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## Innovation and Productivity

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# INNOVATION AND PRODUCTIVITY

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## 1. Introduction[*]

Innovation is the transformation of new ideas into new and improved products and processes. The introduction and adoption of new processes and products ultimately enable consumers to enjoy a higher living standard because new and better products can be purchased at generally lower prices. Innovation seemingly improves society's welfare by making consumers better off.

The purpose of this paper is to survey and integrate the relevant literature dealing with innovation and productivity growth. The two concepts, although distinct, are connected, and both are the focus of a wide range of economic analysis, public discourse and government policy. Recent commentaries have highlighted Canada's stagnating productivity performance relative to that of the United States.[1] Various possible explanations have been suggested including a long-standing concern in Canada about the relatively small amount of research and development (R&D) carried out in this country. Other possible explanations for the poor productivity performance offered in public discussion and commentary include; i) government regulation, and the tax system, which retard incentives to undertake cost-reducing processes, infrastructure investment and the development of new products, and ii) the decline in the value of the Canadian dollar, which raises the cost for Canadian firms to import productivity-enhancing innovations.

The inclination of policymakers to promote innovation activities as an important component of economic growth strategies in Canada, and in other countries throughout the world, where a debate about the causes and consequences of innovation continues, and is foreseen to continue into the future. The relationship between innovation and productivity growth is conceptually complex and difficult to measure. However, the significance of innovation to society far outweighs the contribution of innovation to productivity growth. The evidence suggests that the average resident of a country where innovation has fostered enjoys higher income than does the average resident of a country in which innovation was impeded.[2] One interpretation of this result is that innovation improves a country's standard of living, but another might be that wealthier countries spend more on innovation. In fact both interpretations may be true.

[*] The author would like to thank Erwin Diewert, Andrew Sharpe, and Dennis Weisman for helpful comments and discussion on the issues addressed in this paper.

[1] See for example, Bernstein (2000a).

[2] See Rao et al (2000)

This paper proceeds in the following way. Section 2 sets out the conceptual framework for innovation. This section identifies knowledge as the basis for innovation, and discusses the relationship between innovation and the traditional production framework. Section 3 identifies and evaluates three fundamental proxies for innovation measurement; patent numbers, innovation counts, and research and development (R&D) spending. The section also considers the relationship between these alternative measures. Section 4 considers the distinctive features of innovation. For example, a firm introduces a new cost-reducing process, but it may not be able to prevent a rival from freely using this process. The "free-rider" problem implies that there are "spillover effects" from innovation activities. There is a substantial literature examining spillovers, which is briefly reviewed here. Section 5 considers the elements that determine the rate of innovation in an economy. This section reviews and synthesizes four major elements; intellectual protection, market competition, workforce skills, and international openness. Section 6 summarizes empirical studies of the relationship between innovation and productivity growth. This section looks at whether there is any temporal pattern in the observed link between innovation and productivity growth. The last section is the conclusion where the main messages of the paper are drawn together.

## 2. Innovation and Production

This section of the paper delineates the concept of innovation and the relationship between innovation and "conventional" production. Generally, innovation can be thought of as the introduction and adoption of new processes, and products. Although in the past innovation has been narrowly identified with product and process introduction, while diffusion has been identified with adoption, most observers now recognize that any distinction between introduction and adoption is arbitrary. Transmitting the new knowledge embodied in an innovation from one producer in a particular location to another producer operating in a distinct location is as important as creating the new product or process for the first time anywhere in the world. An innovation is useless to a particular producer in a specific geographical area unless the producer knows about the innovation. Moreover, since knowledge transmission typically results in adaptation, and thereby improvement, the adapted innovation can be thought of as a new innovation. Adaptation, accompanying transmission argues against distinguishing between introduction and adoption.

In order to understand the nexus between innovation and production, it is important to define innovation more precisely. At a particular time period and geographical area a producer transform inputs into outputs to serve its customers. For this area and time, producer knowledge is the set of feasible input-output combinations. Formally, economists refer to this knowledge as the production possibilities set. Innovation can then be defined as the set of new input-output combinations that are feasible in the geographical area, and in the current period compared to the previous period. Innovation is the growth or accumulation of knowledge. In formal terms it is an expansion in the size of the current period production possibilities set compared to the previous period's set.

Both process and product innovations are included in the above definition of innovation. Product innovations lead to outputs with new attributes or greater established attributes, while process innovations lead to inputs with new attributes or fewer traditional attributes, and improved organizational features associated with the complete "production and distribution process" incorporating all stages from input transformation into outputs, and output transportation to customers. Process innovations that are organizational are usually referred to as disembodied process innovations, while the remaining process innovations are embodied in the factors of conventional production. The distinction between a new product and an improved product is often one of degree rather than kind. New product attributes, which are synonymous with additions to the number of outputs, that is greater diversity, are often related to higher quality, as represented by a larger number of traditional attributes. For example, consider a product B that is created by bundling products A and C. If the market perceives that product B is a new product, then it may be willing to pay a premium over and above that which it would be willing to pay for products A and C individually. In other words, the whole may be greater than the sum of the parts. The bundled set of established attributes of B, contained within A and C separately, are considered by the market to be new attributes.

Often there is also no clear dividing line between a new process and a new product. For example, new processes often require the introduction and adoption of new products, such as new equipment, in order to be used. Nevertheless, new processes primarily lead to cost-reductions, whereas new products lead to additional cost and accompanying increases in revenue by offering customers new attributes or greater established attributes for the same (or lower) price as older products.

The introduction and adoption of new processes and products ultimately enable consumers to enjoy a higher living standard because new and better products can be purchased at generally lower prices. Innovation seemingly improves society's welfare, by making consumers better off. However, innovation is not a "free lunch". Resources must be expended to encourage innovation, but the presumed net result increases the standard of living. It might be noted that meaningful increases in living standards also arise from reductions in undesirable outputs in the economy, such as pollution, crime and disease. Hence, innovation does not have to be associated with traditional output expansion in order to improve society's welfare.

Innovation generates output supply-side effects through cost-reductions associated with process innovations and cost-expansions accompanying product innovations. Moreover, innovation influences the output demand-side of markets by offering customers new attributes or greater established attributes for the same (or lower) price as older products. It is difficult to underestimate the significance of innovation in propelling living standards. De Long (1998), summarizing the empirical data on standards of living, finds that, "The past six generations of modern economic growth mark the greatest break in human technological capabilities and material living standards since the evolution of language or the discovery of fire." Morck and Yeung (2000) find that a 1 percent increase in innovation, measured simply as the number of patents normalized by gross domestic product (GDP), leads to a 0.63 percent increase in a country's living standard, measured by per capita GDP. Further Rao et al (2000) document that a 1 percent increase in patents per million persons granted in the US lead to a 0.63 percent increase in GDP per employed person. In general, economies where innovation has fostered have prospered relative to countries in which innovation was impeded.

