Technology and economic growth :

a survey

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THE INFORMATION SYSTEM FOR SCIENCE AND TECHNOLOGY PROJECT

The purpose of this project is to develop useful indicators of activity and a framework to tie them together into a coherent picture of science and technology in Canada.

To achieve the purpose, statistical measurements are being developed in five key areas: innovation systems; innovation; government S&T activities; industry; and human resources, including employment and higher education. The work is being done at Statistics Canada, in collaboration with Industry Canada and with a network of contractors.

Prior to the start of this work, the ongoing measurements of S&T activities were limited to the investment of money and human resources in research and development (R&D). For governments, there were also measures of related scientific activity (RSA) such as surveys and routine testing. These measures presented a limited and potentially misleading picture of science and technology in Canada. More measures were needed to improve the picture.

Innovation makes firms competitive and more work has to be done to understand the characteristics of innovative, and non-innovative firms, especially in the service sector which dominates the Canadian Economy. The capacity to innovate resides in people and measures are being developed of the characteristics of people in those industries which lead science and technology activity. In these same industries, measures are being made of the creation and the loss of jobs as part of understanding the impact of technological change.

The federal government is a principal player in science and technology in which it invests over five billion dollars each year. In the past, it has been possible to say how much the federal government spends and where it spends it. The current report, Federal Scientific Activities (Catalogue 88-204), released early in 1997, begins to show what the S&T money is spent on with the new Socio-Economic Objectives indicators. As well as offering a basis for a public debate on the priorities of government spending, all of this information will provide a context for reports of individual departments and agencies on performance measures which focus on outcomes at the level of individual projects.

By the final year of the Project in 1998-99, there will be enough information in place to report on the Canadian system on innovation and show the role of the federal government in that system. As well, there will be new measures in place which will provide a more complete and realistic picture of science and technology activity in Canada.

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Introduction

Modern economies and firms invest an increasing amount on resources in research and development (R&D). These two activities are of different nature, but both contribute to technical progress. The first results of these activities is a set of intangible goods, basically knowledge, expertise and new designs for goods and equipment. These intangible goods usually materialize into new and improved products and superior process technology. **Process development** involves the creation and introduction of new technology typically embodied in new or improved capital equipment in production. Such technology rises productivity in firms, industries and the overall economy. Companies, thus, invest in process technology to compete through prices. **Product development** involves the creation of new or improved goods; companies invest in product development in order to secure competitive advantages, such as exclusive or superior products. Once established, new processes and products tend to be **diffused** to other firms; technology is at least partially a "public good": it is non-rival (it can be used by more than one user at a time) and only partially excludable (the owner has limited power to exclude others from using it). The original inventor, thus, can only keep the control of its novelty for a certain number of years. **Social returns** (or spillovers) then appear and justify government support for R&D. These social returns include lower prices for consumers, new and improved designs for competitors and higher general economic welfare.

However, one should not expect a strong correlation between expenditures in technology (whatever the measurement methods) and productivity growth. Several reasons explain this apparent paradox. The first reason is that a significant proportion of these expenditures are devoted to new and improved products, which are not captured by conventional output measures. Second, the national account system does not allow either for quality change, which is often the result of R&D. Third, due to inter-industry and international spillovers, some of the technological investments in one industry (or country) appear as productivity gains in another. Fourth, time lags complicate the measurement of productivity gains: new technologies must compete with existing capital equipment incorporating older designs; the diffusion of new products and processes may take decades before the full impact of the new technology becomes evident.

The objective of this brief non technical survey is to overview the fast growing literature on contribution of new technology to economic growth. It starts at the macroeconomic level, then it examines the contribution of new technology to economic performance of industries and firms. The emphasis is on relating empirical findings to the underlying theoretical framework and hypotheses.

1. Sources of macroeconomic growth

Over the period 1870-1979, Canada's output per person-hour grew by a factor of 11. This is slightly lower than the ratio for the US, more than the UK and much lower than Japan. What are the principal determinants of this growth?

The productive potential of an economy is determined by available resources and by how these resources are used. Economists use the concept of production function to describe the productive potential of an economy at the given time. Economic functions, however, are rarely at the frontier of its potential. Imperfect allocation of resources, unemployment of factors of production, poor economic and social organization are among reasons why in the real world the productive potential of an economy is never quite reached. The gap between the potential and actual product of an economy depends on its economic efficiency and social organization. The production possibility frontier itself is determined by the technology available to and mastered by firms and institutions of the given economy.

The size of an economy grows as more inputs (workers, machines, material inputs, energy, etc.) are used in production. The rate of growth of labor is generally constrained by the population growth. Since capital investment (machines, production equipment, buildings, etc.) is financed by savings, the growth of capital is limited by the willingness of the society to postpone consumption and save. Thus, if there were no change in transforming inputs into outputs, i.e. no technological change, economic growth in terms of GDP per capita would necessarily come to a limit determined by demography and willingness to save.

In fact, most of the growth of the standard of living, measured by GDP/capita, is the result of improvements in productivity. Productivity, is the relationship between the output and the inputs used in production and it measures the efficiency of the economy. The most common indicator is labor productivity e.g., value added per hour of work, or per person employed. It is however only a partial measure of productivity because its level and evolution over time depends on other factors of production, above all on the amount of capital used in production. As machines and equipment are substituted for labor, the labor productivity increases. A better measure than labor productivity is what economist call the total factor productivity, TFP. It is the ratio of an index of output to the composite index of all inputs used in the production process.

Since an economy is practically never at the frontier of its production possibilities, an observed change in productivity is a combination of a change in economic efficiency and a change- an outward shift- of the production possibility frontier, i.e. a change in technology.

To illustrate the point, Table 1.1 shows how Canadian economy grew in the last one hundred years.

Table 1.1
Productivity in Canada: Major Sub-periods
(Average annual Percentages)

	1891-1910	1910-26	1926-56	1961-73	1973-81	1981-88
Growth						
Output	3.38	2.46	3.89	5.9	3.6	3.6
Labour	2.31	1.25	0.77	1.9	2.1	1.8
Capital	3.82	1.47	2.86	5.0	5.3	3.2
Labour Productivity	1.07	1.21	3.12	4.0	1.5	1.8
Contribution of:						
Labour	1.82	0.98	0.58			
Capital	0.81	0.31	0.61			
TFP Growth	0,75	1.16	2.70	2.8	0.2	1.3

Source: Lithwick, 1971 reported as Table 2 in: Thomas J. Courchene and Douglas. D.Purvis, (Eds), (1993) Productivity, Growth and Canada's International Competitiveness. The 1961-1988 data for business sector in the Canadian Economy, from Andrew Sharpe, Measurement Problems and Productivity Growth in the Canadian Economy, paper presented at the Annual Meeting of the Société Canadienne de science économique, Grey Rocks Inn, Québec, May 17-19, 1990

A look at the table shows that in the first period, at the end of last century, the annual rate of growth of output (3.4%/year) was to a great extent due to a fast increase of labor (2.31%/year) and capital (3.82%/year). Labor productivity increase by 1.07% annually and when the increase of capital is taken into account, the total factor productivity increased only 0.75%/year. Thus at that period, most of the growth was explained by increasing labour and capital; productivity growth was not very important. In contrast, labor and TFP increased much faster in the 1961-73 period and then slumped at the beginning of the 1980s.

1.1 Explanations of economic growth

Even though it is important, technological change is not the only determinant of economic growth. From the very beginning, economists have recognized the importance of producing more efficiently.

Trade and specialization. In The Wealth of Nations, Adam Smith used the example of a pin factory to illustrate how the division of labour and the resulting specialization increases the productivity of workers. Division of labor and specialization are the sources of gains from trade, be it exchange between two individuals, two groups in the same region or country, or international trade. Examples of economic growth spurred by gains from trade abound: Dutch and British empires, Japan and, most recently the East Asian Tigers.

Diminishing returns? Malthus advanced in his theory that in a world of finite resources, growth has to come to halt. As population increases, the output of food per person declines, unless there is an offsetting influence to counter diminishing returns in agriculture. As history has shown, that dismal forecast was wrong. Population and food production have each increased dramatically. Discovery and invention kept Malthus' bleak prediction from coming true.

Scale or size effects. The increase of population, up to a saturation point, is leading to improved division of labour and decreased fixed costs for infrastructure, public services and so on. As the size of the population grows, resources for production of public goods and services (education, health, transport infrastructure, etc.) are saved and can be used for production of private goods and services and contribute to the growth of the economy.

Learning by doing and using (cumulative causation). Productivity increases with accumulation of experience and the quantity of output produced. In another terms, there is a learning curve; as the experience of production and /or the output of the same product increases, the unit production cost declines (Arrow, K., 1962). An empirical expression of this finding is the so called Verdoorn law predicting that productivity rises with the increasing rate of economic activity. Nicolas Kaldor (1966) developed these ideas formally into a growth model of cumulative causation. The model predicts that those regions-countries- that experience a strong growth of output will be increasing their lead relative to backward regions. According to Kaldor's model, we should not expect to observe a convergence between rich and poor countries. On the contrary, owing to externalities from learning by doing, economies of agglomeration, scale and scope, the gap will be widening.This is the exact opposite of the prediction of the neoclassical growth theory developed by Solow, which predicts convergence between rich and poor countries.

Investment. As the workers use more tools and machinery, their output increases. Investment, i.e. the increase in the stock of productive capital (machinery, equipment, buildings) has been an important source of economic growth of industrialized countries.

1.2 Models of economic growth

1.2.1 Neoclassical model of growth. In the 1950s, Robert Solow (1956) proposed a simple model in which the output of an economy is produced using labour and capital in a production process determined by the available technology at that time. Labour growth, the rate of saving and technology, were all supposed to be determined independently **outside** the economic system. Solow has shown that as the quantity of capital per worker grows, so does the output per worker. However, as capital per worker increases, the remuneration of capital declines and with it the scope for further increase of the capital labour ratio. Ultimately, the capital labour ratio approaches a constant and the productivity growth ceases.

When testing his model, Solow discovered that most of the growth of the US over the past one hundred years could not be explained by increased use of labour and capital. He attributed the unexplained "residual" to technological progress. In his interpretation technology is a free good, i.e. something that is accessible for everybody free of charge. There is no attempt to explain where it comes from or what it costs.

1.2.2 Growth accounting. After identifying that most of the growth is unaccounted for by the growth of conventional factors, many economists attempted to reduce Solowian residual by adjusting (augmenting) both labour and capital input measures to take into account improved education of labour and changes in age and quality of machinery and equipment. Progressively, other determinants of economic growth were included. Prominent among these is the **catching-up effect** that describes the advantage of being a follower country. They enjoy opportunities of backwardness, which means that over a considerable range of technologies they can emulate the leader - the United States - and, through diffusion of technology, achieve a given rate of growth with less expenditure for R&D. Japan is considered to have benefited more than any country from this effect in the "golden" period, from 1950 to about 1973. Structural change is another source of aggregate growth. As labour is moving from low productivity sectors and industries (agriculture, old, labour intensive manufacturing industries) to high value added industries and services, the overall productivity of the economy increases.

