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SCIENCE AND TECHNOLOGY:

PERSPECTIVES FOR PUBLIC POLICY

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SCIENCE AND TECHNOLOGY:

PERSPECTIVES FOR PUBLIC POLICY

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SUMMARY

The conventional justification for a government's role in innovation activities (or in any other economic activity) is the *market failure rationale*. This approach demonstrates that under specific conditions, market institutions do not allocate resources as efficiently as is theoretically possible. Failures are often identified in markets that are characterized by at least one of the following: externalities, public goods, indivisibilities, imperfect information, incomplete markets and imperfect competition.

This paper thoroughly discusses the theoretical explanations of why markets and governments may allocate insufficient resources to various forms of innovative activity and knowledge creation. This paper also argues that government support of S&T can be effective in correcting market failures. However, intervention may not improve on market outcomes if the programs or support do not follow the micro-economic principles of efficient policy design.

It is generally agreed that knowledge has several properties that are likely to lead to its under-provision by private decision makers. One of these properties is that knowledge can be only imperfectly appropriable. This means that individuals or firms creating knowledge might be unable to prevent others from making use of it, and making a profit from it. Knowledge has two other characteristics that lead to a social interest in its diffusion. First, if it is to have any value, knowledge from one source must often be used in conjunctioin with knowledge from other sources. Second, knowledge is a public good, which means that its use in one purpose does not preclude its use in another setting.

The paper looks at externalities or spillovers, defined as the excess amount a user would have been willing to pay over and above what he had to pay for a good. The sources of spillovers which are reviewed include: imitation, demonstration effects, experience and incubation.

Evidence on spillover benefits from R&D spending and innovation is also examined. This discussion begins by surveying the case study evidence which attempts to estimate the difference between the social and private rates of return to innovative activity. In looking at government sponsored R&D in particular, the paper finds that government sponsored, precompetitive R&D yields good rates of return while the record of government-supported proprietary R&D is much less impressive.

The paper then surveys the evidence that points to a decline in R&D spillover rates in recent years. It also discusses local agglomeration effects and concludes that agglomeration economies exist and that their most likely sources are labour market and infrastructure (especially transportation) specialization. It finds, however, that there is little to indicate that firms located at a distance from their rivals are technologically disadvantaged.

International spillovers are then examined. The existence of international spillovers complicates prescriptions for efficient resource allocation. Policy should favour activities with large domestic spillover benefits. The types of innovations that generate the largest domestic spillover benefits might be those that add value to unique domestic resources.

Various forms of legal mechanisms, particularly patents, are evaluated in their function to protect intellectual property rights and increase the appropriability of knowledge. The evidence suggests that patent protection now is, on balance, stronger than is required. However, there are in Canada some concerns about the terms of access that justify a somewhat stronger patent protection system.

The paper then goes on to discuss the policy instruments aimed at offsetting the inappropriability of knowledge, in particular, tax incentives, subsidies, procurement, and concessionary financing. It finds that the efficacy of policy instruments indicates that tax incentives and concessionary financing may be more effective than direct subsidies, although the empirical evidence is limited.

In concluding the paper, models of innovation are examined in conjunction with public policy. The linear model of innovation characterizes the innovative process as a flow beginning with basic research and proceeding to applied research and then to development and commercialization. Scientific discovery is regarded as exogenous. The public policy response in the face of such a model is a progression from substantial direct government support at the early stages of the model to limited direct support at the later stages. The feedback model, on the other hand, emphasizes the cumulative and interdependent nature of the innovative process. Here, the simple rule that basic research is the sole responsibility of government, no longer applies. The feedback model of innovation appears to be a more realistic representation of the true process.

The implications for government policy in the face of the feedback model are complex. Overarching government plans are not necessary. In many cases, governments may be merely participants in an ongoing evolution. The feedback model sees the business sector as an important potential source of support for university research. The role of government is to accord universities the flexibility to participate in theses arrangements. Also, research conducted in government labs may have commercial applications in this model. This suggests the need for more cooperative research involving contracting-out, contracting-in, alliances or consortia. If the feedback model applies, the internal organization and incentive structures of government labs may have to be altered if they are to interact effectively with other components of the innovation system.

INTRODUCTION

This study has two purposes, the first is to examine the economic rationale for public sector support for science and technology and to consider the role that public policy plays in technological development. The second is to describe the role of science and technology in the process of economic growth and develop the microeconomic foundation for sound public policy.

The study identifies the characteristics of certain scientific and technological endeavours to which private market mechanisms may allocate insufficient resources. This involves the analysis of such phenomena as spillovers, agglomeration economies, clustering, and generic and infra-technology R&D.

The study describes the various market institutions that bring private incentives for innovative activity into line with social incentives. The role of various public institutions, policies and programs in either reducing the discrepancy between the social and private rates of return on innovative activity or reducing the resulting misallocation of resources is also described.

Part 1 of the study discusses the reasons why "markets" and "governments" may allocate insufficient resources to various forms of innovative activity. Part 2 examines the evidence on innovation spillovers and social rates of return on innovative activities. Part 3 describes the role that intellectual property rights can play in bringing the private rate of return on innovative activity into line with the social rate of return. The role that tax incentives, subsidies, procurement and concessionary financing have played and should play in encouraging innovative activity is examined in Part 4. Theories of technological innovation and their public policy implications are discussed in Part 5 and Part 6 draws some general conclusions.

PART 1
A COMPARISON OF RESOURCE ALLOCATING INSTITUTIONS

Introduction

The role of government in the economy is often discussed in terms of the market or the government as being mutually exclusive alternatives. In fact, it is seldom a choice between polar alternatives; rather, it is a matter of determining the appropriate extent and nature of government participation in the innovative process -- an exercise that requires some understanding of the circumstances under which the public sector is likely to have a comparative advantage. Fundamentally, it is a question of institutional design; that is, of determining the appropriate incentive system for the problem of resource allocation at hand. Government organizations may rely extensively on market-style incentives. Many groups such as research associations and nonprofit organizations may not be readily identifiable as either government or market institutions.