## 3. Innovation Measurement

Innovation involves the transformation of ideas into new products and processes, and consequently, like production, entails input-output combinations. However, unlike production processes, where conventional inputs are molded into established outputs, the innovation process utilizes such inputs as scientists, engineers, specialized equipment and structures, in order to develop new products and processes. The innovation process is inherently uncertain, whereas production processes are designed to eliminate any uncertainty.[3] Additionally, the innovation process is typically not undertaken independently from production. Management coordinates the creation and implementation of new products and processes in a manner that is integrated with established processes and products. Indeed, as Bernstein (1985) discusses, translating new ideas into new profitable products is a complex, dynamic and uncertain process.

The conceptual problems associated with the innovation process and the ensuing practical problems associated with innovation measurement make it difficult to conceive that a single measure would adequately reflect its complex nature. Consequently, various alternative variables are used.[4] However, there are certain variables that we can measure that will probably be positively correlated with innovation. The empirical literature on innovation most often uses one or more of three measures of innovative activity; i) patent numbers, ii) innovation counts, and iii) research and development (R&D) expenditures. The limitations of each are discussed below.

### 3.1. Patent Numbers

A patent is a temporary monopoly awarded to inventors for the commercial use of a newly invented device. For a patent to be granted, the innovation must be non-trivial, meaning that it would not appear obvious to a skilled practitioner of the relevant technology, and it must be useful, meaning that it has potential commercial value. As its definition suggests patents are output indicators of innovative activity. If a patent is granted, an extensive public document is created, which is an extremely detailed and rich data set. However, there are two important limitations of using patents (see Griliches (1990)). First, the range of patentable innovations constitutes just a subset of all innovation outcomes, and second, patenting is a strategic decision and hence not all patentable innovations are actually patented. As to the first limitation, consider for example mathematical equations. They could not be patented since they do not constitute a device (ideas cannot be patented). Additionally, a "marginally" improved product is not patentable because the innovation has to be non-trivial. Thus, patents do not capture basic scientific advances devoid of immediate applicability, as well as run-of-the-mill improvements that are too trivial to be accepted as distinct, codifiable innovations.

[3] Uncertainty arises in conventional production with respect to product demand conditions facing producers, and on the cost side through such things as climate. However, the process whereby traditional inputs are transformed into established outputs is known.

The second limitation is based on the fact that inventors may not apply for patents even though their innovations would satisfy the criteria for patentability. Firms may elect not to patent and rely instead on secrecy to protect their property rights.[5] In addition, there may be legislatively based reasons for not patenting. As Trajtenberg (2000) notes, until 1980 universities in the United States could not collect royalties for the use of patents derived from federally funded research. This limitation greatly reduced the incentive to patent results from such research, which constitutes about 90 percent of all university research in the United States.

Patent data can sometimes over represent innovation. Firms that have a new process, and that fear other firms may attempt to steal their innovation by finding a different process (which satisfies the patent office requirements) that circumvents the innovator's patent could engage in "patent thicketing". This involves filing patents on variants of the original patent, not because these are "substantial" innovations, but because they could block a competitor's attempt to circumvent the original patent. Patenting in these circumstances may be motivated primarily by a desire to increase the costs of entry facing potential rivals, in which case the major direct outcome of patenting activity is to generate monopoly profits rather than productivity improvements.

Simple patent numbers, even within a narrowly defined class, are a very imperfect measure of innovative activity, because patents vary a great deal in their economic "importance" or "value", and because the distribution of such values is extremely skewed. Recent research has attempted to overcome this difficulty by introducing patent citations as a proxy for the "importance" of patents (see Trajtenberg (1990)). Citations define the references to previous patents that appear in each patent. Patent citations serve an important function, since they delimit the scope of the property rights awarded by the patent. Thus, if patent 2 cites patent 1, it implies that patent 1 represents a piece of previously existing knowledge upon which patent 2 builds, and over which 2 cannot have a claim.[6] It should be emphasized that patent citations, as for patent counts, are

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[4] Since innovation is the change in the stock of knowledge, it is possible to measure the value of the stock of knowledge of publicly traded firms by subtracting the sum of net physical and financial capital from the equity market valuation. However, the problem exists of converting a value estimate into a real magnitude.

[5] Levin et al (1987), find a large variance across industries on the reliance of patents.

[6] As Trajtenberg (2000) notes, the applicant has a legal duty to disclose any knowledge of prior patents, but the decision regarding which patents to cite ultimately rests with the patent examiner, who is supposed to be an expert in the area and hence able to identify relevant prior patents that the applicant misses or conceals. Because of the role of the examiner and the legal significance of patent citations, patent citations may be less likely to be contaminated by extraneous motives in the decision of what to cite than other

dependent on the innovator actually applying for and being granted a patent. Consequently patent citations relate to the worth of a patent, but not to non-patented innovation outcomes. Moreover, if patent thicketing has occurred in order to foreclose competition by to increasing the costs of entry facing potential rivals, then "citation thicketing" results, because of the requirement to cite all relevant patents.

### 3.2. Innovation Counts

Innovation counts are lists of innovations made by various firms. They are usually constructed from large surveys. In principle innovation counts should be the best output data, because they measure all innovation outcomes, and survey organizers can apply similar rules in constructing data for different firms. However, in practice, innovation counting is often arbitrary, since the surveyors must decide what is an "innovation" and what is not. Simple innovation counts, even within a narrowly defined class, are an imperfect measure of innovative activity, because innovations vary in their economic value, and because, typically, the distribution of such values is extremely skewed. Moreover, it is even more difficult to determine the value of a particular innovation compared to discerning patent values, since a variable comparable to patent citations (although imperfect) does not exist for innovations.