Other, less important determinants of growth include effects of foreign trade, economies of scale at the national level, the rise of energy prices, effects of natural resource discovery, hoarding and cyclical factors (capacity utilisation, labour hoarding). A simple example of growth accounting of the growth and the slow down in Canadian Labour productivity is presented in Table 1.2.

Table 1.2
Determinants of the growth and the slow-down of labor productivity, Canada, 1966-73 and 1974-85

	Growth				Slow Down	
	Business Sector		Manufac. Sector		Business	Manufac
	1966-73	1974-85	1966-73	1974-85	1966-73	1974-85
Productivity trend	43	118	45	70	-1	-9
Effect of foreign trade	5	16	17	28	0	-4
Domestic innovation	4	20	13	21	-5	-5
Real energy prices	8	-34	7	-18	32	62
Capacity utilization	18	-19	4	8	39	-5
Inter-industry transfers of capital and labor	8	-13	...	...	21	...
Substitution of factors of production	14	17	18	3	12	49
Real exchange rate	-1	-7	-4	-11	2	12
Total	100	100	100	100	100	100

Source: Conseil économique du Canada, *Agir ensemble, Productivité, innovation et commerce,* 1992, Ottawa, (Table 5) , translation by the author

When these methods of "growth accounting" are pushed to the limits, they may succeed in "explaining away" the residual but, this does not contradict Solow's conclusion that the technical change is the most important source of growth of productivity. Growth accounting distributes implicitly or explicitly technical change as increased knowledge and technical progress incorporated in improved skill of labour and in more efficient machinery and capital equipment. So we are back where we started: knowledge and technology (concepts often used interchangingly) remain, in growth accounting models, the principal sources of economic growth. One of the major problems of growth accounting is the decomposition of growth into independent factors, when in fact, there are several evident sources of interdependence between growth factors. The interdependence is crucial for correct analysis of growth. An excellent example of interrelatedness among growth factors is the need for a country to perform R&D in order to be able to adopt and adapt technology developed abroad. It is estimated that most of Japan's R&D in the 1960s and 1970s was devoted to the absorption of foreign technology.

Cumulative effects of R&D. Kendrick (1981) was the first to include among growth determinants a contribution to growth from cumulative investment in R&D. He also recognized that adoption and adaptation of technology from abroad may often require domestic R&D in order to develop the necessary absorptive capacity.

While Solow's approach is solidly rooted in neoclassical economic theory, growth accounting is an empirical method not necessarily constrained by any particular theoretical model. In attempting to explain the residual, its results depend, however, on arbitrary assumptions.

1.2.3 Endogenous growth. According to implications of Solow's model, one should observe a pattern of convergence of the rate of growth: advanced countries should experience a deceleration, developing countries an acceleration. While there is evidence of convergence among the select group of advanced industrialized countries, the gap between industrialized and many developing countries is widening. The neoclassical assumption of a freely and universally available technology is contradicted by the industrial reality of sharp technological rivalry; technology is far from being a public good and its creation is increasingly costly. Even though economic historians and students of technological change at micro-economic level (firms and industries) developed many realistic insights in economics of creation and diffusion of technological change, their findings were of partial nature and descriptive, and were not integrated in the main body of formal economic theory of growth until recently.

A series of articles published by Paul Romer (1986,1990,1994) and others in the mid 1980s broke the status quo. As the name of the new theory indicates, it recognizes that technological change is an endogenous, i.e. a byproduct of economic activity, as well as one of the fundamental sources of growth. New knowledge and new technology (the two concepts are often used as being interchangeable and loosely defined) is an output resulting from investing in human capital (education and training), employment of specialised labour (R&D personnel), equipment and material inputs. Even though it may involve a degree of randomness, in the sense that forces outside the control of the researcher determine whether the discovery is made, the aggregate rate of discovery is endogenous. When more people start experimenting with bacteria, more valuable discoveries will be made. The problems of measurement are recognized, their existence can not, however, invalidate the economic character of activities creating new knowledge and technology. R&D expenditures measure the value of inputs, alternatively, the labour input may be measured by number of scientists and technicians employed in R&D. The difficulty is how to measure outputs of research and development. Since most of new knowledge and technology is not sold on the market, there is no way to assign it a price.

The endogenous growth model that includes a rather realistic knowledge and technology creation mechanism assumes simply that the aggregate output of an economy depends not only on the amount of inputs employed by firms (labour, human capital, capital and R&D inputs) but also on the stock of results from research and development undertaken by all firms in the economy. These "spillovers" of new knowledge and technology are assumed to be freely available (scientific discoveries, and information in general are nonrival goods; many peoples and/or firms can use them at the same time). Contribution of these spillovers explains why in the model the total output of the economy grows faster than would indicate the use of inputs. In contrast to microeconomic studies where a similar model has been used since the 60s, the endogenous growth theory is concerned with a formal structure of relationships determining the long term growth of the whole economy.

The second important step towards more realism involved abandoning the unrealistic assumption that knowledge and technology are free and universally available. Important innovations are at least temporarily excludable. A good is said excludable if the owner has the power to exclude others from using it. Patenting and trade secrets are the common means to exclude others from using the new product or process in order to ensure that the innovator can appropriate benefits from his innovation. This gives the owner of the proprietary knowledge and technology a competitive advantage that can be turned into a higher price and monopolistic profits. This step towards competitive reality has been taken by endogenous growth models in which monopoly profits motivate innovation. The ongoing investment in R&D and resulting flow of innovations leads to steady improvements of quality of goods, and productivity increases keep the economy growing at a pace determined by the rate of investment into R&D.

The endogenous character of innovation means that the process is rooted within each country or region. Firms are the important actors in generating new technologies and their behaviour is determined on the one hand by the national environment and on the other hand by the increasingly global competition.

-The first aspect is recognized in studies of national system of innovation. The national system of innovation is a set of concretely functioning relationships between firms as technological generators and the institutional environment in which they exist. As described below, recognizing the particularity of national systems of innovation enhances our understanding of international differences in innovativeness.

-The second aspect is integrated in endogenous growth models that include international trade and global competition. Since this is one of the more interesting branches of endogenous growth theory, two of their unconventional implications are presented below.

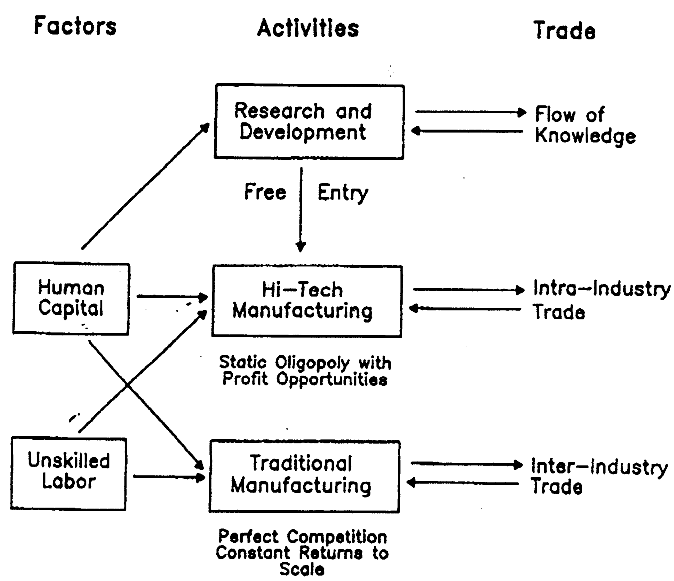
Foreign trade increases the profitability of R&D in a country if its firms can hold their own in the rivalry with foreign competitors. In contrast to classical precepts of free trade as the best solution for rapid economic growth, Grossman and Helpman (1994) constructed examples of cases in which closing off trade might actually increase a country's long-run growth rate.

The recent development in GATT negotiations suggest that these ideas have penetrated the policy making. Frustrated by their declining technological advance, the US sought to prevent their competitors, especially from Japan and the fast growing Newly Industrialized Countries (NICs), free access to the American technology. The US government obtained that rules against the breach of intellectual property be included in the Uruguay Round of GATT trade negotiations. This illustrates quite a turnabout in economic policy provoked by an awakening to the importance of technology as fundamental source of national economic welfare.

The structure of the Grossman-Helpman model is illustrated in Figure 1. It provides a theoretical underpinning to empirical research in international trade.

Figure 1.1

Structure of the Grossman-Helpman Model



Source: Siebert (1991)

1.3 Appreciative theories of technology and growth. The formal models of economic growth discussed above provide a theoretical underpinning for a more realistic representation of interaction between various aspects of technical progress and economic growth. Long before the theorists succeeded to formulate mathematical models of economic growth, economic historians and students of technological change accumulated and interpreted wealth of empirical evidence on specific aspects of technological change and its relationship to economic growth. To paraphrase Nelson, appreciative theorising is mostly expressed verbally and is the analyst's articulation of what he or she really thinks is going on. Both theoretical modelling and appreciative theorising work in harness, though not without significant time lags between their various analytical concerns. Theoretical economists are now trying to absorb the findings of an increasing amount of empirical research and appreciative theorising and incorporate a more realistic set of assumptions in their models. We now turn to appreciative theories regarding empirical evidence on the relationship between new technology and economic growth on the macro-economic level.

Schumpeterian growth. The first and still in many ways the most influential theory of technological change in economic growth was undoubtedly Schumpeter's (1942) theory of innovation as the engine of capitalist development. His theory of innovation was based on his definition of the "entrepreneur" as that individual (or group of individuals) responsible for the business decisions which lead to the introduction of new products, processes and systems or the opening up of new markets and new sources of supply. In his view, such innovative entrepreneurship was an act "not of intellect but of will" and this creative leadership was the source of the enormous dynamism in capitalist society. This lead him to concentrate attention on the more spectacular "heroic" types of innovation, which were identified with outstanding individuals, reflecting the business climate before the first World War. There is however precious little in Schumpeter's writings about the source of scientific and technical ideas, which were ultimately embodied in new products and processes. By conceptualising the process of technological change into a linear sequence: "invention => innovation=> diffusion" that dominated economic thinking about technological change until recently, he put the main emphasis on radical innovations and relegated invention and diffusion to a somewhat inferior status. Equally important, his emphasis on radical, path breaking innovations, did not allow him to recognize that the process of technological change is a continuous process of search and incremental leaning where small incremental innovations are often as important as the spectacular ones.

