY

Canada has one of the world's highest levels of real income per capita. As Table 1 indicates, the latest Organization for Economic Co-operation and Development (OECD) ranking (for 1991) puts Canada in fifth place among industrial nations, behind the United States, Luxembourg, Switzerland and Germany. It may therefore appear somewhat paradoxical that Canadians currently show so much concern about the growth performance of their country.

Chart 1 provides much of the explanation for this paradox. It shows that, over the last 30 years, Canada's real income per capita has more than doubled (in constant 1986 Canadian dollars). But it also reveals an important deterioration of the country's growth performance in the last 20 years relative to the earlier period. Growth has become slower, more irregular and more unequally shared.

First, since 1973 growth has slowed down. Between 1961 and 1973, the average annual growth rate of real income per capita was 4.2 percent. But since 1974 growth has proceeded at less than half that pace, or 1.9 percent per year on average.

Second, Chart 1 makes it visually clear that, in the last 20 years, growth has been more irregular. In the 1961-1973 period, the standard deviation of real income per capita around its long-run trend was 1.6 percent. But in the 1974-1993 period, the standard deviation was more than twice as large — 3.6 percent. The greater instability of the growth process is underlined by the 1990-1993 recession, which was the worst among the G-7 countries (including Canada) since the Depression of the 1930s. Throughout most of the 1961-1993 period, real income per capita in Canada was second only to that of the United States, and the gap was closing. But, in recent years, Canada has lost ground to the United States and to other countries as well.

Third, in the last two decades, growth has become more unequally distributed among members of society. This dimension of growth is crucial to an understanding of the current concern, but is not captured by the averages presented in Chart 1. From 1964-1973 to 1984-1993, the national unemployment rate doubled, increasing to 9.6 percent from 4.8 percent. Moreover, even as the standard of living continued to rise from 1973 to 1989, real wages of the 20 percent of full-time, full-year workers with the lowest earnings experienced an absolute decline of five percent. At the other end of the income scale, real wages of the 20 percent with the highest earnings increased by 12 percent. Hence, the question has been raised: Does economic growth necessarily entail higher unemployment and greater income inequality?

To begin to understand what happened in the last 20 years, and also to identify the set of questions the theory of economic growth can address, it is useful to express real income per capita as the product of six contributing factors:

1. The income–output ratio, or the ratio between gross national income (GNP) and gross domestic product (GDP). Canada's national income is less than the value of its domestic product because it has to pay interest and dividends on its large net foreign debt.

2. The terms of trade, or the ratio between the average price of what we sell and the average price of what we buy. This is approximated by the ratio of the GDP price index to the domestic absorption (C+I+G) price index and is chiefly determined by the ratio of export prices to import prices.

3. Labour productivity, or the ratio between real GDP and total employment (output per employee).

4. The employment rate, or the percentage of the labour force which is actually employed. This ratio is the exact complement of the unemployment rate (i.e., the percentage which wants a job, but does not have one). For example, if the employment rate is 91 percent, the unemployment rate is nine percent.

5. The labour force participation rate, or the percentage of the population aged 15 and over which is in the labour force (i.e., which wants to work).

6. The working-age ratio, or the percentage of the total population which is 15 and over.

By definition, the growth rate of real income per capita from one year to the next is the sum of the growth rates of these six components.

Table 2 shows that, over the last 30 years, growth in real income per capita of Canadians has been fuelled by three main developments:

- advances in labour productivity;
- rising labour force participation (mainly of women); and
- the relative decline in the population aged 14 and under (following the lower birth rate).

Rising unemployment has been a retarding factor. The other two elements — the income–output ratio and the terms of trade — had a relatively minor influence. Table 2 also indicates that growth has slowed down since 1973 mainly because the annual growth rate of labour productivity has dropped, and because the working-age ratio has begun to grow more slowly. (Since the mid-1980s, it has actually stopped growing.)

The central message of Table 2 is that labour productivity, as a contributing factor to economic growth, accounted for about 60 percent of the overall economic growth in both the 1961-1973 period and in the post-1973 period when overall economic growth slowed. The dominance of labour productivity in Canada will most likely become even stronger. Now that the birth rate has stabilized at a low level, the benefits of a growing working-age ratio are gone. The labour force participation rate will continue to grow, but at a declining pace, mainly because the fraction of participating women will likely converge to some social equilibrium, and because the demographic weight of the older (non-participating) population has begun to increase. In the following analysis of growth, we emphasize labour productivity, as opposed to demographics, and long-term, as opposed to short-term, developments.

Short-term cyclical developments understandably receive much attention, because of their strong impact on measured economic growth and employment levels from year to year. In many circumstances, negative or slow economic growth does not reflect a deficiency of the engines of growth, but a falling degree of utilization of the existing economic potential. For example, a recession may have been allowed to set in as an anti-inflation discipline, as was the case in Canada in 1981-1982 and in 1990-1991. Applying appropriate short-term macroeconomic management becomes the remedy for the temporary lack of growth.

Short-run demand disturbances and management are not the kinds of problems we have in mind when looking at long-term growth. Accordingly, we have put aside the subject of the business cycle for the time being. We do believe, however, that there may be important connections between trend productivity growth and the long-run degree of cyclical instability. As we have noted above, cyclical instability increased in 1974-1993 relative to 1961-1973. We will return to this later.

If the labour productivity slowdown was the major cause of the decline in the growth rate of real income per capita beginning in the first half of the 1970s, the next logical question is why annual labour productivity gains have been smaller ever since. The first step toward an answer is to observe that the productivity slowdown has not been at all specific to Canada. It has been a worldwide phenomenon. Table 3 shows that, among the G-7 countries, the long-term reduction in the growth rate of labour productivity from 1960-1973 to 1974-1993 ranged from 1.2 percent in the United Kingdom to 5.5 percent in Japan. For the average OECD country, trend productivity growth declined by 2.3 percent.

The second step is to acknowledge another fact: Not only have mean productivity growth rates fallen in the advanced economies, but cross-country differences around the mean also declined sharply from 1960-1973 to 1974-1993. For the G-7 countries, it is immediately apparent in Table 3, which shows that the distribution of growth rates across countries was much reduced from the earlier to the later period. Table 4 confirms that visual impression more formally. It shows that, since 1974, the much tighter distribution of labour productivity growth rates across countries is a property not only of the G-7 economies, but of all industrial economies. Comparing 1974-1993 to 1960-1973, the cross-country standard deviation of labour productivity growth rates around the mean declined by a factor of three among the G-7 countries (whether Japan is included or not) and by a factor of two among wider groupings of OECD countries.

A third step toward understanding productivity in recent decades is to recognize that real incomes per capita (i.e., levels as distinct from growth rates) have also become more tightly distributed around the mean in industrial countries. As Table 5 shows, the proportional distance between the typical country's real income per capita and various group means fell appreciably from 1960 to 1990. The drop in cross-country differences is particularly striking among the 19 more advanced economies. In 1960, real income per capita of the leading country (the United States) was 3.2 times as high as that of the least advanced country in the Group of Nineteen (then Japan). But in 1990, real income per capita of the United States (still the leader) was only twice that of the least advanced country of the Group (now Ireland).

These facts are strongly suggestive of an ongoing process of global convergence of levels and rates of growth of real income per capita among OECD countries. Recent empirical literature on growth confirms this hypothesis, and an active search for explanations has begun. With this in mind, we now focus on the non-demographic determinants of the growth of real income per capita.

CHAPTER 2
INGREDIENTS FOR GROWTH

Demographics aside, the growth of income per capita closely tracks the growth of labour productivity (i.e., output per worker). We can break down the growth of labour productivity into two sources:

- growth in the quantity of capital per worker; and
- technological progress.

For current purposes, technological progress is defined in broad terms that include improvements in manufacturing techniques, the quality and diversity of products, organizational methods and the productive capacity of the labour force. We therefore discuss capital accumulation on the one hand and the various components of technological progress on the other. The latter are measured by the growth of total factor productivity.