### 3.3. R&D Spending

R&D expenditures are widely used as a measure of innovation. Whereas patent and innovation counts are output-based measures of innovation, R&D spending is an input-based measure. The main criticism of using R&D spending is that it measures innovation inputs, not innovation outcomes. The usual criticism runs something like the following from Morck and Yeung (2000), "We know that firms often invest money in unprofitable capital projects, so the possibility that must R&D spending might be wasted cannot be rejected out of hand." First, it is not clear why firms would knowingly waste R&D spending. Second, if by waste they mean a dollar of R&D does not translate into a dollar of innovation outcome, then their statement only implies that the

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bibliographic data such as citations in the scientific literature. Moreover, bibliometric data are of limited value in tracing the economic value of scientific results, since they are not linked to economic decisions.

marginal product of R&D to innovate is less than unity. However, there is no presumption in economic analysis that marginal products should be any number other than positive.[7]

This criticism is misplaced. As noted, innovation processes, like production processes, involve multiple inputs and multiple outputs. It is well known (see for example the textbook by Varian (1992)) that production processes can be summarized by either a production function, which is output-based, or a requirements function, which is input-based. Both functions characterize the same process. In practical terms the choice over an output-based versus an input-based representation rests on data availability and not on conceptual correctness. Of course there may be limitations to the R&D data as an adequate input measure, but that is a measurement issue, in principle input-based measures, as well as their output counterparts, are similarly able to represent innovative activity.

R&D spending today leads to innovation outcomes in the future. Consequently it is accumulated R&D spending that causes new processes and new products. R&D spending leads to a durable input, i.e. one that lasts for more than a single period, which in turn generates innovation outcomes. In this sense R&D spending is like investment expenditures on plant and equipment capital. Accumulated investment contributes to plant and equipment capital, which is an input used to produce established outputs. Hence, as for other forms of investment, R&D spending must be converted from value terms to real or inflation-adjusted terms and real R&D spending must be accumulated over time. This calculation leads to the construction of "R&D capital", a more appropriate input-based indicator of innovative activity than R&D spending. As described, two particular challenges complicate the construction of R&D capital stock measures: 1) determining the appropriate price index for R&D spending, and 2) determining the appropriate depreciation rate for historical R&D expenditures.[8]

The close link between output-based measures and input-based measures of innovative activity has been established for a number of countries. Griliches (1990) surveys this literature and finds that there is a strong and contemporaneous relationship between patents and R&D spending. Recently, this relationship was investigated for Canada by Trajtenberg (2000, p.9) who found that, "Regardless of the "race" between regressors, the fact is that innovative output in Canada, as reflected in the number of patent applications filed in the United States, seems to be highly

[7] Firms need an incentive to waste. One incentive may arise from the legislative or regulatory regimes under which they operate.

responsive to civilian R&D performed 2-3 years earlier. Thus, fluctuations in the level of R&D resources invested do manifest themselves after a while in the number of patented innovations produced."[9] This result is also confirmed by Rao et al (2000) who find for the years 1995 and 1997 that a 1 percent increase in R&D personnel per 1,000 population led to a 0.8 percent increase in patents granted in the US per 1 million inhabitants by OECD countries. Thus input-based indicators appear to be as valid as output-based indicators of innovative activity. In practical terms the choice of indicator thus rests upon data availability. As Globerman (2000) recognizes, observing organizations performing relatively small amounts of R&D does not necessarily suggest that R&D is unimportant to innovation outcomes. Rather, it might suggest that conventional measures of R&D are poor proxies for the actual rate of knowledge accumulation. Even more significantly, Trajtenberg and Rao et al show that Canadian innovation output is the outcome of R&D spending. Just as there is no free lunch in the production of established outputs, the lunch bill must be paid in order to garner the fruits of new processes and products.

## 4. Innovation as a Public Good

The value of an innovation to a firm is based on that firm having proprietary knowledge about how to make a cheaper or better product. However, knowledge, and thereby innovation which is the growth or accumulation of knowledge, is different from ordinary commodities in two ways. First, knowledge can be used, or consumed, by a producer or consumer without reducing its availability to other producers or consumers. Put differently knowledge possesses the feature that it is nondepletable or nonrivalrous. This is the so-called "publicness" feature of knowledge, and so it is classified as a public good. Typical commodities do not have this publicness characteristic and are called private goods.

Intermediate cases between private and public goods are also possible in which the use or consumption of the good by one producer or consumer affects to some degree its availability to others. A classic case is the presence of congestion effects on roadways. For this reason, goods for which there is no depletability or rivalry are referred to as pure public goods. Indeed knowledge may not be a pure public good. For example, as Morck and Yeung (2000) note, "If

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[8] Griliches (1979), Bernstein (1985), and Mohnen (1992) discuss these issues further.

[9] The patent data relates to Canadian patents granted in the United States, which is a much larger number, and therefore more representative of innovative outcomes than Canadian patents granted in Canada.

one person devises a better way of producing widgets, the same technique can be used in every widget factory without any physical harm to its use on the innovator's factory. This is true until the increased use of the innovation starts to drive up the costs of any special inputs it requires – for example, skilled workers trained to operate new equipment."

A distinction can also be made according to whether exclusion of a consumer or producer from the benefits of a public good is feasible. Every private good is excludable, but public goods may or may not be. The patent system, for example, is a mechanism for exclusion, albeit an imperfect one, from the use of knowledge developed by others. These public good characteristics are the first way in which knowledge, and consequently innovation outcomes, differs from ordinary, or private, goods

The second feature of public goods is that they can generate nonconvexities, or increasing returns to scale in production. Intuitively, a public good affecting a production process of a private good, can be thought of as an input into the private good production. From the viewpoint of the private good producer, the public good is in fixed supply since public goods are nondepletable. The fixed input, consequently, is a source of fixed cost. As the scale of operations increases, fixed cost is recovered over greater sales and consequently the impact of this cost on profit diminishes. Therefore the return on sales increases with the scale of operations, and production is said to exhibit increasing returns to scale.

In the context of innovation, increasing returns to scale presents itself since typically the major costs of creating an innovation are often up-front costs. For example, Gambardella (1995), notes that about 30% of a pharmaceutical firms costs relate to clinical testing, while 50% relate to pre-clinical research, which occurs a decade before marketing. Production and marketing costs are typically 20% or less. This means that, when a new product is available for sale, most of its costs are already sunk, and the marginal cost of producing another tablet of a new medication is typically very small. Since patent laws give the innovator a temporary monopoly over the medication, the innovator can charge a price that exceeds the cost of production. Therefore, the more tablets the innovator produces and sells, the greater its profit.[10]

[10] Caves (1982) also provides an overview of this topic as it is applied to the determinants of innovation.

Market solutions are likely to work poorly in the case of pure public goods, and perhaps in cases of public goods generally. Market failure can occur if a firm introduces a new cost-reducing process may not be able to prevent a rival from freely using this process. Solutions to this “free-rider” problem involve quantity-based intervention (government provision, legislation or regulation) or price-based intervention (government taxes and subsidies). For example, an innovation is protected by patent laws, which are designed to prevent (albeit imperfectly) others from free riding on an innovator’s new process or product. Other firms may be able to use the new process, or sell the new product the innovator developed, but they must pay a license fee.