As far as the economic impact of new technology is concerned, studies of economic historians show that most of the productivity gains associated with the diffusion of new technology do not come as an immediate consequence of the first radical innovation. On the contrary, they usually are only achieved as a result of a fairly prolonged process of learning, of improving, scaling up and altering the new product and process.

Today, it is believed that Schumpeter's theory overstated the importance of path-breaking innovations and understated the role played by incremental innovation created in the process of technological change. Referring to Schumpetarian growth Mokyr (1990) defines technological progress: ".. as any change in the application of information to the production process in such a way as to increase efficiency, resulting either in the production of the given output with fewer resources (an increase in productivity) or the production of better or new products." Note that application of information does not necessarily means "new" information. Indeed much growth is derived from the deployment of previously available information rather than from generation of altogether new knowledge.

While it is a step forward to acknowledge the importance of incremental improvements in technological progress, it would be as step back not to recognize the importance of successive industrial revolutions spurred by radical innovations. A satisfactory theory of innovation, therefore, must embrace both the innumerable incremental improvements and the radical discontinuities.

1.4 Technological paradigms and revolutions. Some new technologies become "generic" in the sense that they open up a wide range of possibilities for further innovation in many sectors of the economy (Nelson and Winter, 1982). Other economic historians who observed the importance of inter-related innovations developed similar ideas about "systems", "trajectories" and "paradigms" (Dosi, 1982), Perez (1983, 1985). Economists conceptualize today technological progress as an interaction between demand for new products and processes and technology push, i.e. scientific and technical advances that make it technically possible and affordable to create new products and processes. Sahal (1985) and Perez go further. Sahal maintains that "technology both shapes its socio-economic environment and it is in turn shaped by it ». Perez develops the interplay between institutional change and technical change in her concept of "techno-economic paradigms". The productivity potential of a new "techno-economic paradigm" is at first realized only in one or a few leading sectors. Only when these effects have been clearly demonstrated, does the diffusion process begin to affect the whole economy. But, since what is involved is now a new infrastructure, many institutional changes, universal availability of skills, as well as new types of equipment and materials, there is inevitably a prolonged period of structural adaptation.

Freeman (1992) argues that the new "information technology" paradigm (according to some estimates, computer based capital equipment already accounts for between a quarter and a half of all new investment in plant and equipment in the USA) is explaining the productivity paradox. The ever increasing use of information technologies has so far failed to bring about significant increase in productivity. On the contrary, actual rates of productivity increase have declined since the levels achieved in the 1960s. To Freeman "the slowdown in average labour productivity gains over the 1970s and 1980s by comparison with the 1950s and 1960s is the aggregate outcome of a structural crisis of adaptation or change of techno-economic paradigm, which has accentuated the uneven development in different sectors of the economy."
In an attempt to explain why "we can see the computers everywhere but in the economic statistics" Paul David (1991) compares today's "computer revolution" with the "dynamo revolution" that marked the beginning of mass electrification one hundred years ago. The historical analogy is compelling, but it should not be overstated. He stresses also the significant differences between the two cases, the most important being that information as an economic commodity is not like electrical current. The direct measurement of production and allocation of information is very difficult and reliance upon conventional market processes very problematic. One of the practical consequences is that conventional productivity statistics are of questionable value when it comes to measure productivity change involving information technology and part of the productivity paradox may simply be related to bad measurement of productivity.

1.5 Technological gap and catching up. From the point of economic growth it does not matter whether income grows because of application of entirely new information to production or the diffusion of existing information to new users. In fact, as the experience post-war growth shows, many countries that started from a lower level of economic development benefited from a catch-up premium, i.e. that translates the economic advantage of being able to use and apply to own conditions technology developed at greater cost by the leaders in the field. However, there is nothing automatic in this process. Two variables influence the extent to which firms in countries that are technologically behind the leader are able to catch up. According to Abramovitz (1991) one of these was "opportunity" the other was "social capabilities." To illustrate the idea, before the World War II the US were the undisputed leaders in productivity, but there was little evidence of most other countries doing much of catching up. In mass production industries other countries with social capabilities (European countries and Japan) lacked the wealth of resources and the mass market supporting American mass production and barriers to trade foreclosed the possibility of replicating the US path on an international bases; the opportunity was not there until. The persistence of the lead of the US in high technology industries lasted until the European countries and Japan made the requisite investment in scientific and engineering education, and in the R&D, they lacked the "social capability" to catch up in these industries (Nelson and Wright, 1992 and Table 1.3).

Table 1.3
Sources of Convergence in Labor Productivity, 1960-88
(Differences in growth rates between follower countries and the US)

	1960-73	1973-88	Interperiod Change
US-Japan differences			
Labor productivity	6.6	1.9	-4.7
Capital per labor hour	2.0	0.6	-1.4
Total factor productivity	4.6	1.3	-3.3
Scale and intensity	0.6	0.1	-0.5
Other nontechnical sources	1.4	0.0	-1.4
Technical residual	2.6	1.2	-1.4
USA-OECD Europe differences			
Labor productivity	2.2	1.1	-1.1
Capital per labor hour	0.7	0.3	-0.4
Total factor productivity	1.5	0.8	-0.7
Scale and Intensity[a]	0.9	-0.5	-0.5
Other nontechnical sources[b]	0.5	0.0	-0.5
Technical residual	1.0	1.3	0.3

Source: Moses Abramovitz: “Catch-up and Convergence in the Postwar Growth Boom and After,” in W.J. Baumol, R.R.Nelson and E.N.Wolff,eds. (1994), *Convergence of Productivity, Cross-National Studies and Historical Evidence,* (Table 1.3)

One may add that the transfer of US technology through multinational enterprises, education of foreign students in US universities and, in the case of Japan, deliberate and systematic policy of licensing and borrowing Western technology, helped to speed up building of the social capability needed to catch up. Figure 1.2 shows the pattern of catching up in 15 industrialized countries relative to the USA.

Figure 1.2

Fagerberg: Technology and Growth Rates

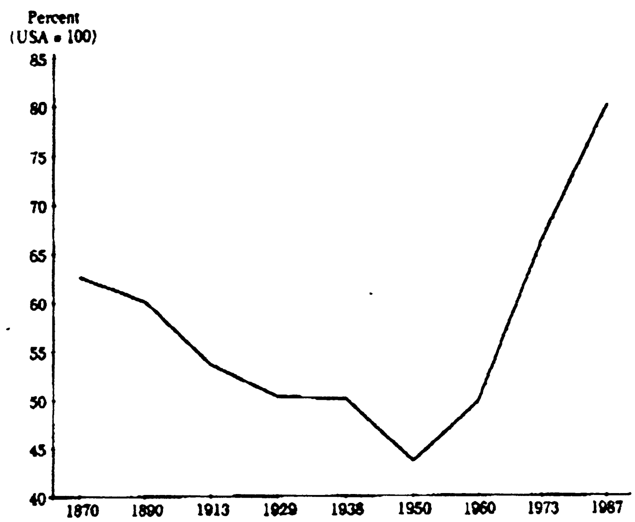


Figure 1. Catching up or Falling Behind? GDP per man hour in 15 Industrialized Countries Relative to the USA

Source: Maddison 1991, Table C.11.

The post World War II period became a "convergence boom" when many constraints that blocked-up catch up during the inter-war were gradually removed. Nelson and Wright (1992, p.1962) argue that national borders matter less today than before; that advanced nations of the world have come to share a common technology. In their view, the vehicle is the growing influence of the transnational corporations, aided by an increasing role for science (international) - as compared to learning (national and local) - in technology creation.

This interpretation of the present and vision of the future globalization is however not supported by empirical evidence. Patel and Pavitt (1991) analysed the technological activities of the world's largest manufacturing firms as reflected in patenting and found that: (1) the large firms carry most of their technological activity in their home country and (2) this activity is influenced by home characteristics. Porter (1990) came to a similar conclusion that the home nation factors acquire growing significance because they are the source of the skills and technology that underpin competitive advantage.

1.6 National systems of innovation. The concept of national systems of innovation entered the vocabulary of national and international policy makers engaged in the Technology-Economy programme (TEP) launched by OECD in 1988. When the outcome of this programme was summed up in Montreal in 1991, the concept, national system of innovation (NSI), was given a prominent place in the conclusions. The essence of NSI is to examine technological change as the joint outcome of innovation and learning activities within organizations, especially firms, and interactions among these and their environments.

Systems of innovation, thus, are sets of economic agents participating in the creation and development of new and improved products and processes (basically, innovative firms, public laboratories and universities), and the collection of flows that occur among these agents (informational, financial, personal or other) occurring within the borders of a national (or a regional economy) (Niosi et al., 1993). The central argument in this perspective is that, under similar general labels, different institutions may seek widely diverging goals and produce different results which may be more or less conducive to economic growth. Also, the flows of knowledge between institutions may vary widely from one nation to the other, depending on historical factors.

As Lundvall (1992) notes in his introduction to the volume devoted to NSI, the first explicit reference to the concept appeared in Freeman's (1987) book on Japan. The organization of R&D and production in firms, interfirm relationships and the role of government are at the centre of analysis which is both historical and based upon modern innovation theory. At about the same time Nelson (1988) presented studies of the US-system, where his analysis focused on the combined public and private character of technology and the role of, respectively, private firms, governments in the production of new technology. The two authors focus on different aspects of the system they study. First, Nelson concentrates more on institutional aspects of producing knowledge and innovation in the narrow sense, Freeman focuses upon the interaction between the production system and innovation. Second, Freeman applies a combination of organization and innovation theory to answer the question- which organizational forms are most conducive to the development and efficient use of new technology? Nelson's main theoretical tool is related to the law and economics-how well can different institutional set-ups take account of and solve the private-public dilemma of information and technical innovation.

The concept of national system of innovation seems to be contradicted by the ever increasing tendency to globalization. As Patel and Pavitt (1991) show, the globalization trend did not - (yet?) - eliminated strong attachment to a NSI. Porter also stresses the importance of the national home base for the competitiveness in the increasing global economy. One of the aspects of globalization on NSI is their increasing openness to various forms of international cooperation and networking.

1.7 Technology infrastructure. Social capability depends to an important extent on the technology infrastructure, which consists of science, engineering, and technical knowledge available to industry. Technology infrastructure (TI) includes generic technologies, infra-technologies, technical information, and research and test facilities, as well as less technically-explicit areas including information relevant for strategic planning and market development, forums for joint industry-government planning and collaboration, and assignment of intellectual property rights. TI includes industrial laboratories for testing and accreditation, standards and patent systems, networks of efficient techno-economic information sources such as specialised libraries and databases, public research and development institutes providing engineering and consulting services for small and medium size enterprises to name only the most important components. It is by definition a national system, even though its different components are increasingly connected to international networks. A characteristics of TI is that it depreciates slowly, but requires considerable effort and long lead times to put in place and maintain. It is provided by a variety of institutions-public, private and public-private combinations.