Capital Accumulation

Output per worker depends on the stock of capital per worker as long as the efficiency of workers, and capital and technology do not change. The larger the capital stock with which a worker is employed, the larger the worker's output level. It is, however, often the case that the marginal productivity of capital declines as more machines and equipment are employed with a unit of labour. As a result (and this is a crucial point), the marginal profitability of capital accumulation declines as more and more capital becomes available for each unit of labour. For this reason, the neoclassical theory of economic growth reaches the conclusion that growth of income per capita will be brought to a halt in the absence of improvements in the technology or the labour force. For example, given a constant population and a fixed subjective rate of time preference ρ, a one-sector economy approaches a long-run equilibrium in which the marginal product of capital just equals the subjective rate of time preference, i.e.,

$$f'(\kappa) = \rho \tag{1}$$

where
$f(\cdot)$ represents output per labour unit; and
κ represents capital per labour unit.

When capital accumulation reaches the level described by (1), capital per worker and output per worker remain constant forever. This may be preceded, however, by a long period of growth in real output per capita driven by a rising capital stock.

It has been suggested that the marginal product of capital may never become as low as the subjective rate of time preference, no matter how much capital the economy accumulates.[1] In this event, it would pay to accumulate capital indefinitely, and the economy would continue to grow forever.[2] As a result, the share of capital in GDP would approach one. Although much effort has been spent analyzing economies of this type, we feel that this description is not particularly useful.

The assumption that the efficiency of workers, and capital and technology do not change, seems to be at a variance with the evidence. If anything, during the 200 years since the industrial revolution, growth rates have been positive and rising. While it is true that, during the last 30 years, labour productivity growth has slowed, this does not reflect a tendency of the growth rate of capital per worker to decline toward zero. The crucial fact is that labour productivity growth tends to exceed the level that can be accounted for by the growth rate of capital per worker, i.e., the residual growth rate

$$\varepsilon = \hat{y} - \beta\hat{\kappa} \qquad (2)$$

is positive, where
$\hat{y}$ is the growth rate of output per worker;
$\hat{\kappa}$ is the growth rate of capital per worker;
β is the elasticity of output with respect to capital (usually around one third); and
ε, the residual growth rate, is sometimes referred to as the "Solow residual" and represents the growth rate of total factor productivity (TFP).

Chart 2 depicts the time path of TFP in Canada since 1961. It has the same properties as real income per capita and labour productivity, i.e., trend growth of TFP has been positive, but has been slower and more irregular since 1973. TFP grew two percent a year on average in the 1961-1973 period, but only at 0.3 percent per annum in 1974-1993. The decline in the trend growth rate of TFP (i.e., the fall in ε) from one period to the next is almost exactly of the same magnitude as the decline of the trend growth rate of output per worker shown in Table 3. The implication is that, from 1961-1973 to 1974-1993, the trend growth rate of capital per worker did not change significantly; it remained stable at around three percent per year. Hence, the slowdown of labour productivity growth in Canada has not been the result of trend decline in the rate of capital accumulation, but of other developments that have translated into a decline in the growth rate of total factor productivity.

This phenomenon is not specific to Canada. It has also been observed in the other G-7 countries. Table 6 shows that the trend growth rate of TFP has been positive everywhere

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[1] See, for example, Rebelo (1991).

[2] Under these circumstances, the growth rate of real income per capita converges to the difference between the lower bound on the marginal product of capital and the subjective discount rate.

throughout the 1961-1993 period and that, from 1961-1973 to 1974-1993, it declined by roughly the same amount as the trend growth rate of labour productivity.

Exogenous Technological Progress

We have reached the conclusion that a positive growth rate of capital per worker is a regular feature of the industrial countries and contributes to the trend growth of output per worker. We have found, however, that the actual growth rate of output per worker exceeds the value that can be accounted for by the growth rate of capital per worker. This difference varies in degree across decades and countries, and suggests that the efficiency of workers, and capital and technology are not the same in all countries and that they change over time. We therefore discuss possible sources of change in efficiency.

Technological progress changes the pessimistic prediction of the neoclassical growth model, where technological progress is viewed as a constantly rising efficiency of available inputs.

Consider the case of labour augmenting technological progress, where the efficiency of a unit of labour rises at a constant rate g_A per unit time as a result of improvements in manufacturing and organizational techniques, and the labour force is constant. In this case (1) needs to be replaced with

$$f'(\kappa) = \rho + g_A \qquad (3)$$

where
κ is now the ratio of capital to the *effective* size of the labour force, and the effective size of the labour force is measured in efficiency units.

Since, in this long-run equilibrium, κ is constant, it means that the stock of capital grows at the rate of labour-augmenting technological progress g_A and, therefore, output also grows at this same rate. The result is that output per capita grows at the rate g_A.

We have seen that the presence of technological improvements that raise the productivity of workers at a constant rate ensures long-run growth of output per capita. During the transition phase to the long-run equilibrium, an economy's income per capita grows faster than the rate of technological progress because, during the transition, the ratio of capital to effective labour is lower than the long-run ratio. As a result, the rate of capital accumulation exceeds the rate of technological progress. Nevertheless, the rate of growth of income per capita declines over time.

It is important to note that, although both technological progress and capital accumulation contribute to output growth, long-run capital accumulation in this economy depends on the presence of technological progress. Technological progress raises the marginal productivity of capital and makes the investment in capital equipment worthwhile. Thus, technological progress has a direct effect on output growth and an indirect effect via its inducement of capital accumulation. This secondary effect can be quite large.

Human Capital

As we have seen, improvements in the productivity of labour can result from the accumulation of capital and technological progress. However, other direct measures, such as education and training, can also raise the productivity of workers. A young individual spends several years in school, developing basic skills that enhance his or her productive capacity. Afterward, he or she decides how much more formal education to acquire. Part of the cost of schooling is foregone income during the schooling period. This and other costs, such as tuition fees, are compared to future benefits in choosing how much to invest in schooling. Thus, schooling can be viewed as an investment decision that raises an individual's human capital.

The same applies to various training programs, including on-the-job training. Firms invest in workers, directly and indirectly. For the most part, this type of investment provides skills that are particularly useful to the firm, but some of these skills are also useful for other employers. And the productivity of a worker often rises with experience even in the absence of a formal training program.

Since human capital is embodied in the individual, it enhances the worker’s productivity as long as he or she is employed. The implication is that, due to the finite lifetime of individuals, human capital, per se, cannot raise the productivity of workers without bound (the upper bound on schooling and training is an individual's lifetime). In other words, the productivity of workers cannot rise forever at a constant rate g_A due to the accumulation of human capital, unless the acquisition of human capital provides economic benefits beyond the improvement of the productive capacity of the worker that invests in human capital. The implication is that, without such additional effects, human capital accumulation cannot sustain indefinite growth of income per capita.

It has been argued that schooling and training are useful to society beyond an individual's gains. One channel of influence that has been especially emphasized is the effect of a society's stock of human capital on the ease with which a single individual acquires skills, the argument being that more human capital per capita raises the productivity of the system of human capital accumulation.[3]

We can demonstrate the operation of this mechanism with a simple example. Suppose that people live forever (an unessential simplifying assumption) and that they spend a fraction *s*

[3] See, for example, Lucas (1988) and Bénabou (1993).

of their time in school or in training outside the job. The population is constant and there are L workers. The accumulation of an individual's human capital satisfies

$$\dot{h} = \phi(\bar{h})\, s \tag{4}$$

where
h is the individual's stock of human capital;
$\bar{h}$ is the per capita stock of human capital; and
the increasing function $\phi(\bar{h})$ describes the productivity of schooling time, i.e., the higher the level of human capital per person, the more an individual gains from an hour of schooling.

Since all individuals are the same, the effective size of the labour force equals

$$h(1 - s)\, L \text{ and } \bar{h} = h \tag{5}$$

It follows that effective labour grows at the rate $s\phi(h)/h$ per unit time. If the ratio $\phi(h)/h$ approaches zero as h grows large, then the long-run rate of growth of effective labour approaches zero.