The free-rider problem that emanates from the public good characteristics of innovation prevents firms from completely appropriating the benefits from its innovation because innovators are unable to entirely exclude others from using the innovation. The free-rider problem, and consequent unappropriated benefits mean that there are “external, or spillover, effects” from the innovation activities of one firm on others. A spillover, which may be thought of as new process or product created by one individual or organization that is appropriated by others without compensating (fully or at all) the creators for the value of the innovation appropriated. An implication is that the benefits to society from an innovation extend beyond the (private) returns appropriated by the innovator. The returns to society, or social returns, relate to the benefits from innovation use, while private returns only capture the benefits from the initial innovation creation. Typically, spillovers associated with innovative activities generate social rates of return that exceed private returns, because the impacts of innovation activity may extend over a much broader range of organizations than those performing the bulk of the R&D, patenting and related activities.

There is a substantial literature examining the extra-private returns from spillovers, as well as the elements conditioning the magnitude of those spillovers. This literature is briefly reviewed here, and Globerman (2000) forms the basis for this review. Before undertaking the review, it is worth emphasizing the point made by Globerman that spillovers are of special relevance to Canada. In particular because the presence of relatively high degrees of foreign ownership has been linked to relatively low R&D intensity levels in Canadian manufacturing industries. Those who believe that tighter controls on foreign ownership are in Canada’s economic interest, in turn, have linked low R&D intensity to Canada’s “poor” record on innovation and productivity growth. On the other hand, proponents of a noninterventionist foreign ownership regime argue that foreign-owned companies are a robust source for importing new processes and products, and therefore reduce the need for Canadian companies to undertake costly indigenous R&D.[11]

There have been two broad approaches to identifying the sources and effects of spillovers. One based on econometric models, the other on case studies. The literature review in this section will give separate consideration to econometric and non-econometric evidence. The primary focus of the review will be to amalgamate findings with respect to the following issues: 1) the private and social rates of return to R&D and other measures of innovation; 2) the private and social rates of return to different types of R&D and innovation, e.g. basic versus applied; government-funded versus privately funded; undertaken by for-profit or not-for-profit (including academic) organizations; and 3) the sources of spillovers, e.g. foreign R&D versus domestic R&D. A second focus of the review is to summarize the findings on these issues for Canada and to identify and explain, if possible, any distinctive differences between the Canadian and non-Canadian experiences.

## 4.1. Econometric Studies of Spillovers

These studies encompass statistical analyses of the linkages between output, or cost, or productivity measures with the factors of production and measures of innovation.

### 4.1.1. Canadian Evidence

Bernstein (1988) provides econometric evidence on private and social returns to R&D in Canada based on firm level data for a set of industries. He identifies the relative and absolute importance of spillovers through the fact that social rates of return to R&D investment are substantially higher than private rates of return. In fact, inter-industry spillovers are relatively small for all of the sample industries. Conversely, intra-industry spillovers are relatively large, particularly in industries that have a relatively large R&D spending propensity.[12]

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[11] Globerman (1985) reviews this debate. Evaluation of the two competing positions requires evidence on the magnitude of the returns to indigenous and foreign-sourced innovation, as well as an assessment of the impacts of ownership on each.

[12] The inter-industry spillover variable is defined as the sum of the R&D capital stocks for all other industries lagged one period. The intra-industry variable for any corporation in the sample industry is defined as the sum of the R&D capital stocks of all rival firms in the same industry, lagged one period.

The orders of magnitude are as follows: the social rates of return to R&D capital (net of depreciation) in industries with a larger R&D spending propensity are slightly more than double the 11.5 percent net private rate of return. Social rates of return to R&D capital in other industries are somewhat less than double the net private rate of return.

Bernstein also provides some evidence on the relationship between R&D spillovers and R&D performance in his sample. Specifically, inter-industry spillovers act as a substitute for the R&D capital input of the firm itself in every sample industry. The effect is quite pronounced, especially in industries with a relatively low propensity to spend on R&D capital. The intra-industry spillover effect on the performance of "own" R&D is smaller in absolute value than the inter-industry spillover effect. In industries with a relatively low R&D propensity, R&D spillovers discourage the performance of own R&D. In industries with a relatively high R&D propensity, there is a complementary relationship between intra-industry spillovers and own R&D performance.

Bernstein does not identify the specific channels through which spillovers occur, and he mentions this as an important focus for extending his work. It is perhaps suggestive that in the five industries where there is a significant difference between Canadian and foreign-owned firms' response to intra-industry spillovers, the unit costs of foreign-owned firms decrease relatively more than those of their Canadian counterparts. This result suggests that foreign direct investment may be an especially robust channel for intra-industry technology spillovers.

In a related study, Bernstein (1989) identifies the R&D spillovers from one Canadian industry to another. Nine separate manufacturing industries are examined for the period 1963–83. He finds substantial variation across receiving countries with respect to the number of industries generating spillovers. As well, spillover elasticities for the receiving countries were significantly different from each other. All nine industries had consistently high private returns to R&D, and social rates of return substantially exceed private rates of return. Industries with a relatively high R&D intensity did not necessarily have a higher rate of return on R&D capital. Nor were they consistently the major sources of R&D spillovers.

In a more recent study, Bernstein (2000b) focuses on spillovers associated with R&D activity in the communications equipment industry. He finds substantial spillovers from this industry to the entire Canadian manufacturing sector. In terms of relative importance, however, the R&D

spillovers from the U.S. manufacturing sector have a greater impact on Canadian manufacturing factor intensities than spillovers from the domestic communications equipment industry. This study further underscores the importance of international technology spillovers to Canadian industries. The important spillovers from the Canadian communications equipment industry are underscored by the differences between the private and social rates of return to R&D in that industry. Specifically, the social rate of return to Canadian communications equipment R&D capital is estimated at 55 percent, or 225 percent higher than the private rate of return.

Mohnen (1992) reviews a number of Canadian and non-Canadian studies of the returns to R&D and presents some original econometric evidence. Mohnen tends to confirm that social returns to R&D are substantially higher than private returns, and returns are higher on company-financed R&D than on publicly financed R&D. The latter result underscores the indirect contribution of publicly financed R&D, i.e. it is a complement to privately financed R&D.