The rationale for building and maintaining TI stems from the recognition that owing to the existence of market failures, the private sector invests in creation and diffusion of new technology less than what is socially optimal. The most frequently discussed form of market failure is existence of "knowledge" spillovers, where the technical knowledge created in one firm "leaks" or "spills over" to competing firms without compensation. The other form are "productivity" spillovers, when the innovating firms sells the product at a price that does not appropriate fully the value of the improved performance or quality. The other forms of innovation related market failures are inherent technical risk, and time dependency. Any of the three types can cause a divergence between the rate of return expected by the potential innovator and the aggregate return that could be realized by the economy as a whole, once the technology is commercialized and penetrates the relevant markets.

In technology-based sectors of the economy, these markets failures can occur at two levels: (1) the overall level of R&D investment, (2) within specific categories of R&D. The first case of aggregate underinvestment can be removed by fiscal incentives. The second type can occur due to high technical and hence high commercial risk, long expected time to commercialization, intellectual property problems associated with the nature of early-phase technical knowledge development, and mismatches between the scope of market opportunities of the new technology and the existing market strategies of firms contemplating the R&D. Removing such market failures is critical to long-term growth because this early phase generic technology becomes the "technological base" for an entire industry and thus leverages subsequent applied R&D. Because an industry's technological base is drawn upon by a large number of competing firms within the same domestic economy, it has the characteristics of infrastructure. Even thought TI has micro-economic objectives, it is an important part of the National Innovation System and therefore discussed in this section devoted to the macroeconomic perspectives.

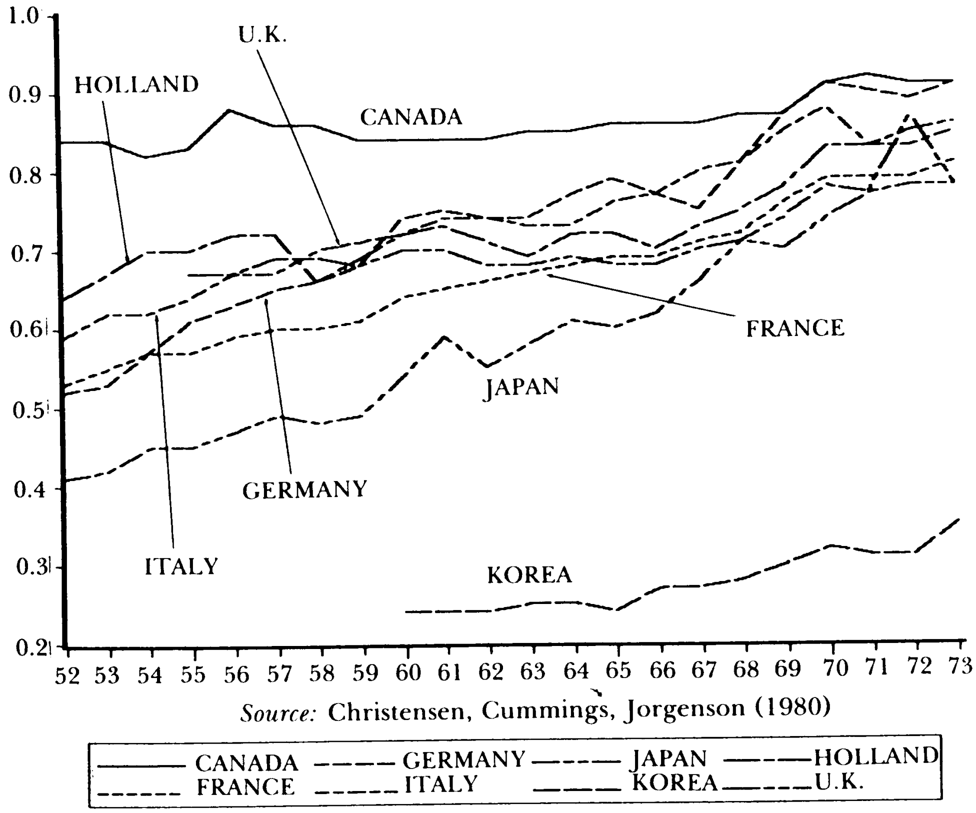
1.8 Empirical studies

A few recent empirical studies can be recalled at this time. They are selected among the many tests and reformulations of the above-mentioned theories

Studies of technological gap and catch-up. There is a growing number of empirical studies that try to explain the rate of growth of GDP, GDP/capita or GDP/worker by a combination of factors which typically include: (1) a catch-variable as a proxy for the gap in productivity and/or technology; (2) variables measuring attempts to reduce the gap, such as investment in physical and/or human capital and resources for innovation; (3) Other institutional, social economic and political variables assumed to affect growth.

The technology gap variables are mostly statistically significant determinants and so are the proxies for national innovation effort, see Fagerberg (1994) for a survey in Figure 1.3 . The methodological problem with many of these models is that the recent empirical work in this area is not able to discriminate between the competing theories. While there is a clear evidence of convergence in rates of growth among the industrialized countries, the picture is less obvious once the sample of countries is large enough to include most of developing countries. Still, when the many individual studies are put together, they convey a clear message: the potential for "catch up" is there, but it is only realized by countries that have a sufficiently strong "social capability" e.g, those that manage to mobilize the necessary resources (investment, education, R&D, etc.)

Figure 1.3: Total factor productivity relative to the US



Source: Fagerberg (1994)

1.9 The impact of R&D and technology diffusion on productivity growth. The number of empirical studies relating the innovation and knowledge creating activities to economic growth on the national level has recently sharply increased. On the one hand, it is a response to the intellectual challenge and opportunity provided by the endogenous growth theory and on the other hand a reaction to the productivity paradox. The studies falling in the first group are mostly concerned with the pattern of growth and convergence-divergence issue at the broadest possible international scale. Of more immediate interest to Canadian R&D community and policy makers are studies in the second group, that are focused on industrial countries that are actively pursuing R&D activities. A recent study by the OECD (1995) is probably the latest and the most comprehensive contribution in this direction. The study includes countries of the G7 group plus Australia, Denmark and the Netherlands and covers the 1970-1990 period.

Before analysing the relationship between technology and productivity, the study presents an overview of the growth and productivity performance in the 70s and 80s. The main result of the study is a decomposition of the observed GDP growth into contribution of labour and capital inputs, the reallocation of resources between sectors and the variation of total factor productivity within each country. In order to shed some light on the productivity paradox of the 1980s, the whole period is subdivided in sub-periods, corresponding roughly to peaks of economic cycles, so as to minimize the effect of variation in capacity utilization. The principal results for Canada by sub-period are presented in Table 1.4.

Table 1.4
Decomposition of Labour Productivity Growth*

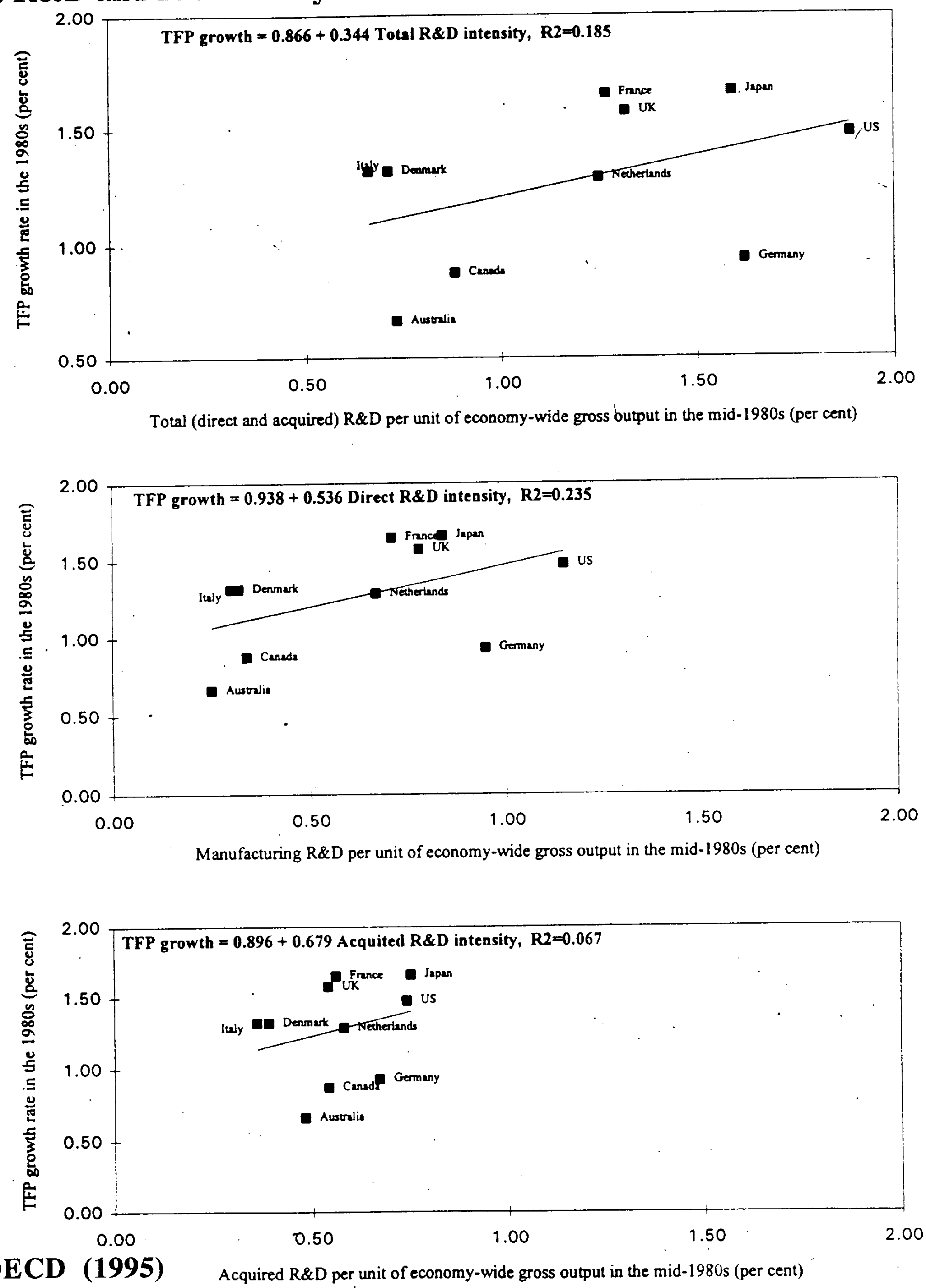
		Labour Productivity Growth	TFP Growth	Capital Intensity Change	TFP Contribution	GDP Growth	Labour Growth	Capital Growth	Capital Intensity Growth
Canada	1971-90	1.30	0.77	0.64	59.0	3.28	1.98	4.49	2.51
	1971-76	2.88	1.34	0.58	71.4	4.68	2.80	4.95	2.15
	1976-81	0.61	-0.03	0.68	-5.4	3.02	2.40	4.90	2.50
	1981-86	2.09	1.10	1.00	52.6	2.52	0.42	3.91	3.49
	1986-90	0.47	0.65	0.23	138.5	2.82	2.35	4.11	1.76

*)Estimates by Divisia aggregation
Source: OECD-STI (1995), Table 2.