In this case, income per capita does not grow in the long run [while (1) still holds]. If, on the other hand, this ratio approaches a positive constant b as h grows large, then effective labour grows in the long run at a constant rate $g_A = sb$. In this instance, the economy approaches a steady state that satisfies $f'1(\kappa) = \rho + g_A$, in which output and capital grow at the rate g_A.

In this long-run equilibrium, output per capita also grows at the rate g_A. The larger the fraction of time spent in school, the larger the growth rate.[4] During the transition to the long-run equilibrium, capital accumulates at a rate that is faster than g_A, output per capita grows at a rate that is faster than g_A, and the growth rate of output per capita declines over time. Similar results are attained when labour augments technological progress.

The point of this example is clear: Even with infinite lives, human capital accumulation cannot sustain long-run growth of income per capita unless there are suitable spillovers from human capital to the cost of its acquisition. When externalities of this sort do exist and individual investment in human capital is driven by an income motive, the resulting investment in human capital turns out to be too low from an efficiency point of view. As a result, public policies that encourage investment in human capital can enhance efficiency and speed up the economy's growth rate. The difficult questions concern the desired composition of such policies. What are, for example, the relative merits of elementary education compared to secondary

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[4] Naturally, the more time workers spend in school, the lower the initial level of output. The trade-off is therefore between a lower initial output and a higher and faster-growing future output compared to a higher initial output with a lower and slower-growing future output.

schooling? Of secondary general education compared to vocational training? Or of higher education versus on-the-job training? Answers to such questions require detailed studies that consider a country's specific circumstances. In Canada, for example, they also have to factor in the ease with which skilled Canadians find jobs in the United States.

Learning by Doing

Our discussion of technological progress has assumed that it takes place at an exogenous rate. This assumption is rather unsatisfactory, because it is at a variance with the evidence, and the endogeneity of technological progress has important implications. Much of our discussion in the rest of the paper is devoted to technological progress that is driven by purposive investment in the development of new technologies. In this section, however, we briefly discuss learning by doing.

The notion of learning by doing was introduced by Arrow (1962) into growth theory. He pointed out that in addition to adding to the capital stock, investment may also raise technological efficiency. Later on, it became more common to treat output as the relevant index of learning by doing. A simple example of the latter is given by the production function

$$X = AL \qquad (6)$$

where
X is output;
A is a measure of labour efficiency; and
L is labour input, where labour efficiency rises at a rate that is proportional to the output level, i.e., $\dot{A} = aX$.

In this instance, labour productivity rises at the rate aL. Therefore, a constant employment level implies a constant rate of growth of output per worker. This is a case of learning by doing that sustains long-run growth.[5]

Our example builds on the notion that learning by doing is unbounded. It has been observed, however, that improvements in technological efficiency resulting from cumulative experience in the manufacturing of a particular product diminish to zero over time. As a result, there is only a limited amount of learning by doing that can be attained.[6] Does this evidence indicate that learning by doing cannot be an important source of long-run growth? The answer is: Not necessarily. Although the fruits of learning by doing are largely confined to the

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[5] The fact that growth is sustained in the long run partly depends on the functional form that we have chosen. For example, with a learning function $\dot{A} = aX^{\gamma}$ and $0 < \gamma < 1$, labour productivity growth approaches zero in the long run.

[6] See Young (1991) for a discussion of the empirical evidence.

manufacturing plant, there may exist important spillovers to other plants, companies or even industries.[7]

Of particular interest are spillovers across different generations of the same product that generate positive externalities. Consider the case of a product from a newer generation that is more effective than the same product from an older generation. Suppose that cumulative experience in the manufacturing of a particular generation of this product raises its productivity via learning by doing. In addition, suppose that experience in one generation of the product also contributes to productivity in the manufacturing of the next generation of the product. Then even if the learning process on a given generation runs into diminishing returns to scale, productivity gains can be sustained forever if manufacturers switch to a newer generation whenever the price–cost comparison justifies it. This result has been shown by Young.[8]

Whenever the fruits of learning are fully appropriated by the manufacturer, there is no need for policy activism. The company will choose an output trajectory that considers not only the effect of current output on current profits, but also its effects on future productivity and on future profits. This calculus is socially efficient.

Inefficiency is introduced when learning by doing produces spillovers across firms. This may happen when a manufacturer learns how to save resources not only from his own experience but also from the experience of other manufacturers. In case a positive externality of this sort exists, public policy should encourage activities that generate the spillovers. The policy needs to be conditioned, however, on the availability of reliable evidence that such spillovers do in fact exist.

Innovation

Inventions and innovations have been a major source of technological improvements and productivity gains. They come in a variety of forms:

- major changes in general purpose technologies, such as the steam engine, electricity or the transistor;
- innovations that help to implement new general purpose technologies by providing machines and equipment to go with them or organizational methods that help to implement the new technologies better;
- the development of new products, such as the automobile, the telephone or the television; and
- small purposive improvements in available techniques of production.

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7 See, for example, Irwin and Klenow (1993) for a discussion of spillovers in the semiconductor industry.

8 See also Grossman and Helpman (1994b, section 2) for a simple exposition.

In the past, it was not unusual to argue that technology is driven by science. This has changed. The works of economic historians, such as Rosenberg (1963) on machine tools, or studies of more recent periods, such as Freeman (1982) on chemicals, have shown that companies invest in new technologies to gain profits.[9] This is corroborated by the fact that, in OECD countries, company investment in research and development has grown faster than output during the last 25 years, and most of this investment is privately funded.

This evidence suggests that we need to consider seriously the role of research and development in the growth process. According to recent theorizing, a country's employment of resources can be broken down into employment in research and development, and employment in manufacturing. In a simple case, where labour is the only input, the resource constraint can be represented by

$$L_R + L_M = L \tag{7}$$

where
L_R stands for employment in research and development; and
L_M stands for employment in manufacturing.

For a given level of the economy's productivity, the employment level in manufacturing determines real output of goods and services. (For the moment, we assume that no capital is used in manufacturing.) As a result, output growth can result from either rising employment in manufacturing or from productivity gains. The size of the labour force limits output per worker on account of manufacturing employment. Therefore, an economy of this type can sustain positive long-run growth only if it is able to secure indefinite productivity gains, and investment in research and development can achieve just that.

For example, suppose that output of goods and services equals AL_M, where A stands for an index of labour productivity. And suppose that productivity gains depend on employment in research and development as follows:

$$\dot{A} = \Phi(\cdot)L_R \tag{8}$$

where
$\Phi(\cdot)$ is a function that determines labour productivity in research and development.

It is now clear that, if $\Phi(\cdot)$ is a constant, the rise in labour productivity $\dot{A}$ is bounded by the available labour supply [see equation (7)]. As a result, the rate of growth of productivity (i.e., $\dot{A}/A$) cannot remain positive forever. In this event, growth peters out in the long run.

9 See also Schmookler (1966) and Landes (1969).

It can be argued, however, that innovation activities contribute to knowledge that is useful to future innovators. Thus, the invention of a material that has been designed for a particular purpose may prove to be very useful for entirely different purposes, or a chemical process that has been developed in order to solve a specific problem may prove to be extremely helpful in solving other problems. The study of the steam engine, for example, led to the development of thermodynamics, and the invention of the transistor contributed to the development of solid state physics. These are examples of spillovers from particular research projects to the general stock of knowledge, which subsequently contribute to future innovative activities. While these are extreme examples, research and development contributes small amounts to general knowledge during the normal course of business. These amounts accumulate and jointly produce large effects.[10]

We may think of A as the outcome of all past innovation efforts and the stock of knowledge as a function of A. In this instance, it is natural to think of $\Phi(\cdot)$ as a function of A, i.e., $\Phi(A)$. Under these circumstances, positive employment in research and development brings about cost reductions, as labour input per unit of research and development declines over time as a result of growth in the stock of knowledge.