#### 4.1.2. Non-Canadian Evidence

Griliches (1998) summarizes the results of extensive econometric studies of rates of return to privately and publicly funded R&D in the United States. These returns tend to cluster in the range of 18 to 20 percent. He highlights the fact that there is no differential return between federal versus private company R&D dollars at the firm level, although differences are evident at the industry level. It is suggested that the latter result reflects the differential rates of government R&D funding across industries. To the extent that government funding is concentrated in areas where private funding would otherwise be “excessively low” from the perspective of social efficiency, perhaps because the returns to R&D are particularly difficult to appropriate in those areas, differences between returns to privately and publicly funded R&D should be expected. The studies almost uniformly show substantial and significant returns to own R&D. Estimated rates of return are in the 30-40 percent range, which is consistent with Bernstein and Mohnen.

The difficulty with identifying returns to own R&D and R&D conducted outside the organization is that own R&D may enable the organization to better exploit available R&D spillovers. Studies tend to show that the interaction between a firm’s R&D stock and R&D spillovers is generally significant. What is less well established in the literature is how the nature of internally performed R&D affects the ability of an organization to benefit from spillovers. For example, is applied research more complementary to spillovers than expenditures implementing new processes? The issue seems especially relevant for Canada, given the prominent contribution of foreign spillovers to cost-reductions in this country. Some evidence from Griliches (1998) suggests that returns to R&D vary with the nature of the R&D undertaken. For example, the rate of return to basic research is higher than the rate of return to R&D expenditures.

## 4.2. Case Studies

Case studies of specific innovations provide another approach to examining the social and private returns to innovation. Such case studies are subject to the familiar criticism that their results cannot necessarily be generalized. However, they tend to be consistent with the outcomes of econometric studies.

Mansfield (1996) summarizes a number of major case studies of industrial innovations including some of his own work. The innovations identified primarily took place in manufacturing industries. Many of the innovations studied were of "average" importance, so as to avoid the obvious bias of focusing on particularly successful innovations. While social rates of return vary across innovations, they are generally in the range of 30 to 50 percent. Typically, these estimated social rates of return are substantially higher than the corresponding private rates of return, and the gap is especially pronounced for major innovations.

Griliches (1998) summarizes several other case studies, particularly those focused on government-supported innovative activities. These studies also confirm the existence of very high rates of return to innovation. For example, the rate of return to R&D expenditures by NASA is about 40 percent per year in perpetuity. This is more than double the rate of return to all other types of R&D undertaken in the United States. However, Griliches offers a number of strong methodological criticisms of these studies.

Existing research tends to conclude that publicly financed R&D has a lower rate of return that privately financed R&D. In part, this reflects the "non-commercial" nature of much of the R&D financed and undertaken by governments. However, government-financed R&D, on average, generates spillovers for private R&D endeavours, and is cost-reducing, but it also seems from Mamuneas and Nadiri (1996) that publicly financed R&D "crowds-out" company-financed R&D in many industries.

# 5. Innovation Determinants

A number of elements promote closer and stronger linkages between innovation and productivity growth, and more generally innovation and living standards. The elements identified as relevant in this regard include: 1) the strength and nature of intellectual property protection; 2) the incentive structure and ability of corporate managers; 3) the extent and intensity of competition in product and factor markets; 4) the education and skill level of the workforce; 5) the stability and development of the financial system; 6) the geographical distribution of firms; 7) the openness of the domestic economy to foreign trade, foreign direct investment, and foreign knowledge transfers; 8) the cultural "infrastructure" of a society; and 8) the types and effectiveness of government policies. While some statistical evidence exists about most of the determinants listed above, the bulk of the evidence concerns intellectual property protection, product market competition, workforce skill-level, and openness of the domestic economy.[13]

## 5.1 Intellectual Protection

The previous section recognized that innovation has public good characteristics, and consequently for private sector provision, intellectual property rights laws such as patent laws protect innovation. These laws prevent others from free riding on an innovation.

As Schumpeter (1950) recognized, innovation brings to the fore the operative trade-offs between static and dynamic efficiency. Static efficiency requires prices set in accordance to marginal costs. In the absence of innovation, the extra profit a monopoly earns is associated with extra costs to consumers, and are consequently statically inefficient. Griliches and Cockburn (1994) find that, when the patent on a drug expires, there are welfare gains to consumers who regard branded and generic versions as perfect substitutes. Thus, consumers must pay more for the patent protected firm's goods than they would if many competitive firms were producing them. This price is inefficient from the viewpoint of static efficiency. Schumpeter argued that the monopoly profit an innovator collects from the economic rent of having the sole right to benefit from its innovation is not rent in a dynamic efficiency context. The rent is the return to

[13] There are also studies investigating the effectiveness of government expenditure and tax policies towards innovative activities (see for example Bernstein (1986), and (2000a), but not considered in this paper, because the issues are sufficiently complex to warrant a separate discussion.

innovation when seen in a dynamic context. The short-term benefits of a lower price must be balanced against the long-term costs measured in terms of reduced rates of innovation.

The innovator's monopoly power does not harm consumers. It is based on an improved product or an improved process that, in either case, makes consumers better off. If they were not better off buying from the innovator, they would have continued buying from its competitors. If consumers prefer the innovators new product, or its old product at a slightly lower price, the innovator will reap market share from its non-innovative competitors, yet still earn profit above its input cost.

To disavow this trade-off between static and dynamic efficiency is to disavow the theory behind patents. Patents are awarded in order to provide the innovator with the requisite incentives to innovate. On any given day, the government could unilaterally declare all patents null and void. In the short-run, this will serve to reduce product prices that previously operated under patent protections. However, such appropriations will greatly reduce or eliminate any incentive for the innovators to invest the resources that gave rise to these innovations in the first place.

Models of optimal patent protection, as first developed by Nordhaus (1969), show that longer patent lives give a greater financial incentive to prospective innovators, but also slow the diffusion of the innovation through the economy, and thereby give rise to prices above marginal cost. The optimal patent life balances these two factors. Practically, however, little is known about what the optimal patent life should be.

Patent protection also has many gaps. Levin et al. (1987) survey 650 individuals in 130 lines of business and found that patents are rated as the least effective means of protecting process innovations, behind secrecy, superior sales and service efforts, learning and experience, and lead time. About 60% of the respondents reported that competitors can easily invent around a patent. Performing independent R&D was rated the most effective means of getting information about new technology developed by others. However, there is strong evidence (Rao et al) that increasing intellectual property rights increases the number of patents.