> Organisational elements emerge in the market to offset market failures, while market-like principles are employed in the firm to remedy "organisational failures." Network organisation emerges to cope with both market and organisational failures in the economic system, and at the same time to obtain the advantages of speedy coordination. (Imai and Baba, 1991, p. 390)

The problem of organizational and incentive design is complex and, insofar as institutions are concerned with innovation, currently very much to the fore (Dasgupta and David, 1994). Both Universities and government laboratories are becoming more commercially-oriented and individual firms are cooperating through different sorts of alliances and consortia. These cooperative arrangements involve varying degrees of government participation. The institutions of what have been called proprietary and open science are being commingled. Each of these institutional innovations should be evaluated on its merits, that is, in the context of its particular resource allocation problem. However, a detailed examination of this nature is well beyond the scope of this study, which is necessarily confined to the examination of broad categories of government involvement in technological innovation.

At a highly aggregated level, there is a rough continuum of levels of government involvement in technological innovation. At one end of the spectrum, government involvement may be limited to the maintenance of an environment conducive to innovation through the specification and adjudication of intellectual property rights and, generally, by maintaining an economic and legal regime under which individuals have an incentive to make long-lived investments. Beyond this, governments can use their taxing and spending powers to make transfers to firms, non-profit organizations and individuals engaged in innovative activity. Such transfers are selective in that they favour certain lines of innovative endeavour over others. Another level of intervention involves active participation by government departments and enterprises in innovative activities. This study draws on both economic theory and experience in an attempt to determine how the extent and nature of government involvement in technological innovation might be altered in the future.

Limitations of the Market

The *market failure approach* is a conventional way to determine an appropriate role for government in innovation or any other economic activity. This approach demonstrates that, under specific conditions, market institutions do not allocate resources as efficiently as is theoretically possible. Measures that government might take to improve market outcomes are then suggested.

Stiglitz (1991) suggests that there are two levels of market failure analysis. The first level focuses on externalities, public goods and indivisibilities. At this level, failures are considered to be relatively infrequent and to require limited intervention to correct. The second level of analysis focuses on imperfect information, incomplete markets and imperfect competition. At this level, imperfections are seen to be ubiquitous. Sometimes there are so many imperfections it is difficult to determine their net effect. In such circumstances, suggested remedies can be idealized as well as complex.

The I Problem of Inappropriability

The goal of research is to create knowledge. It is generally agreed that knowledge has several properties that are likely to lead to its under-provision by private decision-makers in a market environment. The characteristic of knowledge that is likely to lead to this result is that it is *imperfectly appropriable or imperfectly excludable*. As a consequence:

> ...individuals or firms that have devoted resources to generating new knowledge may be unable to prevent others from making use of it. In other words, it may be difficult for the originator of some technological advance to protect his or her property rights, even though patent and copyright laws have been devised exactly for this purpose. (Grossman, 1992 p. 106)

Knowledge has two other characteristics that lead to a social interest in its diffusion. First, if it is to have any value, knowledge from one source must often be used in conjunction with knowledge from other sources. Second, knowledge is not subject to exhaustion or congestion. The use of knowledge for one purpose does not diminish its supply or availability for other purposes. This is known as the "public good" characteristic of knowledge.

Theoretically, the incremental cost of using knowledge once it is produced is zero. Efficient use of knowledge then requires that its price, to the marginal user at least, should be zero. In a market system, however, firms or individuals will fund research only to the extent that it is expected to yield a rate of return equivalent to that which can be realized on other investments. Research that would be financially attractive if its users could be made to pay will not be undertaken if users cannot be made to pay.

Thus, tension exists between the generation of knowledge and its dissemination. If users are made to pay, diffusion may be incomplete.[1] If users are not made to pay, market institutions may under-provide knowledge-generating research.

There is a variety of means by which the users of knowledge can avoid paying, either entirely or an amount commensurate with the benefit they derive from its use. The excess of the amount a user would have been willing to pay over what is actually paid is called a spillover benefit or externality.

The Sources of Spillovers

Imitation: Some innovations can be copied. If the innovator is not

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[1] Diffusion need not be incomplete if users pay their respective reservation prices. The marginal user would then pay nothing. This outcome can be achieved theoretically with perfect price discrimination and approximated in practice with a multi-part pricing scheme.

compensated, the imitator receives a spillover benefit. Competition from imitators and potential imitators drives the price of the innovation down. As a consequence, users pay a price that is less than the value of the innovation. The difference between the value of an innovation to its users and the price they actually pay for it is known as consumer surplus.[2] Thus, imitation or the threat of it results in the receipt of spillover benefits by both imitators and users.[3]

Imitation is not without cost. The R&D cost of duplicating a typical patented new product tends to be between half and three-quarters of the innovator's R&D cost. Generally, the R&D cost of duplicating a typical unpatented new product innovation is between one-quarter and one-half the innovator's R&D cost (Levin *et.al.*, 1987, Table 8). Spillover benefits accrue to imitators performing independent R&D to the extent that the cost of imitation is less than the cost of innovation.

Levin *et.al.* (1987) also find that the means by which new product innovations are copied are, in order of effectiveness, independent R&D, reverse engineering, licensing, hiring the innovating firm's R&D employees, publications or technical meetings, patent disclosures and conversations with employees of the innovating firm. The means by which a process innovation can be copied are, in order of their effectiveness, independent R&D, licensing, publications or technical meetings, reverse engineering, hiring R&D employees from the innovating firm, patent disclosures, conversations with employees of the innovating firm (see Table 1).

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2 Purchasers may also derive surplus from the additional variety available to them.

3 Griliches points out that benefits realized by users from lower prices and by imitators who copy an innovation are *pecuniary* rather than *real* spillover benefits. That is, users and imitators are simply sharing a given flow of benefits with the innovator. A real spillover occurs when one innovation makes others possible.

Table 1
How Does New Technology Leak Out?

	Importance (Rank Order)	
	Product	**Process**
Means of Imitation		
Independent R&D	1	1
Reverse Engineering	2	4
Licensing	3	2
Hiring Innovator's R&D Employees	4	5
Publications or Technical Meetings	5	3
Patent Disclosures	6	6
Conversations with Employees of Innovating Firm	7	7

Source: Levin et.al. (1987).

Complementarities and Interdependence: Innovations in one industry area may yield insights that give rise to contemporaneous innovations in unrelated industries. Innovators integrating or recombining insights derived from experience with or from the observation of new products and practices in unrelated industries may also be realizing a spillover benefit. The magnitude of such benefits is very difficult to establish. In this regard, Rosenberg (1982, p.75) writes:

> Often, however, an innovation from outside will not merely reduce the price of the product in the receiving industry but will make possible wholly new or drastically improved products or processes. In such circumstance it becomes extremely difficult even to suggest reasonable measures of the payoff to the triggering innovation because such innovations open the door for entirely new economic opportunities and become the basis for extensive industrial expansion elsewhere.