They show that labour productivity in Canada grew at an average annual rate of 1.3% over the entire 1971-1990 period, it slowed in the second half of seventies, recovered at the beginning of the 1980s and slumped again in the late 1980s as more labour employment increased. A look at the sub-periods shows that the TFP growth in Canada slowed dramatically in the second half of the 1970, recuperated in the first half of the 1980s and fell again, even though not so dramatically as in the previous decade in 1986-1990. More than half of the growth over the entire period (0.59%) came from the contribution of increased total factor productivity (TFP) and the remainder is attributed to the increased capital intensity. The right hand side of the table shows the growth rate of GDP, labour and capital inputs as well as capital intensity.

The second part of the study addressed directly the role of R&D and of technology diffusion among industries in explaining productivity growth. Technology diffusion is captured by R&D embodied in production inputs (intermediate and investment goods) that are purchased domestically or from abroad. The results show that for the 1970s and 1980s the rate of return on R&D investment for manufacturing sector is about 15% . The rate of return of embodied R&D on services TFP growth was much higher (130%) in the 1970s and even more (190%) in the 1980s. The principal sources of such diffusion-based productivity gains in this sector were on the one hand the equipment investment for R&D intensive products and on the other hand the foreign procurement through imports. Canada is one of the few countries whose rate of return showed an increase in the 1980s and was 10 percentage points higher than that of Japan and the US in the 1980s. See Figure 1.4 for illustration of country observations of TFP growth regressed on direct R&D and embodied R&D.

Figure 1.4: R&D and Productivity Performance in the 1980s



Source: OECD (1995)

Part II Industry, technology and growth

Growth and key competitive advantages determinants differ according to industry. In activities like commerce, finance and personal service, technology plays a minor though an increasing role in growth. This is also true in several manufacturing industries, like food and beverages, tobacco, garment, textiles and leather products. In these areas, companies compete, grow and succeed mostly on the basis of major factors different from technology, like service quality (finance, commerce), advertising (food, beverages, tobacco), design (garment, furniture) and others.

2.1 Industrial differences in R&D behaviour

The propensity to conduct R&D varies widely from industry to industry. Manufacturing firms tend to conduct R&D more often than firms in other sectors of the economy. Within manufacturing, the high-technology industries (see below) show a higher propensity to conduct R&D than low-tech industries. Agriculture, construction, mining and finances seldom conduct any R&D (see Table 2.1). Within services, the R&D activity is mostly concentrated in a few areas, like computer, engineering and scientific services

Table 2.1
Number of R&D Performers, Canada, 1993

Industries	Number of performers	
Manufacturing (including machinery)	1570	
Machinery		223
Fabricated metal products		218
Other chemical products		123
Other manufacturing industries		119
Scientific and professional equipment		100
Food		95
Other electrical products		85
Plastic products		82
Electronic parts and components		65
Business machines		60
Services	2224	
Engineering and scientific services		605
Computer and related services		569
Agriculture, fishing and logging		101
Mining, oils and wells		50
Construction		74
Utilities		17
All industries	4036	

Source: Statistics Canada (1996): Industrial R&D Statistics, Ottawa

Not only R&D expenditures show wide differences between industries; these differences also are stable through time (Table 2.2). High-technology industries spend typically over 4% of their sales in R&D. These include aerospace (in which, in a 1980 average for the larger OECD countries, some 22.7% of sales was devoted to R&D), office machines and computers, electronic materials and components, pharmaceutical products, scientific instruments and electric machines. Industries with medium technological intensity include motor vehicles (2.7%), chemical products (2.3%), other manufacturing industries, non electrical machines, rubber and plastics and non-ferrous metals. In the low R&D intensity group (spending under 1% of sales) one finds building products (glass, stone and clay), food and beverages, shipbuilding, oil refining, ferrous metals, metal products, paper and printing products, wood products, textiles, shoes and leather products.

Table 2.2
R&D Intensity in the OECD Zone
(R&D expenditures as a percentage of sales)

1970		1980	
High technology		**High technology**	
Aerospace	25.6	Aerospace	22.7
Business machines, Computers,	13.4	Business machines, Computers,	17.5
Electronic Material	8.4	Electronic Material	10.4
Pharmaceutical products	6.4	Pharmaceutical products	8.7
Scientific instruments	4.5	Scientific instruments	4.8
Electrical machines	4.5	Electrical machines	4.4
Medium technology		**Medium technology**	
Chemical products	3.0	Automotive vehicles	2.7
Automotive vehicles	2.5	Chemical products	2.3
Other manufacturing industries	1.6	Other manufacturing industries	1.8
Petroleum refining	1.2	Non-electrical machinery	1.6
Non-electrical machinery	1.1	Rubber and plastics	1.2
Rubber and plastics	1.1	Non-ferrous metals	0.1
Low technology		**Low technology**	
Non-ferrous metals	0.8	Stone, clay and glass	0.9
Stone, clay and glass	0.7	Food, beverages, tobacco	0.8
Shipbuilding	0.7	Shipbuilding	0.6
Ferrous metals	0.5	Petroleum refining	0.6
Metal products	0.3	Ferrous metals	0.6
Wood, furniture	0.2	Metal products	0.4
Food, beverages, tobacco	0.2	Paper, printing	0.3
Paper, printing	0.1	Textiles, shoes, leather	0.2
Textiles, shoes, leather	0.2	Wood, furniture	0.2

Source: OECD, Technology and Economics, Paris, 1992, p.35

In Canada, the same basic industrial ranking prevails with respect to R&D, except for some differences which are specific to the Canadian industrial structure: aircraft and parts, telecommunication equipment, pharmaceutical products and business machines head the list of technology-intensive manufacturing industries (See Table 2.3). Computer and related services, and engineering and scientific services are the key industries among tertiary activities.

Table 2.3
GERD by Industry as a Percentage of Company Sales, Canada, Intentions, 1995

Industry	Share of GERD (%)
Telecommunication equipment	15
Aircraft and parts	11
Engineering and scientific services*	9
Finance, insurance and real estate	6
Other electronic equipment	6
Pharmaceutical and medicine	6
Business machines	5
All other industries	42
Total, all industries	100
Total, all industries (C$ Million)	6999

2.2 Industry and growth

Are high-knowledge industries different? One simple way to examine the effect of new technology on industrial growth is to compare performance indicators for industries ranked according to their "knowledge" content, on the basis of R&D, education and occupational data. The three groups - high, medium and low knowledge industries - show strikingly different performance on several accounts. First, the output, employment, investment and wages increased faster in high-tech industries than in the medium and low knowledge groups. High-knowledge industries are increasingly more open to international trade; they export more and at the same time they are also subject to more import competition. Not surprisingly, since they are R&D intensive and employ more educated manpower, they patent much more than the two other categories. Surprisingly, the labour productivity level and growth of the high-knowledge industries was marginally lower than that of the medium-knowledge group. This somewhat puzzling result could have several explanations, the most plausible reason could be that owing to high imports the high tech industry's pricing is constrained by foreign competition and on the other hand, it has to pay increasingly high wages to attract the needed highly qualified manpower. Be it as it may, the productivity paradox seems to be reappearing here and it should be a remainder that high-knowledge or high-tech is not necessarily always (or not yet) synonymous with supreme efficiency, see Tables 2.4 a....d.

Table 2.4a
Performance of Gross output at Factor Cost: 1981-1990

	Annual Growth Rate	Market Share 1981	Market Share 1990	Percentage Point change in market share	Market Share growth rate
	(percent)	(percent)	(percent)		(percent)
High-knowledge	3.6	16.0	17.1	1.1	6.6
Medium-knowledge	3.0	59.4	60.1	0.7	1.2
Low- knowledge	2.0	24.6	22.8	-1.8	-7.3

Source: Frank C. Lee and Handam Has,: A Quantitative Assessment of High-Knowledge Industries Versus Low-Knowledge Industries: Ottawa, Industry Canada

Table 2.4b
Performance of Employment: 1981-1990

	Annual Growth Rate	Market Share 1981	Market Share 1990	Percentage Point change in Market share	Market Share growth rate
	(percent)	(percent)	(percent)		(percent)
High-knowledge	2.7	12.1	13.3	1.2	9.9
Medium-knowledge	1.8	43.5	44.3	0.9	1.9
Low-Knowledge	1.1	44.4	42.4	-2.1	-4.6

Source: Frank C. Lee and Handam Has,: A Quantitative Assessment of High-Knowledge Industries Versus Low-Knowledge Industries: Ottawa, Industry Canada

Table 2.4c
Wages per hour: 1981-1990

	Wage Rate 1981	Wage Rate 1990	Annual Growth Rate	Relative wage rate ratio 1981	Relative wage rate ratio 1990
	($/hour)	($/hour)	($/hour)		
High-knowledge	17.9	30.2	5.9	1.59	1.60
Medium-knowledge	13.5	21.1	5.1	1.19	1.12
Low-Knowledge	6.6	6.6	6.0	0.58	0.59

Source: Frank C. Lee and Handam Has,: A Quantitative Assessment of High-Knowledge Industries Versus Low-Knowledge Industries: Ottawa, Industry Canada
Note:
1. Scientific and professional equipment is included in the low- knowledge group.

Table 2.4d
Labour productivity:1981-1990

	Labour Productivity 1981	Labour Productivity 1990	Annual Growth Rate	Relative productivity ratio1981	Relative productivity ratio1990
	($/hour)	($/hour)	(percent)		
High-knowledge	29.9	31.7	0.7	1.33	1.27
Medium-knowledge	30.08	33.6	1.0	1.37	1.35
Low-Knowledge	12.4	13.6	1.1	0.55	0.47

Notes:
1. Labour productivity is calculated as value-added per hour.
2. Scientific and professional equipment is included in low-knowledge group.
Source: Frank C. Lee and Handam Has,: A Quantitative Assessment of High-Knowledge Industries Versus Low-Knowledge Industries: Ottawa, Industry Canada

2.3 Econometric studies of the R&D--TFP relationship. There is a growing body of literature that provides solid empirical evidence for the R&D-productivity nexus in manufacturing industries in the US and to a lesser degree for other larger OECD countries (see Mohnen,1992; Bernstein, 1994; and Mairesse and Mohnen, 1990, 1995) for comprehensive surveys of econometric studies and their results). The empirical evidence for smaller countries such as Canada is, however, scattered and not yet always conclusive.