Schankerman and Pakes (1986) and Pakes and Simpson (1989) attempt to determine the value of a patent. In some countries, patent holders must pay renewal fees to maintain their patent protection. These studies estimate the private value of patent rights in the UK, France, and

Germany from cohort data on the number of patents renewed at different ages, the total number of patent applications, and patent renewal costs. They find the distribution of private value patent rights to be sharply skewed, with a heavy concentration of patent rights with very little private economic value and an extended positive tail. They also find a sharp change in the 1960s, after which the number of patents fell, but the quality rose.

Mutti and Yeung (1996), in an alternative approach, measure the effect of unfavorable dispositions in court cases of intellectual property rights infringement by importers on the intellectual property owner. They find such decisions associated with five to seven percent drops in profit to sales ratios. However, they only study 59 such cases. Mutti and Yeung (1997) further find that these negative dispositions appear to stimulate subsequent R&D intensity in the plaintiff's industry. In contrast, positive dispositions are, at best, associated with no cut in R&D spending. Hence, they argue that intellectual property rights might currently be too strong, rather than too weak. Notwithstanding, whether intellectual property rights are too strong or too weak, there is strong evidence that increasing intellectual property rights increases the number of patents.

### 5.2. Market Competition

Innovation enables a firm to develop cheaper ways of producing existing products, or to develop new products, and so make additional profit. Innovation gives the innovative firm a degree of monopoly power. Competition takes on a new dimension, in the context of innovation. Firms compete to innovate as well as to cut prices, and competition to innovate may be the more important of the two, for successful innovation bestows monopoly profits upon the innovator. As Schumpeter noted this monopoly is not protected from competitors by permanent barriers to entry. The monopoly power that comes from controlling new processes and products only lasts until the next innovation arises, and brings about the destruction of today's creative firm by tomorrow's entrant. Schumpeter (1950) calls this process of economic selection "creative destruction". Creative firms prosper, but non-innovative firms are destroyed.[14]

Audretsch (1995) investigates the pace of creative destruction, and shows that the turnover of the list of firms in the Fortune 500 has increased rapidly over the past two decades, and that the

[14] Hobijn and Jovanovic (2000), using stock market evidence, find that incumbents resisted the information technology revolution. This caused their value to fall.

majority of new jobs are in industries that were insignificant two decades ago. This result supports the view that the pace of innovation in the United States has accelerated sharply in recent decades. For Canada, Baldwin (1995), uses census data to document that mobility and turbulence are ever more often the rule, and that long periods of stability are likely to be ever rarer. He develops an evolutionary model of dynamic competition that links the magnitude of such turbulence to traditional measures of static competition.

In the Canadian context, as for other countries, with significant regulated industries, it is important that regulatory policies recognize that some of the highest social costs of excessive regulation are likely those not directly observable: welfare losses from innovative new services and processes that are not developed but would have been otherwise. The welfare losses associated with regulatory delays in offering voice messaging in the United States were estimated to be in excess of $5.1 billion (Hausman and Tardiff (1995)).

Scherer (1992) surveys the empirical literature and concludes that the process of creative destruction, overstates the advantages of large, monopolistic corporations as engines of technological change. He comments that it is far from clear countries "should reallocate innovative activity away from venture firms to the well-established giants lauded in Schumpeter's (1952) book." Scherer goes on to say that Schumpeter's view is not necessarily completely wrong, and that big, monopolistic firms may be best positioned to undertake certain types of innovation. Scherer suggests that, "it may be no accident that the US retains a strong lead in microprocessor semiconductor chips, where bold product design advances can capture the market".

Geroski (1994) echoes Scherer's view. He uses innovation counts for UK firms from 1945 to 1983 to show that more monopolistic industries are less innovative. He also finds that innovative firms outperform non-innovators, especially during downturns in the economic cycle, but argues that this difference is due to firm characteristics that give rise to innovations, not to incentives and opportunity. Firms must organize themselves to respond effectively to the opportunities and incentives with valuable innovations. If so, this qualifies the view that established firms should be allowed to fail so new firms can displace them.

Acs et al (1997), like Scherer (1992), argue that new firms are required for "radical" innovation, and that large established firms tend to focus mainly on incremental improvements in existing products and processes. They cite intellectual property rights as the key reason for this. An innovator has clear control over his innovation in his own firm. Innovations in a large firm are usually the property of the firm, with the innovator often getting only a raise or a promotion. However, market entry can be a costly experience for a small firm, often ending in failure. Large firms usually have more resources and experiences in market entry. Acs et al argue that "intermediated" market entry can sometimes by a solution to this imbalance. Small radical innovators can enter a market via a large firm by selling either its output or its process to the bigger firm. The advantage to the small innovator is that it avoids the costs of market entry. The disadvantage is that the big firm takes an ownership interest.

Market structure does appear to affect both the rate and direction of innovation, with large firms generally producing more incremental innovations and smaller firms producing more radical innovations. However, it must be recognized that smaller firms usually arise from pools of former employees from large firms. The creation of smaller innovating firms is, in part, an outcome of the public good characteristics of knowledge. Large firms are unable to completely appropriate all present and future benefits associated with their innovations from both current and potential rivals.

### 5.3. Workforce Skills

Human capital is the knowledge held by individuals that makes them valuable to an economy. Becker (1962) advanced this concept. He regards human capital as a critical input to production, as well as innovation. There is a clear relation between a country's stock of human capital, usually measured by the educational achievements of its population, and per capita national income (see Makiw (1995), Morck et al (1999), and Rao et al (2000)). The average resident of a high-income country is better educated than is the average resident of a low-income country. One interpretation of this result is that an educated population improves a country's standard of living, but another might be that wealthier countries spend more on education.

Barro (1991, 1996) addresses this issue by showing that a nation's economic growth is significantly positively related to its preexisting stock of human capital, measured by the level of education of its citizens. This finding is consistent with a higher level of human capital causing per capita GDP to grow more rapidly. Fagerberg (1994) surveys empirical studies of the importance of "technology gaps" on differences in economic growth across countries. He finds a consistent pattern that lagging countries can converge towards higher income countries, but only if they have the “social capability”, which is a large number of individuals capable of managing the necessary resources. He argues that investment in education is an important complement to economic growth.[15]

Human capital and physical capital appear to be complements rather than substitutes in most firms. Ochoa (1996), using country-level OECD data for 1971–1987, finds that physical capital accumulation in a manufacturing sector boosts that sector’s long run growth rate when that sector intensively employs full-time research scientists and engineers. Thus, the data are consistent with the view that R&D effort positively influences the marginal product of physical capital, such that diminishing returns do not necessarily moderate the positive effects of rapid physical capital accumulation.