This is similar to learning by doing as discussed earlier. The difference is that, with learning by doing, the learning took place in manufacturing. In this instance, the learning takes place in research and development. This difference is important, because even if one believes that learning by doing in manufacturing runs into diminishing returns (as the evidence points out) one may still hold the view that research and development investment does not run into diminishing returns. For instance, Schumpeter (1942) held the view that technological progress does not have to run into diminishing returns.[11] In our simple model, constant employment in research and development leads to indefinite productivity growth whenever the ratio $\Phi(A)/A$ remains positive as A grows without bound.

In the recent literature, a common assumption has been that $\Phi(\cdot)$ is proportional to A. As a result, constant employment in research and development brings about a constant rate of productivity growth.[12]

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10 See also Romer (1993) on this point and the evidence discussed in the next chapter.

11 He contrasted technological progress with the cultivation of new plots of land and argued that while the latter must run into diminishing returns,

> we cannot reason in this fashion about the future possibilities of technological advance. From the fact that some of them have been exploited before others, it cannot be inferred that the former were more productive than the latter. And those that are still in the lap of the gods may be more or less productive than any that have thus far come within the range of observation. (p. 118)

12 This statement applies to models of endogenous growth that are based on expanding product variety as well as to models that are based on rising product quality. See Romer (1990) and Grossman and Helpman (1991a, chap. 3) for examples of the former, and Grossman and Helpman (1991b) and Aghion and Howitt (1992) for examples of the latter.

Up to now, we have discussed properties of research and development technologies that lead to long-run productivity growth with bounded employment in inventions and innovations. However, we have left out a central question: What does it take to provide business firms with incentives to employ resources in innovative activities?

We address this question in the next chapter. Before turning to it, we would like to stress that the ability of an economy to experience indefinite productivity gains is not an integral part of these theories. We have emphasized this feature for convenience. However, the *mechanisms* that we portray are important, and they help us to understand modern growth. These mechanisms remain important even if they sustain productivity growth for only a limited period of time.

CHAPTER 3
ENDOGENOUS INNOVATION

In Chapter 2, we pointed out that recent contributions to the theory of endogenous growth have taken the view that commercial companies invest in research and development to increase profits. This is, of course, not a new concept, and some people have thought about this type of investment even in the framework of a neoclassical economy.

Suppose that a firm knows how to manufacture a homogeneous product — knowledge that is summarized in a concave production function.[13] In this scenario, the firm's value is determined by the present value of its future profit stream. As long as the firm controls this technological and organizational information, its value can be positive.

Our sample firm may choose to invest resources in the improvement of its technology to increase the present value of future profits. The firm's investment decision, in this type of technological progress, is driven by well-known considerations which are familiar from the theory of investment in capital equipment. The assumptions that the firm owns the manufacturing technology and that it can appropriate the fruits of technological improvements become critical elements. If other competitors could freely use the same production function, entry would reduce the firm's value to zero, and the firm would have no incentive to invest in technological improvements. Therefore, an economic environment that protects property rights in a way that enables firms to enjoy the fruits of their research and development efforts has to be provided in order for privately funded research and development to take place.

It is worth noting that the availability of a concave production function that does not exhibit constant returns to scale is not sufficient for the validity of the above argument about investing in research and development to save costs. A standard replication argument implies that constant returns to scale have to emerge under these circumstances, unless there are limitations on divisibility.[14] On the other hand, indivisibilities introduce increasing returns to scale. We therefore see that some form of increasing returns and lack of perfect competition are necessary in order to make sense of research and development investment.

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[13] We may also include the firm's specific capital as part of this definition, but this is inessential.

[14] Suppose that a concave production function $F(\upsilon)$that does not exhibit constant returns to scale is owned by a firm, where υ is a vector of inputs. The firm can replicate this production function as many times as it wants. Therefore, for any employment vector υ, it can choose to manufacture in N separate "plants" employing, in each one, the vector of inputs υ/N. The result will be a joint output level $NF(\upsilon/N)$, which is rising in the number of plants. Clearly, it pays, in this case, to expand the number of plants indefinitely, which will lead, in the limit, to constant returns to scale.

Recent literature has emphasized two channels through which firms can gain from investment in research and development.

First, when a firm successfully reduces unit manufacturing costs or improves the quality of a product that has a perfect substitute in the market, it gains monopoly power in the price range below the lowest effective unit cost of its competitors. As a result, it can charge any price that does not exceed the lowest effective unit cost of its competitors and can sell, at this price, the entire demanded quantity.[15]

Second, firms often develop products that do not have perfect substitutes in the market. This is common in sectors with product differentiation such as specialized machine tools, consumer durables or even food products. In this case, the innovating firm faces a downward sloping demand curve over a large segment of the price range.[16] In both instances, an incentive exists to invest in research and development in order to appropriate *monopoly* profits. In either case, the reward to research and development requires a system of property rights that protects the monopoly profits. Sometimes, this protection is naturally provided, for example, when trade secrets can be maintained (at least for a limited period of time). And sometimes, the legal system provides protection of monopoly profits via trademarks and patents.

To see how an economy with protected monopoly profits can grow and how its growth is related to labour productivity in research and development as described above, consider an economy in which every good can be improved by means of research and development designed for this particular purpose. More labour employed in research and development that attempts to improve a product implies a larger probability of success. Success raises the usefulness of the good by a fixed factor $\lambda > 1$. The improved product provides services that are equivalent to the services provided by λ units of the unimproved product.[17] In this instance, a successful innovator, whose unit manufacturing costs equal the manufacturing costs of the unimproved product, can sell all the demanded quantity for prices that do not exceed λ times the common unit manufacturing costs. In this case, the profits the innovator can attain from charging a price above unit costs but below λ times unit costs provide the reward to investment in product improvement.

If the measure of available products is normalized to one, and L_R units of labour are employed in targeting the improvement of each one of these products, thereby making the instantaneous probability of a successful improvement equal to L_R for each one of them, then a fraction L_R of the products get improved per unit of time.

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[15] See, for example, Grossman and Helpman (1991b) and Aghion and Howitt (1992).

[16] See, for example, Judd (1985), Grossman and Helpman (1989) and Romer (1990).

[17] We assume for simplicity that λ is constant. See, however, Grossman and Helpman (1991a, chap. 4) for an extension that makes the size of this jump endogeneous.

Using the resource constraint (7), this feature implies that the quality adjusted output of these products equals AL_M where $\dot{A} = AL_R \log\lambda$.

As a result, the economy's productivity grows at a rate that is proportional to employment in research and development, with a factor of proportionality that equals $\log\lambda$. Therefore, the more resources are employed in research and development and the larger the improvement brought about by successful innovations, the faster the growth. The profit calculus of firms that invest in product improvement determines the equilibrium split of employment between research and development and manufacturing.[18]

An alternative is provided by simple models with expanding product variety. In those frameworks, employment in research and development is proportional to the flow of newly invented brands. If this factor of proportionality is constant, long-run growth cannot be sustained because innovation costs remain constant in real terms while the benefits of innovation decline as more and more products are introduced into the economy.

But, as we have argued, unit labour requirement per invented product can be expected to decline with research and development experience. As a result, research and development costs can be expected to decline over time. If they decline fast enough compared to the falling reward to the invention of new products, the result will be a sustained incentive to invest in research and development and thereby sustained long-run growth.

Using the terminology from the previous section, we have

$$\dot{A} = \Phi\,(A)L_R \qquad (9)$$

where
A equals the number of brands available in the economy, which also represents a measure of cumulative experience in research and development.

Then, whenever $\Phi(A)/A$ does not decline to zero as A grows without bound, there will be long-run productivity growth. And again, the decomposition of employment between research and development and manufacturing is determined by the profit calculus of business firms.[19]

We have described two mechanisms that link research and development to sustained productivity growth. These mechanisms have been portrayed in the framework of very simple economic models. It is therefore important to observe that the same type of mechanisms operates in more realistic economic environments, which admit multiple sectors, multiple inputs

[18] See Grossman and Helpman (1991a, chap. 4) for details.