Technologies with wide applicability and the potential to trigger innovations or further R&D leading to innovations in a variety of industries are termed *generic technologies* (or, in some cases, *enabling technologies*).

Commentators on technical change in Japan have described the innovations that emerge when two or more streams of scientific discipline or technology are merged as "fused". Robotics or "mechatronics" is an example of such fusion (Imai and Baba, 1991). The development of new information technologies, particularly the digitalization of telecommunications, is seen both as having a pervasive impact on a range of products and as triggering a proliferation of new business opportunities and clusters of innovations.

Subsequent Innovations: Innovation is a cumulative process. One of its benefits is that it may make subsequent innovations possible. Today's innovators may draw on the knowledge embodied in the stock of past innovations. It is frequently said that, as a result, they "stand on the shoulders of giants".[4] The benefit derived by today's innovators from past innovations is a spillover benefit in that, provided either that any patents on the prior innovations have expired or that the follow-on innovation is sufficiently novel, no compensation is required.[5]

The spillover benefit derived by current inventors from past inventors is at the core of recent theoretical models of endogenous growth (Grossman and Helpman, 1991, Ch. 3-4). In the variety model, increases in cumulative R&D spending reduce the cost of current R&D, thus maintaining the incentive to add new varieties. In the quality ladder model, current quality improving R&D efforts draw upon all the know-how embodied in existing products, thus maintaining the incentive to invest in quality improvements.

Learning, Experience and Incubation: Employees of organizations engaged in innovative activities may acquire transferable skills or knowledge in the course of their employment, thereby increasing their value to competitors and thus the wages they can command. They may also use their skill or knowledge to start a new business of their own.[6] To the extent that they have not compensated their employer for providing this skill or knowledge, these employees receive a spillover benefit. Of course, the employer can be

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[4] See, for example, Scotchmer (1991).

[5] One measure of this inter-temporal spillover benefit is patent citations. These reflect the extent to which a patented invention is derived from knowledge revealed in earlier patents. See Caballero and Jaffe (1993).

[6] The businesses providing the transferable skills or knowledge which serve as the basis for the formation of new businesses are known as incubators.

compensated. The normal assumption is that an employer who is known to offer valuable transferable skills has an easier time hiring than other employers. In addition, the "incubating" employer may be able to pay lower wages or attract more highly qualified employees for the same wage. In this case the potential externality is internalized and there is no distortion. Grossman (1992) assesses the training or incubation externality argument as follows:

> ... there must exist some imperfection in capital markets for any such externality to arise. Otherwise workers could finance their own training by accepting lower wages during an initial period of apprenticeship. Only if a worker has few assets and a limited ability to borrow against his or her future earning potential will he or she be unwilling to bear the cost of acquiring skills. While such capital market failures undoubtedly exist, there is also substantial evidence that workers accept low wages during their early less productive years. (p.110)

Demonstration Effects: Early adopters of new technologies as well as inventors may also be imitated. Early adopters make an investment in assessing the economics of a new technology and in solving problems related to installation, integration and break-in. To the extent that these investments are not user-specific, later adopters may be able to "free ride" on them. Again, this depends on the extent to which early adopters can keep their particular knowledge from leaking out. This may be difficult because merely knowing that another firm has adopted a particular technology in itself conveys some information.

Demonstration effects have been cited as a source of host-country spillover benefits from foreign direct investment (McFetridge, 1994) and as a source of the "diffusion externality" (Stoneman, 1994). Free riding by later adopters may delay the diffusion of new technologies relative to its ideal rate. There may, however be offsetting imperfections with commercial process or intermediate goods technologies. First, suppliers of new technologies advertise and they may over-advertise relative to the ideal. Second, early adopters may also gain a strategic advantage over competitors in their own markets.

Information Asymmetries

An information asymmetry exists when the assertions of one party in a potential transaction cannot readily be verified by the other party.

Information asymmetries burden market exchange in general and markets for experience goods (the characteristics of which cannot be verified on inspection) in particular. Information asymmetries can also constitute a barrier to the diffusion of new technologies to the extent that potential purchasers may undervalue a new technology unless or until they are fully informed as to its characteristics. If they are fully informed, however, they may make use of the technology in question without paying for it.[7] This problem is mitigated but not necessarily eliminated by intellectual property rights which allow the innovator to reveal a new technology without losing the power to exclude others from using it.[8]

It has also been argued that, under certain conditions, information asymmetries distort the operation of capital markets. The asymmetry in this case is that borrowers know their risk characteristics (i.e., probability of default) while the lenders do not. This creates problems of adverse selection and adverse incentives.

Adverse selection is best understood in connection with insurance markets. At a given insurance premium, individuals who know themselves to be better than average risks, but who cannot credibly demonstrate this to insurers, may opt to self-insure while those who know themselves to be worse than average risks will continue to seek insurance. The result is a deterioration in the overall quality of the risk pool and a requirement for an increase in rates if insurers are to break even. Successive increases in rates may result in further deterioration of the risk pool with the result that the market ultimately fails.

In the context of loan markets it has been argued that adverse selection may cause the supply schedule of loans to bend backward, with the possible result that there is no interest rate that can equate the supply

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[7] This point was made by Arrow (1962) who wrote:

...there is a fundamental paradox in the demand for information; its value to the purchaser is not known until he has the information, but then he has in effect acquired it without cost. Of course, if the seller can retain property rights in the use of the information, this would be no problem, but given incomplete appropriability, the potential buyer will base his decision to purchase information on less than optimal criteria. He may act, for example, on the average value of information in that class as revealed by past experience. If any particular item of information has differing values for different economic agents, this procedure will lead both to a nonoptimal purchase of information at any given price and also to a nonoptimal allocation of the information purchased. (p.615)

[8] Many features of patent licenses (running royalties, grantbacks, field of use restrictions) can be seen as facilitating diffusion while ensuring appropriability. This has not always been widely appreciated. This is discussed in greater detail in the section on intellectual property.

and demand for loans, making nonprice rationing necessary. The scenario in this case is that an increase in the interest rate charged on loans may induce borrowers with low risk projects either to self-finance or to abandon their projects. Borrowers with riskier projects (those with a higher probability of failure) are more likely to continue to seek loans because they would not pay the interest in the event of failure. For the same reason borrowers may conduct their operations in a riskier fashion at higher rates of interest. This is called the adverse incentive effect.