Globerman (2000) notes the “conventional wisdom” that universities and technical colleges can promote the productivity-enhancing effects of innovation by, among other things, encouraging the dissemination of “laboratory” results to industrial practice. In principle, government research institutions can play the same role, although the absence of a teaching function in these organizations deprives one channel, namely student migration into industry, of faster innovation commercialization.

Bartholomew (1997) argues that the “academic” environment is an important conditioning factor of national performance in the biotechnology industry. In particular, closer ties between the academic research system and industry, which can take many forms, such as more funding of academic research, promote the rate, as well as the direction, of innovation. Thus, human capital, as measured by educational achievement, appears to determine an economy’s ability to undertake innovation.

## 5.4. International Openness

[15] Ochoa (1996), presents a different view. He finds the rate of growth (as opposed to the stock) of a country’s human capital not related strongly to overall economic growth. One way to reconcile Ochoa with the other results is that for any period human capital investment is quite small compared to a country’s stock of human capital.

The available evidence tends to provide overwhelming support for the arguments that international trade and foreign direct investment are important channels for new product and process diffusion. Additionally, smaller countries such as Canada are disproportionate beneficiaries of international knowledge flows. There is less agreement on the relative importance of specific alternative international modes with regard to linking innovation to domestic productivity growth.

Potential channels for the international transmission of technical knowledge include: 1) imports of capital goods and intermediate inputs; 2) foreign direct investment; 3) joint ventures and strategic alliances; 4) technology licenses; and 5) migration of skilled labour. Some studies have attempted to evaluate the robustness of these various channels of international knowledge transfer, although most do not address the issue in any comprehensive manner.

Gera, Gu and Lee (1998b) study imported information technology (IT) products. In particular, they conclude that international R&D spillovers from the IT sector played a dominant role in Canada over the period 1971–93. They estimate the rate of return on R&D embodied in IT imports at about 37 percent per year over the period, while it is only around 9 percent per year on R&D embodied in non-IT imports. They also find that international R&D spillovers are insignificant for the United States, although when they distinguish between international R&D embodied in IT and non-IT imports, they find a strong and significant return from international R&D spillovers embodied in IT imports.

Bernstein (2000) underscores the importance of international R&D spillovers to Canadian industries. Specifically, he finds that Canadian manufacturers substitute knowledge from U.S. manufacturing spillovers for domestic R&D. U.S. spillovers cause domestic manufacturing production to become more plant and equipment intensive.

Industry-specific studies further support the notion that the importance of specific international channels of technology transfers is “context-specific”. For example, international cooperative alliances are a particularly important means for firms to enhance their innovative capability in biotechnology (Bartholomew 1997). Whether this will remain true as major multinational companies emerge as important suppliers of biotechnology products is a matter for speculation. More generally, while the available research summarized above strongly suggests the existence of international spillovers to Canada, the ways in which enterprises, especially small and medium sized ones, assimilate and use new foreign-sourced knowledge have not been studied extensively.

## 6. Innovation and Patterns of Productivity Growth

The effect of innovation on productivity growth is one of the product supply-side channels through which innovation improves living standards. Productivity growth, or total factor productivity (TFP) growth reflects output growth net of input growth used to produce these outputs.[16] Since TFP growth captures the "residual" growth in output after accounting for the growth in the factors of production, TFP reflects an "extra-input" output advance. The extra-input, or residual, nature of TFP growth prompts economists to emphasize the importance of innovation to productivity, as the introduction and adoption of new processes and products enable society to enjoy higher levels of output net of the inputs used in output production. Hence, innovation typically leads to productivity gains. Nevertheless, in this context, it must be recognized that the productivity gains emanating from innovation are not generated through a "free lunch". As previously noted, resources must be expended to innovate.

Focusing on the TFP gains arising from innovation captures only a fraction of the significance to society from innovation, and this relationship, at best, emphasizes cost reducing or process innovation not embodied in the factors of production. The reasoning here emanates from the observation that output and input measures used to calculate productivity growth rates, should, in principle, account for both quantity, including new products and factors, and quality improvements for both outputs and inputs. In this context, the TFP residual measures only innovation not reflected in outputs or inputs, namely disembodied process innovations. If innovation is embodied in the traditional inputs, a potential identification problem arises. Specifically, it becomes difficult to identify empirically the contribution of conventional inputs to productivity growth separately from the contribution of innovation. Indeed some economists have argued that the greatest portion of innovation takes the form of improved inputs. To the extent that this is true, increased usage rates of newer inputs will contribute to productivity growth, and it may be difficult to separate the impact of using improved inputs from that of an increased use of inputs.

[16] In this context inputs include labour, plant and equipment. TFP growth is also referred to as multifactor productivity growth. Additionally, there are partial productivity measures. For example, labour productivity growth measures output growth net of labour input growth.

A similar consideration applies to situations in which innovation is accompanied by increases in the scale and scope of organizations. It can be difficult to empirically separate the productivity effects of increases in the scale and scope from the effects of implementing new processes. Hence incorporating additions and quality changes meaningfully into output and input series presents a difficult challenge. To the extent additions and quality improvements are not accurately representative of the actual mix of outputs and inputs implies biases in the calculated productivity growth rates. Moreover, if features contributing to measurement errors vary in importance over time, even the temporal performance of measured productivity can be an inaccurate guide to true productivity trends.

This section now addresses the conjecture that the relationship between innovation and productivity growth has undergone major changes over the post-war period. Two major suggestions put forth in the literature are; 1) the productivity payoff to innovation declined in the 1970s and 1980s because the major "breakthroughs" of earlier periods had been largely exploited, and 2) the recent emergence of new computer and communications technologies, have dramatically increased the productivity gains associated with innovative activities.

Griliches (1998) argues against the existence of a secular decline in R&D-induced productivity gains based upon the observation that manufacturing and agricultural productivity in the United States has exhibited no secular declining trend. He argues that the linkage between R&D and productivity growth is probably more stable and more readily measured in those two sectors than in other sectors of the economy. Hence, if the R&D contribution to productivity were declining, it should be most readily apparent in a declining productivity performance of the manufacturing and agriculture sectors.

Mohnen (1992) surveys the literature relating productivity growth to R&D performance. He interprets the evidence as rejecting the notion that the productivity of "own" R&D has declined over time, but he considers the evidence more equivocal with respect to whether there has been a decline in the productivity of "imported" R&D. However, Gollop and Roberts (1981), study a sample of approximately 20 U.S. industries. They conclude that foreign-supplied intermediate inputs have important direct and indirect effects on the sectoral productivity growth of their sample of U.S. manufacturing industries. Bernstein and Mohnen (1998) find significant asymmetric spillovers between the U.S. and Japanese economies. U.S. spillovers contribute about 46 percent to Japanese productivity growth. Bernstein (2000b) also finds that spillovers from U.S. manufacturing accounts for three-quarters of the average annual productivity growth for the Canadian manufacturing sector, and this contribution increases in the post 1973 period.