In their pioneering studies neither Lithwick (1969) nor Globerman (1972) could establish statistically significant association between the growth of productivity and R&D in Canada. Globerman argued that the R&D performed outside the user firm (industry), especially in home countries of foreign controlled firms, may be a more significant determinant of productivity growth of manufacturing industries than their own R&D. His empirical results (Globerman, 1979) failed to provide a convincing evidence in support of the hypothesis that foreign subsidiaries' presence in Canada contributes to productivity growth of Canadian-owned firms.

Postner and Wesa's (1983) study provided the first indication that in Canada, as in the US, productivity growth in manufacturing industries is better explained by a proxy variable approximating effects of R&D executed in other industries than by industry's own R&D activity. Hanel (1988) found also a positive and statistically significant association between Quebec manufacturing industry's change in labour productivity and both its own R&D and spillovers from R&D executed in other industries. More recently, Ducharme (1991) found statistically significant associations between the rate of growth of TFP, industry's own R&D and a series of proxies for R&D spillovers.

Longo (1984) and Bernstein (1988) found a statistically significant association between R&D and TFP for samples of Canadian manufacturing firms. They found a statistically significant positive relationship suggesting a rate of return on R&D investment in the range of 12 to 25%. The latter study also identified returns from R&D spillovers as being about twice as important as the return on own R&D.

Most studies come to conclusion that the private rate of return on R&D investment is significantly higher than the return on investment in machinery and equipment. The social rate of return to R&D is mostly larger than the private rate of return. Some industries generate significant gains in productivity to their customers in other manufacturing industries and even more so in services. Canadian results corroborate conclusions of earlier studies of the US manufacturing industries.

Mohnen's (1992) study was the first attempt to identify the effects of international spillovers of technology on the growth of TFP of the Canadian manufacturing sector. Owing to close trade and investment links between the two countries, the bulk of spillovers comes from the US. The results of the study suggest, however, that the effect of foreign spillovers on productivity growth may not be as strong as the effect of R&D performed by the industry itself. Hanel's (1994) results point in the same direction. On the other hand, a study using a different econometric methodology, suggest that foreign spillovers are potentially more important than R&D executed in Canada (Bernstein, 1994). There is an obvious need for further research in this area.

Since different studies of the R&D-TFP relationship were using different samples and time periods and at least two distinct methodologies, it is not surprising that there is little agreement as far as the size of the estimated return on R&D and on inter-industry spillovers. There can be no doubt today, however, that R&D at least in high-tech industries, contributes significantly to the growth of productivity not only in the industry performing R&D, but also in other industries. There are also indications, both from studies in the US and in Canada, that returns are higher for the process R&D than for the product R&D (Bernstein, 1994, Hanel 1994).

While there is growing evidence, especially from the US, that the R&D-productivity nexus exists, recent studies suggests that owing to externalities and measurement problems, the issue is more complex than previously believed. The main problem is that the statistical association between TFP growth and R&D is strongly affected by the inclusion or exclusion of the computer industry. The case of computers illustrates the fact that the measurement of productivity in industries undergoing fast product changes presents serious problems. The OECD (1995) study attempted to identify the return on R&D by industrial sector across all countries and received mixed results. Only the direct R&D performed in high-tech machinery sub-sector (electrical and non-electrical machinery, instruments, transport equipment and metal products) and in the information (finance and insurance), communication and transportation services was associated in a statistically significant manner with the rate of growth of TFP. In other subsectors the association was not statistically significant. This finding seems to corroborate Griliches (1994) and Hanel (1994) studies that show that once the computer industry is excluded from the sample, the R&D - TFP relationship collapses.

2.4 Technology and trade in industrial goods New technology impacts on trade directly in two ways. On the one hand, it is the main determinant of competitive advantage in industries producing high-tech products (computers, aicraft, scientific instruments and specialized machinery) on the other hand, it helps to reduce the production cost and improve quality of conventional goods. The latter effect makes it possible to reduce prices and increase the share in international market in those products which rely mainly on price competition. Prices remain an important but secondary consideration for commercial success on high-technology markets.

Since it was realized that an increasing proportion of international trade consists of exchange of products manufactured by industries performing intensively R&D, the so called high-technology trade became a major preoccupation of international economists and policy makers. Both the product cycle theory (Vernon, 1966) and the technology gap theory (Posner, 1961; Hufbauer, 1966) emphasize the inter-country differences in innovativeness as the basis of international trade flows. These theoretical hypotheses contradicted the tenets of the received international trade theory which postulated that technology is universally and freely available to all countries.

Empirical studies started to accumulate evidence showing that this basic assumption was not supported by the real world experience. By the end of the 1970s there was enough evidence indicating that countries performing more R&D export more R&D intensive (hi-tech) products than others. More importantly, it was also established that among high-tech industries, export performance of a national industry is positively correlated with its innovation input indicator - R&D/Sales or with an innovation output indicator like the share of patents in the given product category. One of the first examples of empirical evidence regarding the relationship between R&D and exports and innovation and exports in Canada was presented respectively by Hanel (1976), Mcguiness and Little (1981) and Hanel and Palda (1981). Soete (1981, 1987) summed up the international evidence.

A series of theoretical models developed by Krugman (1979) and Brander and Spencer (1985) integrated innovation and monopolistic competition formally in the "New" international trade theory". As we have seen in the first part of this survey, Grossman and Helpman (1991) provided the bridge to the endogenous growth theory.

Even though high-technology trade is growing faster than the overall trend of international trade, its importance has to be put into perspective. High-technology trade increased from 16% of total trade of all OECD countries in 1970 to 22% in 1986. It represented the highest share (more than one third) of total exports in the US, one third in Japan, 28% in UK and less in other countries, see Table 2.5 for details.

Table 2.5
High-technology exports as a share of total manufactures exports, selected countries,1970-86 (Percentages)[a]

Year	All countries[b]	France	Germany	Japan	United Kingdom	United States	Other	Europe[c]
1970	16	14	16	20	17	26	11	14
1975	16	14	15	18	19	25	11	14
1980	17	14	16	24	21	27	11	15
1982	19	18	18	26	24	31	12	16
1984	21	18	18	32	26	34	12	16
1985	22	19	18	32	27	36	13	17
1986	22	19	18	33	28	37	14	18

Source: Laura D'Andrea Tyson: *Trade Conflict in High-Technology Industries*
Note: a/ High technology products are those defined by the OECD as "high-intensity technology products
b/ Includes the remaining OECD countries (including Canada)

The catch-up phenomenon discussed in the first part of the paper is reflected also in the gradual change of high-technology trade. Even though the United States still dominate the world markets for these products, their share slipped from close to 30% in 1970 to about 20% in 1986.

On the other hand, Japan's share more than doubled and that of Asian NICs increased even more. More recent figures would undoubtedly show continuation of this trend. In spite of Canada's increasing R&D activity, her share of world export declined from 4.24% in 1970-73 to 2.65% in 1988-89, see Table 2.6.

Table 2.6
Shares of world high- technology exports, selected countries, 1970-89(percentages)[a]

Country	1970-73	1973-76	1976-79	1979-82	1982-85	1985-87	1988-89	Change 1970-89
OECD	95.57	93.93	91.52	88.79	86.80	85.40	83.64	-11.94
United States	29.54	27.36	24.37	25.07	25.24	22.29	20.64	-8.91
Canada	4.25	3.05	2.45	2.03	2.47	2.37	2.65	-1.61
Japan	7.07	7.54	9.21	10.06	12.93	15.03	16.01	8.94
EC-9[b]	46.38	47.50	47.48	44.14	39.26	38.60	37.38	-9.00
Germany	16.59	17.07	16.52	14.66	12.98	13.07	12.52	-4.08
France	7.22	8.06	8.78	8.10	7.26	7.07	6.80	-0.42
United Kingdom	10.12	9.47	9.70	9.87	8.45	7.54	7.64	-2.48
Italy	4.41	4.15	4.10	3.92	3.72	3.72	3.41	-1.00
Other EC- 9	8.04	8.74	8.38	7.59	6.84	7.20	7.02	-1.02
Greece, Portugal, Spain	0.50	0.65	0.71	0.85	0.91	0.98	1.12	0.62
EFTA[c]	7.56	7.53	7.06	6.11	5.53	5.88	5.57	-1.99
Non-OECD	3.99	5.64	7.61	9.29	12.03	13.70	15.03	11.04
Asian NICS	0.3	2.28	3.18	4.06	6.05	7.56	8.76	7.46

NICS =newly industrializing countries (Hong Kong, Korea, Singapore, and Taiwan)
a. Each number is average ratio of the country's or region's high-technology exports to total world high- technology exports. (Guerrieri and Milana classification) for each subperiod.
b. The nine member countries of European Community before the accession of Greece, Portugal, and Spain (includes, in addition to the four countries listed, Belgium, Denmark, Ireland, Luxembourg, and the Netherlands.
c. The countries of European Free trade Association: Austria, Iceland, Norway, Sweden, Switzerland, and (associate member) Finland.

Source: Laura D'Andrea Tyson: ***Trade Conflict in High-Technology Industries***, Institute for international economics, Washington, 1992

Since the competition in the high-technology industries is increasingly intense, even running faster than before is not enough to keep the initial position. In this context we have to ask whether it is important for a country to stay in this race, whether high-technologies matter for Canada's economic welfare. Tyson discussed the same question from the point of view of the U.S.. She advanced the following arguments:

- Development of high-technology industries generates spillovers to the benefit of the whole economy; social returns on R&D exceed private returns.

- These industries generate more employment and pay higher wages than the rest of the industry
- High-technology industries tend to develop innovation and knowledge locally and generate further development
- These industries are essential for national security
- They invest intensively abroad and at the same time, foreign R&D intensive firms in the US. This may be in advantage of both the country of origin and the host country as well, but Tyson discusses also the cases, when it may not be in the best interest of the host country.