While some have argued that an interest rate subsidy or below market lending by a government lender would be beneficial in that it would attract the better risks back into the loan market, the rationing result is not robust. It does not hold if riskier projects have higher expected values (social rates of return); nor does it hold if lenders set the interest rate and collateral requirements simultaneously (Bester, 1987). The adverse selection and incentive problem can also be reduced if the lender can hold equity in the borrower. Information asymmetries themselves may be reduced by giving the lender privileged access to the borrower's financial data.

There remains a suggestion, however, that these remedies may be less effective in the case of financing innovative activity. Knowledge is intangible and does not admit as readily to collateralization. Information asymmetries may be more difficult to overcome. Intellectual property may be helpful here.[9] The role that alternate organizational forms such as the Japanese *keiretsu* might play has also been cited. These groups of industrial firms and financial institutions linked by equity cross-holdings may be able to internalize a greater portion of the benefits of their members' innovative activities and may also be able to provide member financial institutions with more credible evidence regarding proposed investments in innovative activity.

Government Failure: The Limits of Intervention

The literature on public policy toward innovation focuses on market failure. Market outcomes frequently fall short of the ideal; occasionally,

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[9] It has been argued, for example, that financing the transfer of public sector technology to start-up ventures can be more readily arranged if the technology involved is patented (remarks made by Mr. Jon Sandelin, Office of Technology Licensing, Stanford University at a conference on technology transfer held at Stanford University, March, 1994).

they fall far short. But the ideal is not an option.[10] All human institutions are imperfect. Non-market organizations and arrangements are also subject to failure. Governments have their own imperfections. (Henderson, 1977; Wolf, 1987; Krueger, 1990)

Attempts to formulate public policies in support of innovation should recognize, first, that "the government" and "the market" are polar cases. Institutions vary in the respective roles they assign to the government and to market incentives. Second, each set of institutional arrangements has its own strengths and weaknesses. The task is to determine the set of institutional arrangements that is most suitable to the resource allocation problem at hand.

Government intervention involves both political and bureaucratic decision-making, and there are compelling reasons to believe that there are many circumstances under which the political-bureaucratic resource allocation process is unlikely to improve on market outcomes. Indeed, from a resource allocation perspective, it may do much worse.

The economic theory of interest group politics, as developed by Stigler (1971), Peltzman (1976) and Becker (1983, 1985) predicts that concentrated interest groups can use the political system to extract surplus (transfers) from the less well organized segments of society. This is also called rent seeking; it is wealth-reducing in aggregate. A number of regulatory policies have been identified as being redistributive rather than efficiency-enhancing in their motivation.[11] There is also evidence that policies intended to support innovation have been influenced by distributional considerations. This is examined in more detail below.

The theory of interest group politics does not suggest that efficiency-enhancing policies cannot be produced. Policies that make everyone, or virtually everyone, better off are attractive as are policies that are wealth-increasing in aggregate but disadvantageous to the weakly organized. Even here, however, the political process may seriously distort decisions. For example, decision-makers in markets have been characterized as being impatient. Political decision-makers may be even less patient. (Cohen and

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[10] The comparison of imperfect markets with an abstract ideal government is known as the Nirvana approach. This is due to Demsetz (1969). Some advocates of government intervention go still further. They advocate government intervention to correct *theoretical* market failures. The use of the simple monopoly model as a rationale for antitrust policy is a case in point.

[11] The evidence is surveyed by McFetridge and Lall (1991).

Noll, 1991b; Wolf, 1987) The nature of political coalitions and voter evaluation is such that political decision-makers cannot be expected to take a long-term view. The consequences are considered in greater detail below.

Political decisions are implemented by government bureaucracies, which have their own objectives. Bureaucratic self-interest may or may not involve the pursuit of policies intended to enhance economic efficiency. Bureaucratic interests may or may not be in alignment with those of political interest groups. In some cases bureaucratic self-interest may thwart the redistributive ambitions of political interest groups; in others it may thwart efficiency-enhancing public policies.

Measures designed to increase bureaucratic accountability may reduce both the flexibility and the productivity of government research facilities. The National Advisory Board on Science and Technology (1990, p.25) has noted a number of features of bureaucracy that are inimical to the provision of a good research environment. These include tenure arrangements, delineation of functions, limited financial discretion, limited differentiation on the basis of merit and the absence of property rights.

The effect of redistributive activity on the management of six R&D commercialization programs undertaken by the U.S. government has been examined by Cohen and Noll (1991b). They found that redistributive pressures distorted decisions in three general ways.

First, the projects did not explore a sufficiently wide range of technological options in their early stages. An essential function of research is to explore alternatives and eliminate those that are likely to be fruitless. These projects failed to investigate the alternatives properly because the sponsoring agencies were committed to certain technologies and because owners of proprietary substitute technologies wished to limit the competition they faced (1991b, p.368).

Second, the projects moved too quickly from the exploratory stage to the demonstration and prototype stage. There was a premature commitment to hardware and facilities that locked the project into a specific course of action and reduced the extent to which new information could be taken into account. There were two reasons for this excessive haste: one was that the political coalitions in support of these projects were fragile. Vulnerability to shifts in political support can be reduced by quickly sinking resources into specialized facilities or hardware. Research activity is more readily scaled back and is therefore more vulnerable. Project beneficiaries have an incentive to make large irreversible commitments as early as possible in order to lock in their benefits. The other reason for haste was that the construction of hardware or prototypes gives legislators some tangible distributive benefits to show voters:

> Electoral politics causes politicians to favor programs that promise tangible results for the next election. Large, visible projects satisfy this political demand, not only because they stand as obvious signs of a return on expenditures but also because, unlike earlier research activities, they can deliver distributive benefits to constituents that pass the threshold of political saliency. (1991b, p.370)

Third, project expenditures tended to be subject to an excessively rapid build-up and then to subsequent instability. It is difficult to compress the exploratory research process; results do not increase commensurately with the rate of expenditure per period. Budget cuts usually require that resources be used to reconfigure programs. In addition, knowledge may even be lost as a consequence of the termination of experiments and the dispersal of personnel. The reason for this boom-bust cycle is again, the fragility of political coalitions supporting these programs.[12] Their proponents have an incentive to spend as quickly as possible both in anticipation that support may be withdrawn and in an effort to achieve political visibility and shore up support. Thus the haste and inflexibility, and the boom and bust cycle of these programs can be traced to the fragility of the political coalitions supporting them.