The decline in R&D intensity in many developed countries is potentially consistent with a future decline in productivity, although the decrease in R&D intensity does not seem sufficiently substantial to be a major part of the post-1973 productivity growth slowdown story. This result is substantiated by Rao et al who find a correlation between "own" R&D intensity and TFP growth to be only 0.22 for the U.S., and 0.31 for Canada. Moreover, international spillovers, to the extent they exist, have tended to mitigate the productivity slowdown.

Turning to the link between computerization and productivity growth, Siegel (1997) summarizes and evaluates a number of relevant studies. His main point is that earlier studies are potentially unreliable because of biases in the measurement of computer prices and utilization, and because of a failure to explicitly acknowledge that improved labour quality usually accompanies increased computerization. Previous studies also generally ignore that computerization is, itself, the result of a decision calculus on the part of producers. These shortcomings make it likely that earlier studies have produced misleading estimates of the linkage between productivity growth and computerization.

Siegel estimates a model linking TFP differences across a set of four-digit (SIC) U.S. industries to differences in computer usage, as well as to other independent variables. His results imply that the marginal productivity of investment is higher for computers than for other types of capital. Moreover, he finds a positive and statistically significant relationship between productivity growth and investment in computers, with an estimated rate of return on computers of about 6 basis points above the returns on other types of investment.

Stiroh (1998) argues that sectoral differences are crucial in understanding the impact of computers. He examines data on 35 manufacturing and service sectors for the period 1947–91. He finds that the computer-producing sector enjoyed rapid TFP growth over the sample period. For other sectors of the economy, the decline in the price of real computing power encouraged a substitution away from relatively expensive labour and non-computer capital towards relatively cheap computers. However, there is no evidence that this accumulated investment in computing capacity increased TFP in using industries, on average. In a similar vein, Lehr and Lichtenberg

(1996) examine trends in computer usage and the effect on productivity growth for a sample of U.S. federal government agencies over the period 1987–92. They find that computer usage contributed to productivity growth, although the impact was not dramatic.

Other studies focus more broadly on "Information Technology" (IT) and its linkages to productivity growth. Bernstein (2000b) focuses on spillovers associated with R&D activity in the communications equipment industry. He finds substantial spillovers from this industry to the Canadian manufacturing sector. Spillovers from communications equipment accounted for about 9 percent of the average annual Canadian manufacturing TFP growth. The OECD also considered the linkage between investment in information technology and productivity growth for the service sector in an international context. Their results underscore the difficulties in reliably identifying the precise linkage in the presence of measurement errors associated with the output measurement in services. Hence, while it finds a positive impact of IT capital on productivity in the service sectors of OECD countries, its statistical significance was not confirmed.

## 7. Conclusion

The purpose of this paper is to answer the following set of questions. 1) What is the innovation process, and how does it relate to conventional production processes? 2) How is innovation measured and what are the relationships between the various proxies? 3) How do innovation-based spillovers arise, and how do they affect the returns to innovation? 4) What are the elements that determine innovation, and 5) How does innovation affect productivity growth?

There are five main messages from this paper. First innovation, which is the introduction and adoption of new processes, and products, is the growth or accumulation of knowledge. Innovation ultimately enables consumers to enjoy a higher living standard because new and better products can be purchased at generally lower prices. However, innovation is not a "free lunch". Resources must be expended to encourage innovation, but the presumed net result increases living standards.

Second, innovation involves the transformation of ideas into new products and processes, and consequently, like production, entails input-output combinations. Various alternative proxies are used to measure innovation. The empirical literature most often uses patent numbers, innovation counts, and research and development (R&D) expenditures. Although there are limitations of each, there is a strong, direct, and contemporaneous relationship between the three proxies. Thus input-based indicators, such as R&D expenditures, appear to be as valid as the output-based indicators of innovative activity. This suggests that observing organizations performing relatively small amounts of R&D does not necessarily suggest that innovation outcomes do not involve innovation inputs. Rather, it might suggest that conventional measures of R&D spending may be poor proxies for the actual investment in the stock of knowledge. Even more significantly, the empirical results show that just as there is no free lunch in the production of established outputs, not surprisingly, there is no free lunch associated with the creation of new processes and products.

The third message is that the public good characteristics of innovation generate spillover effects, and the free riding that typically ensues forms the basis for government involvement in the innovation process. Spillovers generate extra-private returns to innovation such that the social return, that is the return to innovation use, is at least twice the private rate of return to the initial innovator. Spillovers affect the rate of innovation by firms that are spillover sources, as well as the rate associated with spillover receivers. Moreover, the empirical results show that spillovers are not limited to firms within an industry but cross both industrial, and national boundaries.

Fourth, there are a number of determinants of innovation. Four of the main ones, about which relatively more is known, are; 1) intellectual protection, 2) market competition, 3) workforce skills, and 4) international openness. Generally, increasing intellectual property rights increases the number of patents. In addition, market structure does appear to affect both the rate and direction of innovation, with large firms generally producing more incremental innovations and smaller firms producing more radical innovations. However, smaller firms usually arise from pools of former employees from large firms. The creation of smaller innovating firms is, in part, an outcome of the public good characteristics of knowledge produced by large firms. In terms of workforce skills, human capital, as measured by educational achievement, appears to be directly associated with an economy's ability to undertake innovation. The available evidence also provides support that international openness, through trade, direct investment, and spillovers, are important channels for new product and process diffusion, and that smaller countries such as Canada are disproportionate beneficiaries of international knowledge flows.

The fifth message, regarding the link between innovation and productivity growth, is that the decline in R&D intensity in many developed countries does not seem sufficiently substantial to be a major part of the post-1973 productivity growth slowdown story. Indeed, the correlation between "own" R&D intensity and TFP growth tends to be only 0.22 for the U.S., and 0.31 for Canada. Moreover, international spillovers, to the extent they exist, have tended to mitigate the productivity slowdown. More recently, innovation associated with computers, and communication, or information technology, in general, have generated important contributions to productivity growth.

The significance of innovation to society, however, far outweighs the contribution of innovation to productivity growth. As Schumpeter (1950, p.83) writes, "The fundamental impulse that sets and keeps the capitalist engine in motion comes from the new consumers' goods, the new methods of production or transportation, the new markets, the new forms of industrial organization that capitalist enterprise creates."

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