[19] See Grossman and Helpman (1991a, chap. 3).

(including capital accumulation) and a number of countries that engage in international trade and direct foreign investment. There are key implications of these mechanisms.

- Research and development leads to productivity growth.

- Private incentives to invest in research and development require the presence of a suitable framework of intellectual property rights that allows business firms to appropriate at least part of the fruits of their research and development effort.

- The ways in which firms appropriate the benefits of their research and development investment often involve the exercise of monopoly power.

As a result, there are two types of distortion in a system in which research and development is privately financed: a distortion in pricing due to monopoly power and an externality that results from research and development investment. This raises three related questions:

- Are there economic benefits to this type of research and development-based growth?

- Is the resulting growth rate optimal?

- If the answer to the preceding question is no (as indeed it is), what policies can improve the outcome?

Welfare

The first thing to observe is that, in a market system with no government support to research and development, the absence of protection of intellectual property rights, such as a lack of patent or trademark protection, prevents commercial companies from securing a return on their research and development investment. As a result, they will not invest in research and development, and innovation will not be a source of productivity growth. The same outcome results whenever property rights are protected but government agencies, such as antitrust authorities, enforce pricing practices that eliminate mark ups because, in this case too, innovators cannot obtain profits in order to cover research and development costs. In either case, there will be no research and development investment and no productivity growth based on this investment.

Although it appears from these arguments that protection of intellectual property rights and the feasibility of mark-up pricing are necessary for research and development-based productivity growth in a market economy, these conditions are by no means sufficient. They have to be complemented by sufficiently low interest rates (and time preferences) and sufficiently low research and development costs to ensure the profitability of investment and active innovation in the resulting equilibrium.

Now consider an economy with suitable intellectual property rights and markup pricing that invests in research and development. Is the resulting productivity growth optimal? Four distortions have been identified for economies of this type.

First, mark-up pricing leads to the usual static misallocation of resources in favour of sectors with the lowest mark ups, and toward competitive sectors in particular. This misallocation need not affect the rate of productivity growth, although it is very likely that it will because it affects relative factor rewards and the relative costs of various economic activities. As a result, it affects the relative costs of innovations, and this has a direct bearing on the rate of investment in research and development. The importance of this channel of influence has not received much attention in the literature.

Second, innovations may have a direct effect on consumer or user surplus. This is particularly true for economies with product differentiation in which variety is valued per se. Because of this influence, the rate of investment in research and development is too low.

Third, a business firm that invests in research and development counts the increase in its own profits as the reward to inventive activity but does not count, as a loss, the profit declines of its rivals. To the economy, the change in net profits of the business sector is what matters. Therefore, the rate of investment in research and development is too high because of this profit destruction effect.

Finally, as we pointed out earlier, research and development investment confers positive externalities by producing non-appropriable knowledge that future innovators can use without charge. This leads to research and development investment that is too low.[20]

Much of the popular policy discussion emphasizes the positive external effects of research and development investment (on consumer–user surplus and on future innovators). This viewpoint leads to the inevitable conclusion that the market provides too little research and development, and that governments should subsidize research and development activities. On the other hand, recent theoretical models point to the existence of one important upward bias in market- supplied research and development levels that results from profit destruction.

In models of expanding product variety, the profit destruction effect is equal in size to the consumer–user surplus effect. Consequently, in these types of environments, the positive externality of research and development investment dominates the outcome, and the resulting rate of innovation tends to be too low.[21] On the other hand, in models with rising product quality, the profit destruction effect is larger than the consumer–user surplus effect. As a result,

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[20] See Romer (1990), Grossman and Helpman (1991a, chaps. 3 and 4), Aghion and Howitt (1992), Helpman (1992) and Stokey (1992) for a discussion of these effects.

[21] See Romer (1990) and Grossman and Helpman (1991a, chap. 3).

the equilibrium rate of innovation turns out to be too low only if the external effect of research and development is large enough, and too high when the external effect of research and development is small. Each one of these cases emerges for suitable parameter combinations.[22]

These investigations suggest that, in theory, the market may generate a rate of innovation that is either too high or too low. For policy purposes, the relevant question becomes: Which is the empirically relevant case?

Empirical studies do not exist that follow the theoretical lead and provide estimates of the decomposition of the bias in the equilibrium rate of innovation according to the above four channels. On the other hand, many empirical studies exist that have assessed the economic benefits of research and development, and we can rely on those studies in forming an opinion about whether the rate of investment is too small or too large. The following findings are particularly relevant for our purpose.[23]

- The rate of return to research and development at the firm level is large. It is larger than the rate of return on capital investment by a factor of two or more.

- Significant spillovers of research and development exist across firms and industries. As a result, the social rate of return on research and development is higher than the private rate of return by a factor that varies from two to five.

- The estimated rate of return to research and development rises with the unit of observation, and it is particularly large when benefits are measured at the country level. In addition, there are significant cross-country spillovers of the benefits of research and development.[24]

- Rates of return on basic research are significantly higher than rates of return on applied research and development, with the exception of Japan where the opposite is true.

It follows from this evidence, which builds on data from the industrial countries, that investment in research and development is too low, and Canada is no exception to this rule. Moreover, in Canada, research and development investment as a fraction of GDP is lower than in the other G-7 economies which strengthens the argument that Canada does not invest enough

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[22] See Grossman and Helpman (1991a, chap. 4) and Aghion and Howitt (1992).

[23] See Mohnen (1992a), Griliches (1994) and Lach (1994) for surveys of the evidence.

[24] See Coe and Helpman (1995), Coe, Helpman and Hoffmaister (1994) and Mohnen (1992b) for evidence on cross-country spillovers.

in research and development.[25] This emerges in spite of the fact that Canada supports research and development programs. As generous as this support might be, the final outcome also depends on a variety of other policies and the availability of suitable inputs.

As in other cases of positive externalities, the growth literature concludes that a subsidy is called for whenever the social benefits of research and development exceed social costs. A subsidy of this type raises investment in research and development and speeds up the rate of productivity growth. In each case, suitable estimates of the divergence between private and social costs and benefits are needed in order to calculate the optimal subsidy.

It is important to note, however, that investment-driven growth is costly to the economy in terms of foregone resources that are employed in the investment process, and investment in research and development is no exception. As a result, faster growth is not always desirable, and the benefits of growth have to be compared to its costs. The implication is that the subsidy to research and development should be carefully calculated, because such subsidies can be too low as well as too high.

It is sometimes suggested that a country needs to subsidize various activities in high-tech sectors. We would like to point out that policies of this sort are not necessarily a good substitute for direct research and development subsidies. In other words, while research and development subsidies are desirable, other types of subsidies to sectors that invest in research and development may be detrimental.

Subsidies to output are a case in point. Grossman and Helpman (1991a, chap. 10) have shown that an output subsidy to a high-tech sector may in fact reduce investment in research and development and thereby reduce the rate of productivity growth. Their example describes an economy that has a high-tech sector and a traditional sector. Manufacturing in each one of these sectors, as well as research and development, employs unskilled and skilled labour, with research and development being the most skilled labour-intensive activity and traditional manufacturing being the least skilled labour-intensive activity.

In this environment, an output subsidy to high-tech products leads to the expansion of high-tech manufacturing. But because high-tech manufacturing uses an intermediate factor intensity, its expansion leads to the contraction of both traditional manufacturing and research and development. The contraction of research and development reduces the rate of productivity growth. It follows that, in this example, an output subsidy to high-tech products has the opposite effect on research and development investment, and on productivity growth as does a research and development subsidy.

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[25] According to the OECD's Main Science and Technology Indicators, in 1992 Canada invested 1.5 percent of GDP in research and development, while in the other G-7 countries the numbers were as follows: 2.68 percent in the United States, 2.8 percent in Japan, 2.2 percent in the United Kingdom, 2.36 percent in France, 2.53 percent in Germany and 1.38 percent in Italy.