It is possible that some public policy failures may be avoided by changes in the decision-making process or in the nature of government participation. In other cases it must simply be recognized that no matter how thoughtfully government participation is structured, it is unlikely to be beneficial and should therefore be avoided. These issues are discussed further in Part 5.

Peer Evaluation: The Institutions of Open Science

A set of institutions has evolved over time to reduce the effect of

[12] Cohen and Noll (1991b, p.372) emphasize that R&D projects are, in general, likely to be burdened by transitory political support. Given that it has a range of possible technological and commercial outcomes, the distributive consequences of an R&D program (hence, its source of support) is likely to change over time. The coalition that supported its initiation may unravel and may possibly be replaced by a new supporting coalition.

rent-seeking on the allocation of public funds to scientific research. These institutions also serve to encourage timely disclosure and the diffusion of publicly-funded research. Dasgupta and David (1994) describe scientific activity managed under these institutions as "open science".

The reward system in open science is based on priority of discovery. This "winner take almost all" system rewards the first to make a scientific discovery and report it publicly in a verifiable form. Winners receive a variety of rewards, one of which is future research funding. Losers must be content with teaching salaries. Publication widens the sphere of applications, facilitates informed peer evaluation, and increases reliability. Peer evaluation rewards inventors on the basis of their contribution to ongoing research; that is, it reflects a consensus regarding the type of findings that are likely to yield future priority claims to others in the field. In addition, the peer evaluation of scientific output frees scientists from inexpert monitoring of their activities and, to some degree, insulates the allocation of research resources from the redistributive pressures of the political system.

While the reward system of open science has its own logic, it also has its own defects. The emphasis on priority of discovery encourages racing, with all its incumbent inefficiencies. It also encourages the suppression of intermediate discoveries that might assist others in the race. Rather than being codified and disclosed, such knowledge remains tacit and "private". Complementary intermediate discoveries may, however, be pooled or swapped in semi-private networks. The incentive to contribute to those networks takes the form of the promise of access to future networks. Reputation effects curb the incentive to free ride on the network.

PART 2
SPILLOVER BENEFITS: THE EVIDENCE

Private and Social Returns on Proprietary Innovations

Case Study Evidence

A number of attempts have been made to estimate the difference between the social and private rates of return on innovative activity. Several methods have been used.

Mansfield *et.al.* (1977) and Tewksbury *et.al.* (1980) calculated social and private rates of return on "samples" of industrial R&D projects. These studies take into account both the R&D costs and the profits of imitators, as well as the cost-savings experienced by users (increases in consumer surplus). Both studies concluded that the profits of imitators generally exceed their (imitative) R&D costs and that users generally experience a cost saving with the result that the social rate of return on R&D exceeds the rate of return earned by the innovator. The median social rate of return on the 17 innovations examined by Mansfield *et.al.* is 56 percent. The median private rate of return is 25 percent.

Tewksbury *et.al.* examined 20 process and product innovations and found a median private rate of return of 27 percent and a median social rate of return of 99 percent; these three innovations had low private but high social rates of return. These innovations were socially beneficial but would not have been introduced had their *ex post* private rates of return been anticipated. It is worth noting that while they were working with a small sample, Tewksbury *et.al.* found that the existence of strong patent protection did not reduce the discrepancy between the social and private rates of return. Mansfield *et.al.* (1977, p.160) came to a similar conclusion.[13]

[13] Mansfield *et.al.* found that, given the cost of imitation, the difference between the social and private rates of return does not depend on whether an invention is patented. It does, however, depend on the cost of imitation; the lower the cost of imitation, the lower the private rate of return relative to the social rate of return. This begs the question of whether the existence of a patent increases the cost of imitation. Subsequent research by Levin *et.al.* and by Mansfield reveals that the existence of a patent does increase

Tewksbury *et.al.* also found that one project with a negative social rate of return helped to make another project successful. They note that it is difficult to allocate benefits and costs to individual projects when there are successive projects and their effects are cumulative. This illustrates the point made earlier that innovation is a cumulative process. The rate of return on a particular segment of the process may be arbitrary.

Mansfield (1991) cites evidence from benefit : cost studies of 40 other new product innovations together with some additional studies of his own that the ratio of the benefits accruing to users to the gross profits of innovators is higher than 8 : 1. The extent of the excess of the social over the private rate of return implied here depends on the profits and R&D costs of successful and unsuccessful imitators as well as on any loss in profits experienced by producers of substitute goods.

Bresnahan (1986) estimated the increase in consumer surplus or spillover benefit accruing to customers of U.S. financial services (banking, insurance and brokerage) firms during the period from 1958 to 1972 as being due to the adoption of general purpose mainframe computers in these industries. The spillover benefit is the additional consumer surplus realized by customers of the financial services industry as a result of the decline in the quality-adjusted price of mainframe computers used by the financial services industry over the period from 1958 to 1972.

Bresnahan calculates the decrease in the 1972 cost of production of financial services as resulting from the difference between the 1972 and 1958 quality-adjusted prices of mainframe computers. If financial services firms are assumed to act as their customers' agents, this is the excess of what these customers would have been willing to pay for the services of mainframe computers over what they actually paid. Bresnahan finds that they would have been willing to pay between $225 million and $417 million in 1972 for computer services for which they actually paid $68 million -- leaving a spillover benefit of between $150 million and $350 million.

Bresnahan does not estimate the profits earned on mainframe computers sold to the financial industry. It would be necessary to add these to the consumer surplus to obtain social benefits. To estimate the social rate of return, social benefits would then be compared with the prorated costs of

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the cost of imitation.

mainframe computer R&D.

In another study, Trajtenberg (1989, 1990) found that the social rate of return on R&D devoted to the improvement of *CT* (computed tomography) scanner technology between 1973 and 1982 was 270 percent.[14] Social benefits were assumed to consist entirely of consumer surplus. Profits are excluded. Trajtenberg does not estimate the private return on CT scanner R&D. He notes, however, that it must have been negative for half of the firms involved since they incurred losses on their CT scanner business (1990, p.167).