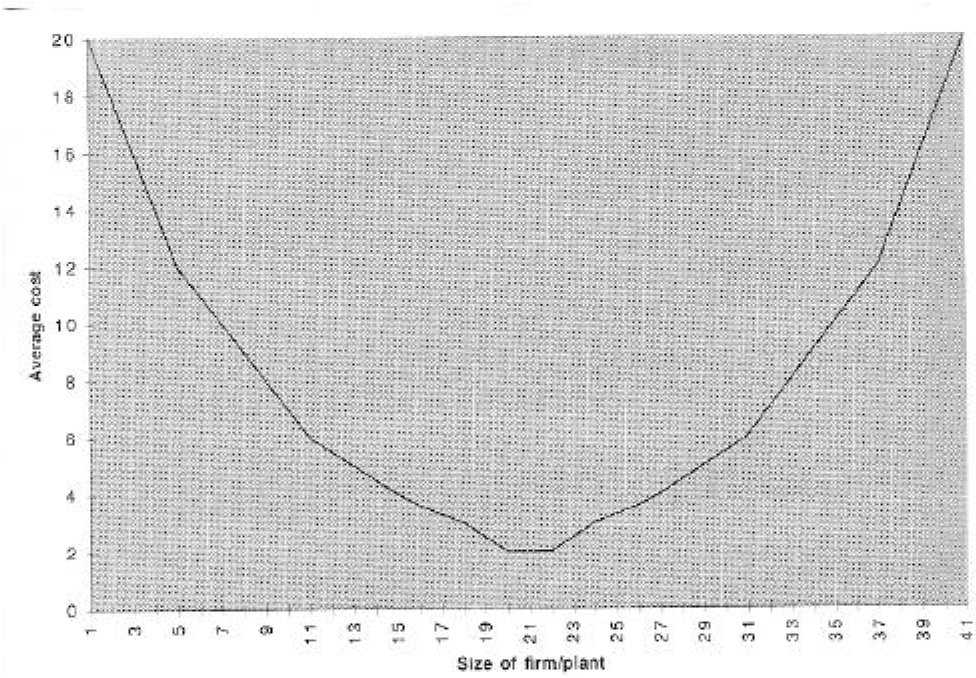
On a more general level, the high-technology competition is often of the type “the winner takes all.” Promotional and protectionist policies by foreign governments can harm domestic economic welfare by shifting industries with high returns and beneficial externalities away from domestic producers and domestic production locations. Conversely, comparable policies at home can improve domestic economic welfare, sometimes at the expense of other nations (Tyson, 1992). This being said, it is not obvious that government strategic policy of pickinning and helping prospective “winners” will actually help them to win. Japan, Korea are examples of an early success, some European initiatives, such as the supersonic Concorde, a costly fiasco. The often cited Airbus example has yet to earn profits, but it may at the end be profitable. The case for interventionnist policy is not a strong one, but there are historical examples and a theoretical rationale supporting the claim that under certain circumstances it could represent a better policy than the “laisser-faire” approach.

Part III. Technology and growth at the firm level

3.1 Main assumptions in economic and business theory and the growth of firms

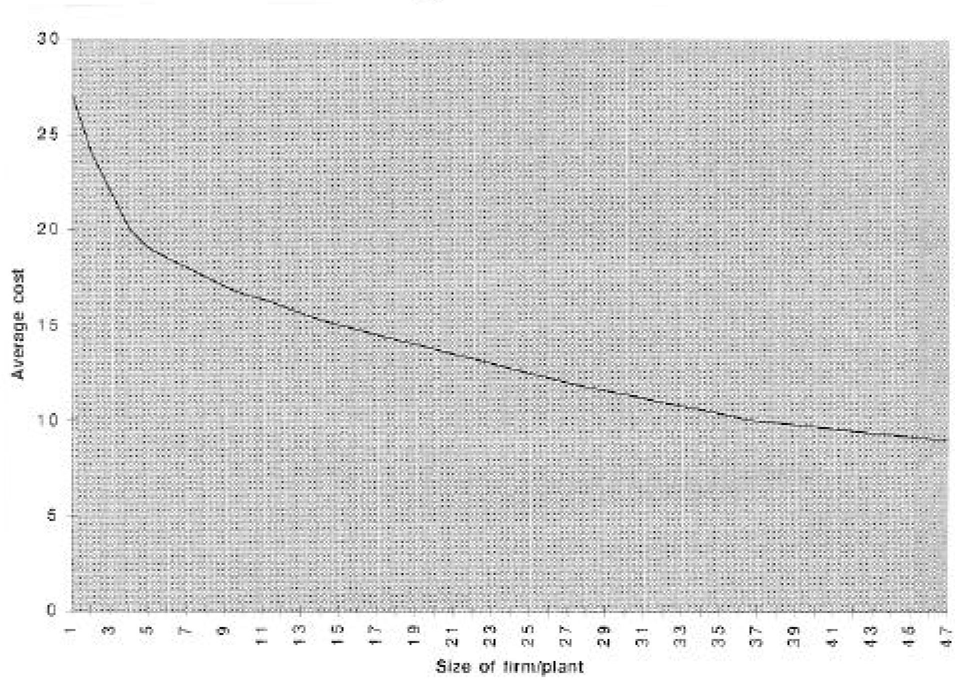
In neoclassical theory, the grow of firms is limited by technological factors, namely the "U"-shaped long-run average cost curve (see Figure 3.1). In this approach, firms could not grow over and above a certain size, as diseconomies of scale appear. Perfect competition and smaller firms would thus prevail in most industries. This neoclassical - and still prevalent - view in economics was attacked from several sides. Edith Penrose (1980) argued that there should not be technological barriers to the growth of firms, due to the existence of multi-plant operations; at the most, technology could be a barrier to growth at plant level. Penrose suggested that, in the long run, the most important obstacle to the growth of the firm was not the technologically-determined cost curve, but the availability of skilled managers, firm's difficulties in finding managerial services.

Figure 3.1
The U-Shaped Cost Curve



On the basis of the empirical observation that as the average size of the firm experiences continuous growth, a small but increasing number of economists argued that constant or decreasing returns to scale was not a realistic assumption. They suggested that increasing returns to scale was more appropriate (Arthur, 1994; Foray and Freeman, 1992), see Figure 3.2. If average costs decrease with the size of firms, then there is no end to the growth of the firm. This is an entirely different perspective from the neoclassical approach, one that is shared by an increasing number of industrial and evolutionary economists on the basis of their empirical studies. In this perspective, history matters: becoming first is important, as early entrants gain economies of scale and experience and may impose their standards and designs to the industry. Positive feedbacks (cumulative causality) increases the chances of a user to adopt a given technology if others have adopted it previously (as in nuclear reactors, software or VHS videocassette recorders). However, strategic mistakes of established firms and paradigmatic shifts (the appearance of new, competing technologies) can dislodge early innovators from dominant positions. Firm growth is not necessarily limited, and it depends on a certain number of factors, most important of which is the capability of entrants to impose - or to adopt - the dominant technology.

Figure 3.2
The Increasing Returns Cost Curve



At this point, diverging behavioural assumptions need to be recalled. In neoclassical theory, the successful firm is the one that enjoys high profits, as profits support both savings and investment. In this approach, profit maximization is thus the only goal of the firm. However, it has been shown, time and again, that firms display a variety of goals, not only short-term profitability. The Japanese firm, in particular believes in increasing returns to scale, and seems more interested in gaining market share and growing sales, even if it has to sacrifice short-term profits. Growth may also be promoted by managers in order to justify higher salaries, or to drive potential or actual rivals out of the market. One thing is clear, growth appears high among the goals of the vast majority of private firms.

3.2 Technological innovation is not the sole determinant of the growth of the firm

The growth of firms is determined by an array of factors. Organization is one of the most important. Alfred Chandler has convincingly argued that the development of organizational capabilities is a major element in the growth of firms. Successful enterprises move from centralized to decentralized management structures, as they increase the number of their products (Chandler, 1990). Firms unable to adjust their structures may experience lower growth rates.

Oliver Williamson argues that firms grow as the costs of conducting transactions through the market appear larger than the costs of conducting internalized transactions. Growth continues until the costs of hierarchical modes of organization encounter limits that force them to revert to markets (Williamson, 1975).

Managerial limits are according to Penrose (1980), the most important barrier to the permanent growth of the firm. In an empirical study on the rise of large firms in England, Hannah (1976) also found that administrative limits - and not technical obstacles - were the most important to the expansion in the size of firms.

3.2 Technological innovation as a determinant of growth

Technological innovation is usually seen as a key determinant of the growth of the firm, through its impact on product and process technology. Technological innovation allows firms to improve the quality of their products, to introduce new products on which the innovators have a temporary monopoly, or to modify products in order to exploit different niches and/or segments of a market. Also, technological innovation allows firms to reduce production costs and to enjoy higher profitability and penetrate new markets with lower-priced products.

In the 1980s, a sweeping movement to conduct technological alliances and collaboration has been observed between firms of all sizes, in all industrial countries (Niosi, 1995). The reasons for this new pattern in the organization of innovation are many, but reducing R&D costs and risks, accelerating innovation , coping with increasing complexity, bringing new products to the market and increasing market penetration are among the most important. While the statistical link between technological cooperation and growth has not been proved, it is well known that most technological alliances take place in high-tech, high-growth industries like electronics, advanced materials, pharmaceuticals and biotechnology.

In the following discussion, we differentiate between small and medium-sized firms and large corporations.

3.2.1 Small and medium-sized firms (SMEs)

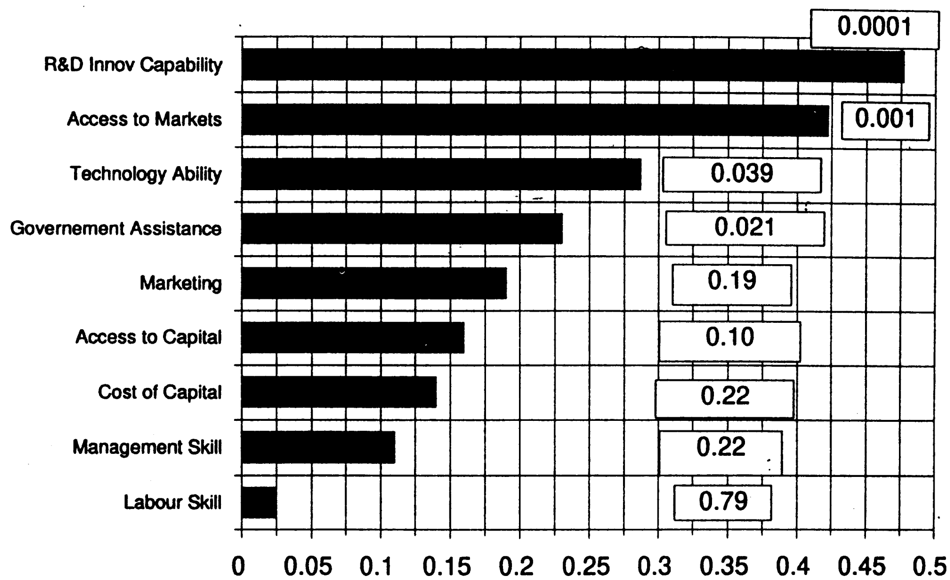
SMEs are less likely to conduct R&D than larger firms. However, their efficiency as R&D agents seems to be higher than that of larger firms, meaning that they tend to produce more patents and more innovations than larger firms by unit of inputs invested in R&D. Also, SMEs often conduct non-permanent R&D, using resources from different departments of the firm. Thus, official statistics tend to underestimate innovation in small firms (Kleinknecht and Reijnen, 1991)

Conversely, small and medium-sized enterprises experience more "turbulence" than larger firms. Turbulence is defined "as the extent of movements of firms within as well as into and out of an industry" (Acs and Audretsch, 1990:136). Also, their life expectancy is shorter than that of larger firms. R&D and technological innovation are factors explaining growth and longevity among SMEs.