General Equilibrium Effects

The case of an output subsidy discussed above shows the importance of general equilibrium effects. It suggests that a proper understanding of productivity growth has to consider the links between different sectors of the economy and their mutual interdependence. Generally, the rate of investment in research and development depends, in a complicated way, on an economy's sectoral structure, available resources and the resulting relative costs because, in a market economy, research and development, and productivity growth materialize from a complex process of resource allocation.

For a country such as Canada, which has many natural resources, the composition of available inputs is a major factor that needs to be taken into account. To see why, consider an economy with two types of inputs: unskilled and skilled labour. If research and development is intensive in skilled labour, traditional manufacturing is intensive in unskilled labour and high-tech manufacturing has an intermediate skill intensity level, then research and development investment and productivity growth will increase as more skilled labour becomes available.

In this type of an economy, a large supply of skilled workers encourages investment in research and development and speeds up productivity growth.

There are two channels through which these effects work. First, the presence of more skilled workers implies that the economy is larger, and a larger economy tends to engage in higher levels of all economic activities, including research and development. Second, the availability of more skilled labour reduces the relative costs of activities that use skilled workers intensively. As a result, research and development expands.

On the other hand, a larger supply of unskilled workers has an ambiguous effect on research and development. Indeed, more unskilled workers enlarge the economy's size, and a larger economy tends to do more of everything, including research and development. But in this case, as a result of the availability of more unskilled workers, the relative costs of skill-intensive activities rise. This is detrimental to research and development. The net outcome of these opposing pressures is that the addition of unskilled workers may increase or decrease the level of innovative activities and productivity growth, depending on the elasticities of substitution in production. If these elasticities are large, there will be more research and development and faster productivity growth. If the elasticities are small, there will be less research and development and slower productivity growth.[26]

Now, replace unskilled labour with natural resources in the description of our economy. The conclusion becomes: An economy with plenty of natural resources that are a poor substitute for highly skilled labour will specialize in resource-intensive sectors. This is particularly true for a small, open economy such as Canada has. An economy of this type is likely to end up with relatively little research and development. The tendency to specialize in resource-intensive

[26] See Grossman and Helpman (1991a, chap. 5).

sectors, which have little potential for productivity growth, limits the economy's overall growth potential.

We have argued that, given the available estimates of rates of return to research and development investment, a country of this type may find it beneficial to subsidize research and development and thereby accelerate, in a welfare- enhancing fashion, its productivity growth. Faster productivity growth directly raises the rate of growth of income per capita. It also raises it indirectly through the inducement of faster accumulation of capital. Indeed, there exists a positive correlation between the growth rate of total factor productivity and the rate of investment.[27] Moreover, evidence points to causality that runs from research and development to capital accumulation rather than the other way around, and to growth of income per capita preceding capital investment rather than vice versa.[28]

Unemployment

Our discussion has so far disregarded frictions in the labour market that may lead to a slow reallocation of labour in response to technological progress. However, in economies with active innovation new employment opportunities frequently arise, but at the same time old jobs get destroyed as a result of the arrival of new technologies. If labour cannot move instantly from old to new jobs, some frictional unemployment is bound to arise during the transition. This possibility raises the question: Does productivity growth that is driven by inventive activities raise or reduce the long-run level of unemployment? This important question has received little attention.

A recent study by Aghion and Howitt (1994) provides some useful insights.[29] They consider an economy in which workers need to be matched with jobs. The job-finding rate is an increasing function of available vacancies while the recruiting success rate is a declining function of available vacancies. This friction generates unemployment as workers leave jobs that become redundant as a result of new technologies, and they remain jobless as long as they do not find a suitable match in one of the new vacancies generated by the arrival of a new technology.

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[27] See Baumol et al. (1989) and Grossman and Helpman (1994b).

[28] See Lach and Schankerman (1989) for evidence from firm level data on the former point and Blomström et al. (1993) for cross-country evidence on the latter. De Long and Summers (1991) find a positive correlation between growth and equipment investment. But their evidence does not establish causality. It is therefore consistent with the view that research and development leads to total factor productivity growth, which leads in turn to higher investment rates and faster output growth.

[29] The long-run level of unemployment that we discuss in this section is structural in nature and differs from cyclical changes in unemployment that take place over the business cycle. We do not discuss the latter type of unemployment, although links between short-term fluctuations and long-term unemployment might exist.

In the Aghion-Howitt model, the relationship between the rate of productivity growth and the resulting long-run rate of unemployment rises initially (when the rate of productivity growth is low) and declines eventually (when the rate of productivity growth is high). If the rate of productivity growth results from a combination of the speed with which new technologies arrive and the degree to which they improve labour productivity, then the effect of a faster average rate of productivity growth depends on whether it results from more frequent arrivals of innovations or from the arrival of larger innovations.

It is hard to judge, from the available studies, the policy implications of this theory for unemployment. It appears, for example, that policies that speed up the transition of workers from old to new jobs are desirable. But evidence also exists that innovating firms invest relatively more in workers.[30] In this event, faster innovation that speeds up worker turnover reduces the incentive of companies to invest in training their labour force. This raises the possibility that fast worker turnover, in response to innovations, may involve significant costs to the economy, and it may be preferable to have a slower rate of innovation, with longer life spans of jobs (in order to take advantage of the human capital that workers acquire on the job) and lower long-run unemployment. These trade offs need to be further studied.

These types of considerations raise additional questions. What type of schooling is desirable in an economy that is subjected to rapid technological change? Should schools emphasize general training as opposed to the development of specific skills? Should on-the-job training play a larger role? These open questions require more research.

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30 See Baldwin and Johnson (1994).

CHAPTER 4
INTERNATIONAL INTERDEPENDENCE

A country's growth pattern depends on a variety of factors. It is now time to introduce a set of additional considerations that play a major role in shaping a country's economic attributes — its international economic relations. International trade, direct foreign investment and international capital movements have greatly expanded in the post-war period, and they have affected many economies in important ways. In the emerging global economy, a country can specialize in a relatively narrow range of products and still be able to consume, and use in production, a much wider range of products supplied by other parts of the world. Of course, many services and some goods are not traded very much on an international level. They are typically supplied within each country or geographic region for local use.

The volume of international trade in both goods and services has greatly expanded in the last 40 years, and the composition of international flows of goods and services has substantially changed. Recent research suggests new explanations for these emerging patterns and speculates that important links exist between international transactions and economic growth.

The literature has identified a number of channels through which international economic transactions affect a country's growth rate.[31] Integration into the world economy provides a country with access to valuable information (e.g., technological, organizational) which enhances its knowledge base. As a result, it can better use its resources and raise productivity. Much of this improvement can be in the form of a once-and-for-all effect. But if the acquired knowledge reduces the country's costs of innovation, it can also lead to faster, sustained productivity growth.

The latter point has been particularly emphasized. It suggests that countries can greatly benefit from “keeping in touch” with developments of economic value in other parts of the world. This can be partly attained by encouraging local institutions whose purpose is to acquire and preserve knowledge, such as universities and research organizations, to perform this task. However, commercial relationships are often essential for this to happen because much tacit knowledge is acquired in the course of business transactions. In this event, foreign trade can play an important role, and links with foreign multinationals can be particularly valuable. The general point is that trade and direct foreign investment generate positive spillovers via the flows of knowledge that they cultivate. As a result, policies that discourage foreign trade and investment hurt growth directly.

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[31] The following discussion is based on Grossman and Helpman (1991a, chap. 9) and Rivera-Batiz and Romer (1991).

We have argued that innovative activities are likely to produce positive externalities for firms in the same sector, for different sectors and for future generations of innovators. The externality on future innovators is particularly important for growth because, by expanding the available knowledge base, current inventive activities reduce future costs of research and development and speed up productivity growth. Given an aggregate level of inventive activity, this spillover is larger when the overlap in various research and development efforts is smaller. Consequently, a company that invests resources in the development of a new product that is available in another part of the world will most likely not contribute to this general stock of knowledge because the information it produces is already available.