Trajtenberg estimates the social rate of return from *improvements* in the CT scanner rather than the rate of return on the *invention* of the CT scanner. Any estimate of the latter would have involved a determination of the difference in the value between the diagnostic services provided by the CT scanner and conventional X-rays, respectively. Instead, Trajtenberg estimates the consumer surplus derived by U.S. users (i.e., U.S. hospitals and clinics with CT scanners) from improvements in scan time, image quality, reconstruction and gantry tilt, which occurred subsequent to commercial introduction.[15]

The case of computed tomography is an example of how research in one area can have applications in other industries or fields of technology. The inventor, Geoffrey Hounslow, was an engineer with EMI, a British firm best known for its records division. EMI was, however, also known for the quality of its research in communications and electronics. Hounslow was working in the general area of pattern identification and computer storage. Although he was not explicitly seeking new diagnostic techniques, one of the problems with which he was concerned was the poor imaging

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[14] The ratio of discounted (at 5 percent) benefits to discounted U.S. R&D costs is 69.2. The ratio of discounted U.S. benefits to discounted worldwide R&D costs is 37.3. The first ratio implies that an R&D expenditure with a present value of one dollar yielded benefits with a present value of $69.20. Calculated at an annual rate of 5 percent, the sum of $69.20 yields a perpetuity of $3.46 per year. This is also known as the *capitalized benefit : cost ratio*. It can also be interpreted as a rate of return. That is, $1 in R&D yields $3.46 in benefits annually in perpetuity. This is a 346 percent rate of return. If foreign R&D is included, the rate of return is 187 percent. The 270 percent figure cited in the text is the simple average of these two. These results depend on the discount rate assumed.

[15] The utility of a scanner is assumed to be a function of its characteristics and its price. This relationship is called an indirect utility function. Trajtenberg employs multinomial logit analysis to estimate the parameters of the indirect utility function. Specifically, these parameters can be inferred from the relationship between the respective market shares and the characteristics and the (residual) price of each type of scanner.

representation of X-ray film. He suggested that crystals be used rather than film. He began work in 1967 and in 1970 installed a prototype CT scanner in London hospital. Commercial production of CT scanners began in 1973.

Fifteen firms entered the market between 1973 and 1978. EMI was dominant for the first five years but was out of the race by 1980. General Electric entered the market in 1976 and by the early 1980s had achieved a position of "undisputable dominance". By 1988 there were eight firms in the market, all of which had the common characteristic of having been suppliers of conventional X-ray technology. Commercial success was based on complementarities in marketing (co-specialized assets) rather than on technological advantage. The customers for CT scanners and X-ray equipment were the same (radiologists). There were economies of joint sales and service and as the pace of product improvement moderated, these advantages prevailed.

The pace of product innovation was very rapid between 1973 and 1980. During that period, performance improved by between 500 percent and 5000 percent, depending upon the dimension. Virtually all the innovation was attributable to the firms already in the market. University and government research "was sparse and had little impact".

Econometric Evidence

Many studies estimate the rate of return on R&D from data samples drawn from firms or industries. Statistical estimates of the private and social rates of return on R&D obtained in these studies have been surveyed by Griliches (1991), Mairesse (1991), Mohnen (1992, 1992a) and Bernstein (1994). The data from which rates of return were estimated in these studies were drawn from a cross-section of firms or industries at a point in time, from time series data on a firm or an industry, or from pooled time series-cross-section data on firms or industries. In those cases where firm-level data are used, the potential exists to estimate the private rate of return (the firm's rate of return on its own R&D), intra-industry spillovers and inter-industry spillovers. Where industry level data are used, the rate of return estimated on "own" R&D is an *industry* rate of return rather than an individual *firm* rate of return. This industry rate of return includes the private rate of return and intra-industry spillover effects.[16] The magnitudes

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[16] Griliches (1991) notes that if there are positive intra-industry spillover effects estimates of the industry level rate of return on R&D should exceed rates of return on R&D estimated at the firm level. He observes that this does not occur consistently and attributes it to the fact that these estimates are gross

of the respective private rate of return and intra-industry spillovers (economies that are external to the firm but internal to the industry) cannot be estimated with industry level data, although inter-industry spillovers can be.[17]

Statistical studies also differ in three other important respects: their assumptions with respect to the production technology of the firm(s) or industry (industries) being studied; whether they estimate the effect of R&D on cost or productivity; and the means by which knowledge generated in one firm or industry is assumed to spill over to others.

Early statistical studies used the production function approach[18] based on the assumption that the underlying technology was Cobb-Douglas. The rates of return on R&D so estimated have been surveyed by Mairesse (1991, Table 4). They vary from -47 percent to 69 percent. These are rates of return on "own R&D".

A number of qualifications are required. Two of the most important are that these estimates vary both as to whether they are rates of return or excess rates of return, and as to whether they are gross or net of depreciation. It is sometimes difficult to separate R&D labour and capital from labour and capital used in production. As a result, R&D is "double counted" in some studies and the estimated return on R&D is consequently interpreted as the excess of the rate of return on R&D over the rate of return on physical capital. Knowledge is also presumed to depreciate in the sense

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of depreciation. Since the R&D of firms is likely to become obsolete faster than aggregate industry R&D, the *net* rate of return at the industry level may still be higher. See the discussion of obsolescence in the text.

[17] Obviously, social rates of return and spillovers cannot be estimated at all when the sample is time series data on a single firm or industry.

[18] The Cobb-Douglas assumption is very restrictive. It implies that no matter what happens to input prices, each input accounts for a constant share of the cost of production. Cobb-Douglas models are estimated either in rate of return form or in elasticity form. A typical rate of return form model would be:
$\Delta TFP = a + b\ RF/Q + c\ SF/Q$

where RF/Q is the ratio of annual *own* R&D expenditures to annual gross output, SF/Q is the ratio of annual *indirect* or *spillover* R&D expenditures to gross output, b is the marginal gross, excess rate of return on own R&D and c is the marginal rate of return on spillover R&D. Under some circumstances, the parameter c can also be interpreted as the excess of the social over the private rate of return on R&D and the sum b+c can be interpreted as the social rate of return on R&D.

that its value declines over time.[19] Depending on the study, estimated rates of return may be gross or net of depreciation. If they are gross of depreciation they should be adjusted downward by an annual decay rate of knowledge. There is some uncertainty as to what this decay rate might be.[20]

Estimates of rates of return from indirect or spillover R&D derived from Cobb-Douglas production function studies are summarized by Mohnen (1992, Table 1). He finds that they vary from 0 to 1200 percent. These studies differ in other respects as well. The most important is the assumptions regarding the means by which an industry or firm benefits from the R&D of others. These assumptions are summarized by Griliches (1991) and Mohnen (1992a). They are:

- *Unspecified transmission mechanism*: The R&D stocks or flows of other firms and/or industries appear in the model as explanatory variables. No weighting scheme is imposed. Weights emerge from the estimation process.