A study on Canadian SMEs transferring technology abroad, showed that these companies, enjoying high sales growth, were also those that spent the most on R&D (between 18% and 21%) and having remained in business for very long time (between 20 and 24 years), were also those that spent most on R&D, approximately twice as much as the average Canadian firm operating in the same industry (Niosi & Rivard, 1990).

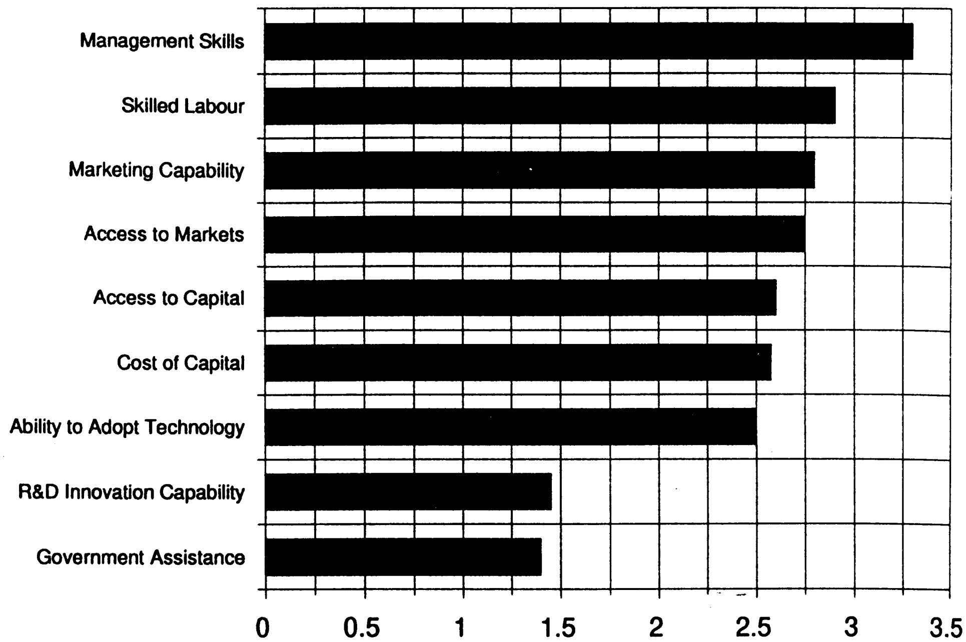
In a more recent study on Canadian small and medium-sized enterprises (under 500 employees) which had expanded their sales between 1984 and 1988, growth factors were analyzed. R&D innovation capabilities showed the highest correlation with growth (Baldwin, 1996) see Tables 3.3 and 3.4. The most successful firms were those that had enhanced their innovation capabilities and applied an aggressive innovation policy. More specifically, developing new technology was the strategy that characterized the most successful group, as opposed to the least successful group, the one that was using other's technology. Also, a larger percentage of the most successful firms were performing R&D and the intensity of the R&D effort was higher among the most successful SMEs.

Table 3.3 Success Factors in SMEs



Source : Baldwin (1996)

Table 3.4 Self evaluation of Factors in SMEs Growth



Source : Baldwin (1996)

3.2.2 Large and multinational firms

Technology is widely accepted as a key factor in the growth and internationalization of larger firms. For one, the propensity to conduct R&D is higher in larger than in smaller firms, following Schumpeter's later theory (Schumpeter, 1942). Also, large firms concentrate a very high proportion of any industrial nation's R&D effort. In Canada, the largest 100 companies concentrate 70% of the country's industrial R&D (Table 3.5). Several explanations have been advanced for this fact. Some research projects may be very large and only financially possible to larger firms. Also, R&D being a risky activity, larger firms may be able to diversify their research portfolio and thus reduce the risk of major research failures. Finally, larger firms may possess other complementary assets (marketing, manufacturing, legal, etc.) that permit them to better exploit the inventions stemming from their in-house R&D laboratories (Clark, 1987).

Table 3.5
Concentration of Industrial R&D among Companies,
Canada 1973 and 1995
(Percentage of total intramural expenditure for R&D)

Rank	1973	1995
Top 10	35%	33%
Top 25	51%	45
Top 50	64%	55%
Top 75	72%	61%
Top 100	77%	65%

Source: Statistics Canada: Industrial Research and Development, Ottawa, Cat. No. 88-202,1985

For two, process innovation in many industries (oil refineries, non-ferrous basic metallurgy, pulp and paper, electric power, and semiconductors) has tended to increase the size of the plants, and thus to increase the average size of the firms. In these industries, most of the R&D efforts of the large corporations is in the area of process R&D, and the goal is to obtain economies of scale and market power. This trend, however, is not general. In a few industries (i.e., steel production), conversely, process technology has tended to decrease the average size of the plants, and has facilitated the entry of new firms.

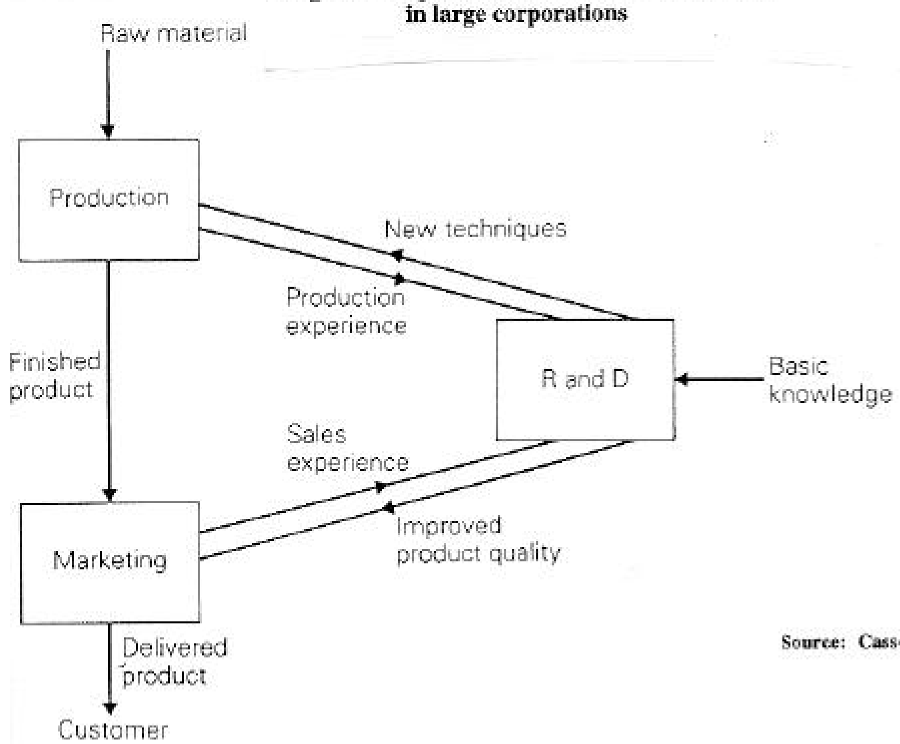
Also, the propensity to conduct R&D is much larger in multinational corporations (MNCs) than in purely domestic firms. The ownership of transferable intangible assets (the most important of which is technology) allows firms to enter into international production by means of foreign subsidiaries that can acquire and use those assets. These special technological assets are often the result of in-house research and development; thus, MNCs are often active in R&D. Some 40% of Canadian multinational corporations have been granted patents in the United States, as opposed to 4% of industrial firms operating within the Canadian borders (Niosi, 1996).

Within large, multinational corporations, R&D is often seen as a key determinant of the rate of growth of the firm:

"If a steady level of expenditure on R&D generates a continuous flow of knowledge then the consequent improvements on technology, product quality, etc., will steadily increase the firm's potential market (assuming a stable environment). This generates an 'acceleration' mechanism by which the *level* of R&D activity governs the *rate of growth* of production" (Casson, 1987:21-2)

Figure 3.6

Integration of production, marketing and R&D in large corporations



Source: Casson (198

4. Conclusion

Technology is seen, in the macro-economy as well as at the firm and industry levels, as a key determinant of growth. However, technology is not the sole determinant of economic growth. At the macro-economic level, the increase in the use of inputs (mainly capital and labour) explains a good part of growth in the national economies. The efficiency of institutions linked to technology (public laboratories, research universities and government programs supporting innovation) are also key determinants in the social capability that countries display in creating and using technology.

At industry level, technology is among the most important determinants in the growth of output. But industries differ in the use of technology. Low technology industries spend much more on advertising, design and marketing than on R&D, in order to increase sales. Medium technology industries are usually capital intensive ones, in which growth is mostly linked to investment in additional equipment, some of which incorporates new process technology. High-technology industries are those that invest more in research and technology, and are also those that experience the highest growth rates. Nowhere is the relationship between technology and growth more evident than in these new activities.

At the firm level, organization, managerial skills and technology are among the key factors in the growth of firms. For both large and small or medium size enterprises, high growth rates are strongly correlated with R&D investment. Technological strategy appears to be strongly correlated with growth at the firm level.

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Note: The bibliography includes several references not directly cited in the text but of interest to the reader. They are marked #.

Glossary

Diffusion: The spread of an innovation through a population of potential users, with or without modification, both nationally and internationally (Freeman et al., 1982)

Economies of scale: those that result when the increased size of a single operating unit producing or distributing a single product, reduces the unit cost of production or distribution (Chandler, 1990: 17)

Economies of scope: those resulting from the use of processes within a single operating unit to produce or distribute more than one product (Chandler, 1990: 17).

Invention: The first idea, sketch or contrivance of a new product, process or system, which may or may be not patented (Freeman et al., 1982: 201).

Innovation: The first introduction of a new product, process or system into the ordinary commercial or social activity of a country (Freeman et al., 1982: 201).

Patents (key): The most important patents in relation to a specific invention (Freeman et al., 1982: 201).

Research and development: Creative work done on systematic basis, in order to increase the cultural equipment, including man's knowledge, culture and society as well as the use of that knowledge to create new applications.

Basic research: Experimental or theoretical work, done mainly to acquire new knowledge about basic fundaments of remarkable facts, without considering any specific application or current use.

Applied research: Original research done to acquire new knowledge. It is, however, mainly focused on a specific practical objective.

Development: Systematic work done according to the existing knowledge obtained from research and practical experience, which is focused on material production, goods and services, implementation of new processes, systems and processes already implemented (Frascati Manual, OECD 1993: 19-45).

Total factor productivity : The residual of economic growth that can not be explained by the increase of the basic inputs, labour and capital, and is thus attributed to technological progress (OECD, 1992: 186)

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