In the absence of international trade, each country is economically isolated. A company that develops a product only considers its profitability from domestic sales and has no incentive to avoid replication of research and development efforts that have already taken place in other parts of the world. In this case, we expect some duplication of research and development efforts. This is wasteful from the point of view of the global economy.

These types of redundant research and development projects are not undertaken in an integrated world economy, in which each producer competes worldwide. We see that international trade yields an additional benefit by preventing the duplication of efforts, and these benefits are globally shared as long as the general knowledge that emerges from research and development flows across countries.

Another effect of trade on innovation and growth stems from its expansion of market size. In an isolated economy, the domestic market determines the level of demand that an innovator can hope to supply with a new or improved product. This demand level affects the profitability of investment in research and development. When the same company can sell in a world market that is many times larger than its domestic market, it faces a much larger demand level and expects a larger return on its inventive activity. It follows that access to larger markets via international trade raises the reward for research and development investment and encourages higher investment levels. The result is faster productivity growth.

Not all trade effects are beneficial to growth. An important exception is the effect of competition. In the absence of foreign trade, a domestic producer only faces competition from domestic companies. With foreign trade, the producer also faces competition from foreign manufacturers. The added competition reduces the incentive to invest in research and development, and slows down productivity growth.[32]

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[32] There are arguments to the contrary which are based on X-efficiency [e.g., Horn et al. (1994)]. The argument is that foreign competition raises the incentive of domestic oligopolistic firms to become more efficient by eliminating managerial slack. As far as we can judge, the available arguments are about efficiency improvements, while their effects on productivity growth are unclear.

Finally, there are general equilibrium effects. International trade leads to changes in the relative profitability of various economic activities and to a reallocation of resources accordingly. These reallocations may work for or against research and development, depending on a country's characteristics compared to those of its trade partners. We have seen that a country's resources have an effect on how many of them will be employed in research and development. Scale and composition effects were identified. The scale effect suggests that a country with more resources is likely to perform more research and development. The composition effect suggests that a country with relatively more resources, such as human capital, in which research and development are intensive, will also perform more research and development.

These same considerations apply to the integration of an economy into the world system. Take, for example, the case in which general knowledge flows freely across boarders — so much so that new information that becomes available in one country also becomes available in every other country. In this case, there is a tendency for rates of innovation to converge across countries because the stock of knowledge that plays a major role in the costs of innovation will be the same everywhere. As a result, the scale effect of trade will be favourable for productivity growth in all countries. But the composition effect of trade will be favourable for productivity growth in countries with below average relative availability of human capital and unfavourable for countries with above average relative availability of human capital.

These theoretical considerations suggest that powerful forces tend to make international transactions beneficial to productivity growth, but forces also exist that may cause international trade to hurt productivity growth. What is the net outcome? If we had to answer this question on the basis of the theory alone, our best judgment would be that, overall, international transactions are beneficial to productivity growth, as long as a country remains open to the flow of ideas from the rest of the world. Once the flows of ideas are secured, the potentially detrimental effects of trade on productivity do not seem to be so large relative to the positive effects. As a policy matter, we would say that the free flow of ideas from the rest of the world should obtain top priority.

Before we turn to the evidence about the effects of trade on productivity and output growth, let us dwell on the importance of the flow of ideas. When ideas that contribute to the stock of general knowledge flow freely around the globe, costs of innovation depend in different countries on the composition of inputs and on the number of products in which a country is a world-class leader. The latter are the outcome of past research and development efforts. Over time, the fraction of products in which a country maintains leadership will converge to whatever is consistent with its composition of inputs, independent of the initial fraction.[33]

Therefore, under these circumstances, long-run patterns of comparative advantage are independent of short-run advantages in various markets. In this environment, it is more

[33] This and the following points are discussed in more detail in Grossman and Helpman (1991a, chap. 7).

important to secure resources, such as human capital, that are important inputs in research and development than to win a particular technology race for the development of a product.[34] Because countries that are well endowed with human capital will control a disproportionately large part of high-tech sectors, countries that are well endowed with unskilled labour or natural resources will specialize in low-tech sectors.

When knowledge does not flow across countries, each country builds its own general stock of knowledge on the basis of its own cumulative experience in research and development. In this scenario, countries that have accumulated much experience have a cost advantage in doing research and development over countries that have little experience. As a result, countries that initially have more research and development experience do more of it and widen their experience advantage. In addition, they win a disproportionately large number of technology races. This cumulative process leads to long-run patterns of specialization that are determined, to a large extent, by the initial distribution of experiences in research and development across countries. Countries that become technologically advanced first dominate the high-tech sectors in the long run, and they experience faster productivity growth.[35]

In these types of economic environments, the availability of human capital can compensate for the lack of initial experience in high technology. In addition, temporary support for such industries, until knowledge stocks are built up, can help overcome initial disadvantages. The difficulty with policies of this sort is that, because of the cumulative nature of the process, policy mistakes also have cumulative negative effects. Moreover, the welfare implications of such policies are not necessarily beneficial, even when they are relatively successful.[36]

We now turn to the empirical evidence. Does foreign trade accelerate growth? A positive association between trade and output growth has been identified in many early studies.[37] It has also been found in recent cross-country estimates.[38] However, few studies look directly at the effects of trade on productivity. Recently, Coe and Helpman (1995) estimated the effects of domestic and foreign research and development capital stocks on the total factor productivity of 22 developed countries, where research and development capital stocks served as proxies for stocks of knowledge. For each country, a foreign research and development capital stock was calculated as a weighted average of the domestic research and development capital stocks of its

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[34] This statement is confined to technology races that are small in impact. The conclusion would be quite different for technology races of major impact, such as general purpose technologies of the type analyzed in Helpman and Trajtenberg (1994). The implications of international races to develop such major technologies have not yet been worked out.

[35] See Grossman and Helpman (1991a, chap. 8) for technical details.

[36] See Grossman and Helpman (1991a, chap. 8) for a discussion of the difficulties to attain a welfare improvement.

[37] See, for example, Michaely (1977) and Feder (1982).

[38] See Barro (1991).

trade partners, using relative import shares as weights. The estimates also allowed for the effects of a country's total trade exposure, as measured by its total import share in GDP. They found significant effects on the research and development capital stocks and on the trade exposure measure interacted with foreign research and development capital. These findings suggest that the more a country trades overall, the more it gains from the research and development of its trade partners, and the more its trade is biased toward countries that invest heavily in research and development.[39] The evidence seems to support the view that trade has a favourable effect on productivity.

We have identified three areas in which policies play an important role in affecting output and productivity growth:

- education and training
- research and development
- international relations.

Policies that encourage the accumulation of suitable human capital, that directly support research and development, and that ensures access to international knowledge and markets help growth. In closing, it is important to note that, in economies of the type we have discussed, faster output and productivity growth do not necessarily lead to higher welfare. As a result, one should not strive to improve productivity and raise output at any cost. Although this point is well understood, it is often disregarded in policy debates. Policies toward growth need to consider both costs and benefits.

[39] Similar results were obtained for a sample of 77 developing countries; see Coe, Helpman and Hoffmaister (1994).

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Table 1
Level of Real Gross Domestic Product Per Capital, 1991

Rank	Country	Real GDP Per Capital (US$)
1	United States	22,204
2	Luxembourg	20,904
3	Switzerland	21,832
4	Germany	19,687
5	Canada	19,281
6	Japan	18,957
7	France	18,152
8	Denmark	17,603
9	Iceland	17,442
10	Austria	17,329
11	Belgium	17,145
12	Sweden	16,877
13	Italy	16,866
14	Norway	16,804
15	Netherlands	16,453
16	Australia	16,195
17	United Kingdom	15,608
18	Finland	15,480
19	New Zealand	13,675
20	Spain	12,714
21	Ireland	11,480
22	Portugal	9,180
23	Greece	7,729
24	Turkey	3,486

Note: GDPs are converted into U.S. dollars by the OECD on the basis of estimated current purchasing parity values.
Source: OECD.