- *Spillovers are embodied in intermediate inputs*: The importance of the jth industry's R&D to the ith industry is assumed to be proportional to the purchases made by the ith industry from the jth.

- *Spillovers follow the same pattern as patent origin and use:* Patents are attributed by patent examiners to an industry most likely to manufacture the patented product and to the industries most likely to use that product. The importance of the jth industry's R&D to the ith industry is given by the ratio of the proportion of patents that j is likely to manufacture, and i is likely to use, to the proportion of patents that j is likely to manufacture.

- *Position in technology space:* Firms are assumed to be in the

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[19] Knowledge is generally not subject to physical decay. An exception might be in the case of pesticides and antibiotics where resistant strains may evolve thus rendering existing technologies obsolete. (Pakes, 1993) In general, existing knowledge decays or becomes less useful in producing new knowledge because it is superceded by superior knowledge. Caballero and Jaffe call this *knowledge obsolescence.* They distinguish it from *creative destruction* or value obsolescence which they define as the decrease in the value of products embodying superceded knowledge.

[20] Using patent citation data, Caballero and Jaffe (1993) estimate the rate of depreciation of knowledge to be between 6 percent and 7.5 percent.

same "technology space" and thus likely to benefit from each other's R&D if their patents are in the same patent classes.

A more recent class of econometric studies focuses on the effect of R&D on cost.[21] The results of these studies are summarized by Mohnen (1992, Tables 2 and 3) and by Bernstein (1994, Tables 2.1-2.3). Some of these studies make less restrictive assumptions regarding the underlying production technology than the Cobb-Douglas assumptions. The authors found frequently that the restrictions embodied in the Cobb-Douglas assumptions are invalid -- which casts doubt on the conclusions reached by the many earlier studies based on Cobb-Douglas assumptions. Nevertheless, commentators continue to cite these earlier studies when generalizing about social rates of return on R&D and the deviation between private and social rates of return.

Estimates of social and private rates of return derived from the studies summarized by Mohnen and by Bernstein vary widely, depending on the specific model employed and on the level of aggregation. Although the definitions of social and private returns vary among studies, they generally find that the social return exceeds the private return. Griliches (1991) summarizes his survey of the econometric and case study evidence as follows:

> In spite of all these [methodological] difficulties, there has been a significant number of reasonably well done studies all pointing in the same direction: R&D spillovers are present, their magnitudes may be quite large, and social rates of return remain significantly above private rates. (pp.23-4)

Government Sponsored R&D

Agricultural R&D

Federal government support of agricultural R&D can be traced to the initiation of experimental farms in 1886. Early contributions made by the experimental farm system include the development of Marquis wheat and the diffusion of the technique of summer fallowing, which increased the rate of return to dryland farming on the prairies. Fowke (1946) notes, however, that both dryland techniques and appropriate wheat varieties would ultimately have diffused into Canada from the prairie states. The

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[21] Of course inferences regarding the effect of R&D on productivity can be drawn from cost functions and inferences regarding the effect of R&D on cost can be drawn from production functions. Duality theory tells us that they are alternative representations of the same thing.

experimental farms simply accelerated this process.

A number of studies estimate the social rate of return on agricultural R&D programs in Canada. These studies estimate the social rate of return on the development of canola (rapeseed) (Nagy and Furtan, 1984); the private and social rates of return on joint venture R&D to improve the characteristics of malting barley (Ulrich, Furtan and Schmitz, 1986); and the social rates of return on beef cattle research (Widmer, Fox and Brinkman, 1988), sheep research (Harbasz, Fox and Brinkman, 1988) and laying hen research (Haque, Fox and Brinkman, 1989).[22]

Ulrich *et.al.* found that research conducted by the federal government and several universities, and supported by certain brewing and malting companies, increased the yield and improved the malting characteristics of barley grown in Canada. This shifted the supply functions of both feed and malting barley outward, reducing its price and increasing the quantity consumed. This, in turn, increased consumer (i.e., maltster, brewer, feedlot) and producer (barley grower) surpluses. This (combined) increase in consumer and producer surplus is known in agricultural economics as the Gross Annual Research Benefit (GARB). Based on the results of other studies of agricultural R&D the GARB is assumed to occur with a lag of seven years and to require "maintenance" expenditures if it is to be maintained.[23] The discount rate that equates the flow of GARB less R&D costs to zero is the social rate of return. Ulrich *et.al.* found that what they call the public rate of return on public expenditures is between 31 percent and 50 percent.

Widmer *et.al.* estimate the rate of return on federal government expenditures on beef cattle research. They use the GARB approach where the GARB is confined to changes in Canadian producer and consumer surplus. The authors estimate the effect of federal R&D spending on the Canadian supply function for beef by including it as an argument in an econometric supply function for beef. They also include U.S. government beef cattle research spending and provincial education and extension

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[22] Palda (1993, pp.195-6) discusses the studies estimating the rate of return on rapeseed and canola development as well as some government-supported proprietary R&D projects. He updates Lermer's (1987) estimates of the rate of return on the R&D investment in the CANDU nuclear reactor (1993, pp.176-90). Lermer's estimates do not include social benefits on by-product technologies.

[23] This is another way of saying that the value of an innovation decays over time. Decay rates are typically assumed to be around 15 percent per year. This limits the extent to which the profitability of a firm can be attributed to an original innovation.

expenditures. They find that Canadian federal expenditures shift the supply function of beef outwards with a lag of between 4 years and 16 years, but U.S. research and provincial extension expenditures do not. They calculate a marginal internal rate of return on beef cattle research of 63 percent when the excess burden of the transfer is excluded from the calculation and 59 percent when a 20 percent excess burden is included.

Harbasz *et.al.* estimate the GARB of Canadian federal sheep research expenditures holding constant the effects of U.S. sheep research, provincial sheep research and extension and education levels. They find that federal research shifts the supply function outward with a three- to six-year lag. Provincial research and extension expenditures also have a statistically significant effect. U.S. research expenditures and education levels are not statistically significant. Harbasz *et.al.* calculate that the marginal internal rate of return on federal sheep research spending is 24.4 percent if there is no excess burden and 20.4 percent if the excess burden is 20 percent of research expenditures.