Table 2
Breakdown of the Average Annual Growth Rate of Real National Income Per Capita into Six Contributing Factors, Canada, 1961-1973 and 1974-1993 (Percent per Year)

Contributing Factor	**Period**		**Change**
	1961-1973	**1974-1993**	
Income–Output Ratio	0.0	-0.1	-0.1
Terms of Trade	0.1	0.2	+0.1
Labour Productivity	2.4	1.1	-1.3
Employment Rate	-0.1	-0.3	-0.2
Labour Force Participation Rate	0.7	0.6	-0.1
Working-Age Ratio	1.1	0.4	-0.7
Total Growth Rate	4.2	1.9	-2.3

Note: The decomposition of real national income per capita into six ratios is exact. The average annual growth rates of each ratio, for the two periods, are obtained from an ordinary least squares regression of the log of the ratio on a constant and on two time trends, one beginning in 1961 and the other in 1974.

Source: Authors' calculations based on Statistics Canada data (see text).

Table 3
Average Annual Growth Rate of Labour Productivity, G-7 Countries and OECD Average, 1960-1973 and 1974-1993 (Percent per Year)

Contributing Factor	Period		Change
	1960-1973	1974-1993	
United States	2.0	0.7	-1.3
Japan	8.2	2.7	-5.6
Germany	4.2	2.0	-2.2
France	4.8	2.0	-2.8
Italy	5.8	1.7	-4.1
United Kingdom	2.8	1.6	-1.2
Canada	2.5	1.0	-1.6
G-7 Average	4.3	1.7	-2.6
OECD Average	4.2	1.9	-2.3

Note: Labour productivity is equal to real GDP per person employed. The average annual growth rates of productivity are calculated by simple actuarial comparison of beginning- and end-of-period productivity levels. This method gives slightly different results than those based on the regression method which are reported for Canada in Table 2. The OECD averages are simple, unweighted averages of member countries' growth rates.

Source: Authors' calculations based on OECD data.

Table 4
Mean Standard Deviation of Annual Productivity Growth Rates in Various Groupings of Industrial Countries, 1960-1973 and 1974-1993
(Percent per Year)

Group of Countries	Mean		Standard Deviation	
	1960-1973	1974-1993	1960-1973	1974-1993
Group of Seven (G-7)	4.3	1.7	2.2	0.7
Group of Nineteen	3.9	1.6	1.6	0.6
Group of Twenty-Four	4.2	1.9	1.8	1.1

Note: The Group of Seven includes the United States, Japan, Germany, France, Italy, the United Kingdom and Canada. The Group of Nineteen also includes Australia, Austria, Belgium, Denmark, Finland, Ireland, the Netherlands, New Zealand, Norway, Spain, Sweden and Switzerland. Finally, the Group of Twenty-Four adds the two smallest OECD countries (Iceland and Luxembourg) and the three least advanced (Greece, Portugal and Turkey). Group means and standard deviations are based on simple, unweighted averages of member countries.

Source: Authors' calculations based on OECD data.

Table 5
Standard Deviation of Real GDP Per Capita
in Various Groupings of Industrial Countries, 1960 and 1991
(Percent)

Group of Countries	Standard Deviation	
	1960	1991
Group of Seven (G-7)	37	14
Group of Nineteen	34	17
Group of Twenty-Four	50	36

Note: The country groupings are defined in the note to Table 4. The typical statistic reported is the standard deviation of the logarithm of real GDP per capita. It should be interpreted as the average percentage difference from the mean.

Table 6
Average Annual Growth Rate of Total Factor Productivity, G-7 Countries, 1960-1973 and 1974-1993
(Percent per year)

Country	Period		Change
	1960-1973	1974-1993	
United States	1.6	0.1	-1.5
Japan	5.6	1.4	-4.1
Germany	2.6	0.5	-2.1
France	4.0	1.4	-2.6
Italy	4.4	1.4	-3.0
United Kingdom	2.5	1.2	-1.3
Canada	2.0	0.3	-1.8
G-7 Average	3.2	0.9	-2.3

Note: The growth rate of total factor productivity (TFP) is calculated for the business sector as per equation (2) in the text. The average annual growth rates of TFP are calculated by a simple actuarial comparison of beginning- and end-of-period TFP levels. The TFP series began in 1960 for the United States, Germany and Italy, in 1962 for Japan, in 1963 for France and the United Kingdom, and in 1966 for Canada. The G-7 averages are unweighted.

Source: Authors' calculations based on OECD data.

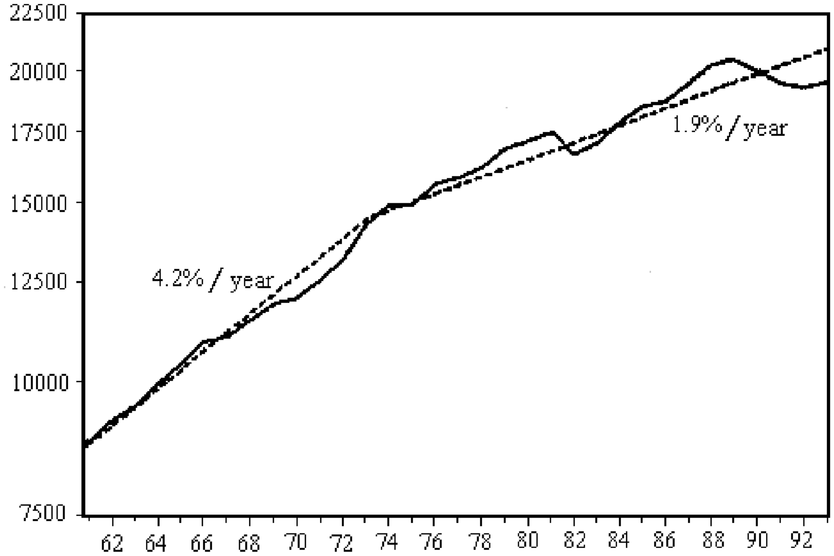

Chart 1
Standard of Living
Real National Income (GNP) Per Capita
Canada, 1961-1993 (C$ of 1986)

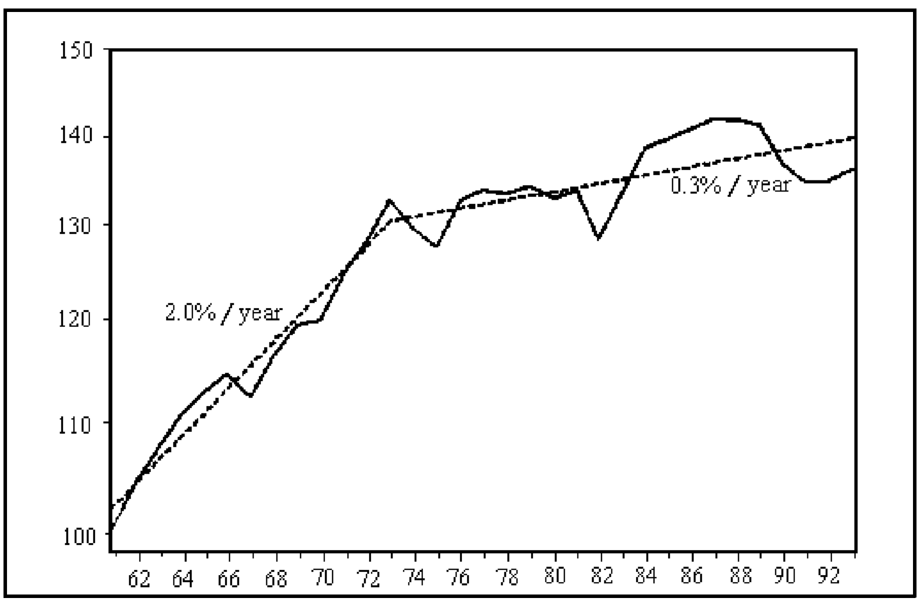

Chart 2
Total Factor Productivity
Estimated Business Sector Total Factor Productivity
Canada, 1961-1993 (1961=100)