Haque *et.al.* estimated the GARB of federal government expenditures on laying hen research, holding constant both provincial and U.S. government egg research expenditures. They found that federal research expenditures shift the supply schedule outward with a lag of three to eight years. U.S. egg research also shifts the Canadian supply function outward, implying an international research spillover or "spill-in" effect, as the authors call it. The estimated magnitude of the GARB depends on the assumptions concerning the market for eggs. If output is constrained by quota, then the research-induced shift in supply reduces cost, but there is no expansion of output. If the quota constraint is not binding, the GARB includes an output expansion effect with a magnitude that depends on the extent to which the marketing board has been successful in keeping price above marginal cost. The authors calculate that in a quota constrained context and with a linear supply function, the marginal internal rate of return to federal laying hen research is 91.2 percent if there is no excess burden. Fox, Haque and Brinkman (1990) later concede that they over-estimated the GARB because the intercept of their supply function was negative for part of the sample period.[24] They then re-estimated the GARB constraining the supply function to have a positive intercept and found that it implies a 77.8 percent marginal rate of return on federal laying hen research expenditures.

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[24] If the supply function has a negative intercept (i.e. it lies below the horizontal axis for some output levels) the GARB is confined to the area between the pre-research supply function and the horizontal axis for those output levels.

Estimates of social rates of return on public agricultural R&D in the United States have been summarized in Griliches (1991, Table 2). These include: hybrid corn (1958), 35 percent - 40 percent; hybrid sorghum (1958), 20 percent; poultry (1967), 21 percent - 25 percent; crops (1990), 45 percent - 62 percent; livestock (1990), 11 percent - 83 percent; aggregate (1990), 43 percent - 67 percent.

Infratechnology R&D

Infratechnologies include evaluated scientific data, measurement and test methods and technical methods and procedures (for example, calibration methods). Infratechnologies increase productivity in both research and production and also reduce the cost of transacting in markets. Infratechnologies have been defined as:

> ...highly precise measurements and organized and evaluated scientific and engineering data are necessary for understanding, characterizing and interpreting relevant research findings. Measurement and testing concepts and techniques also enable the process control necessary for higher quality and greater reliability at lower cost in production. Finally, infratechnologies provide buyers and sellers with mutually acceptable, low-cost methods of assuring that specified performance levels are met when technologically sophisticated products enter the marketplace. (Tassey, 1992,p.100)

Table 2
% Firms Where Technology Leaks Out Within 12 Months

Industry	**Product**	**Process**
Chemicals	54	00
Pharmaceuticals	71	33
Petroleum	55	60
Primary Metals	60	80
Electrical Equipment	88	28
Machinery	62	30
Transportation Equipment	75	67
Instruments	88	66
Stone, Clay and Glass	100	20
Other	45	27
Average	70	41

Source: Mansfield (1985, Table II).

Social benefit : cost analysis of the development of infratechnologies such as electromigration standards for semiconductors, optical fibre standards and electromagnetic compatibility standards has been conducted by Link (1991, 1992a, 1992b). The research required to develop these standards was supported by the National Institute of Standards and Technology (NIST). The benefits derived from these standards include savings in the costs of negotiating, contracting and dispute settlement, as well as savings in manufacturing costs and academic research. While respondents to the surveys of potential beneficiaries agreed generally that the NIST-supported development of standards had reduced their costs, they had difficulty estimating the magnitude of the reduction and the extent to which a reduction was attributable to the standards research supported by NIST.

The net benefit of the development of the standards is the cost saving to industry (vendors and customers) and academics less the cost of developing the standards themselves. Link finds the following internal rates of return:

- 117 percent on the development of electromigration standards for semiconductors
- 423 percent on the development of optical fibre standards
- 266 percent on electromagnetic field measurement standards

These rates of return imply that the resources devoted to the development of these standards have been used efficiently.

Two other questions remain: was government support of this research necessary? and was government participation in the research itself necessary?

Incrementality is the first question. Left to itself, would the industry have promulgated these standards? Would the standards have been slower to develop? Would they have been as useful? It might not be in the interest of any one firm to develop standards whose benefits are realized by customers and rivals alike. A collective effort would be required, which could pose problems. It could require the sharing of commercially valuable information with customers and/or rivals,[25] or there could be disputes about

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[25] One respondent in the semiconductor industry stated:
"We can discuss the extremely sensitive proprietary issues of metal quality problems and their potential resolution as it applies to industry standards [with NIST] without the risk of other companies being told

the standards themselves. Standards may have an exclusionary effect and therefore yield commercial advantage with no corresponding social benefit. Thus, depending on their position in the industry, incumbent firms may disagree on the nature of the standards required or they may agree on standards that are injurious to potential entrants. In sum, depending on the market situation, standards may emerge more quickly with government financial support. The standards that do emerge may be more socially beneficial if the government participates in setting them. Link concludes that this is, in fact, the case.

While government participation in standard-setting may make the process more expeditious and the results more socially beneficial, it does not necessarily follow that the government must conduct the supporting research. Required R&D can be contracted out. This depends on whether a disinterested R&D performer can be found and this, in turn, depends on the extent of economies of scope in R&D in the industry involved. If the economies of scope are significant, there are advantages to the centralization of R&D. The question is then whether the centralized R&D unit(s) serve the industry as a whole or if they are commercially linked to a segment of the industry. A government or quasi-government research organization may realize economies of scope in R&D while avoiding linkages with the proprietary interests of individual firms or segments in the industry. In this respect, it may be well suited to provide objective research on which to base standards.

Government-Sponsored Commercial R&D

United States

Cohen and Noll (1991) report economic evaluations of a number of projects intended by the U. S. government to develop new commercial technology for the private sector. In some cases benefit : cost analyses are also reported. The projects evaluated were:

- the supersonic transport
- the applications technology satellite program
- the space shuttle
- the Clinch River breeder reactor
- synthetic fuels from coal
- the photovoltaics commercialization program.

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about our problems" (Link, 1992, p.21).

With the exception of the applications technology satellite (ATS) program, all these programs are regarded as failures.

> On the basis of retrospective benefit : cost analysis, only one program - NASA's activities in developing communications satellites - achieved its objectives and can be regarded as worth the effort. But that program was killed because it came into conflict with more important political forces than the advancement of commercial technology. The photovoltaics program made significant progress, but it was dramatically scaled back for political reasons not related to its accomplishments. The remaining programs were almost unqualified failures. (Cohen and Noll, 1991b, p.365)

Cohen and Noll regard the ATS program as a success:

> The ATS program pioneered new satellite technology. While no evaluation of the program was ever performed, in a sense it would have been superfluous. A social evaluation should asses whether government actually has to do the work: if private industry would have done it anyway, the federal effort would have been unnecessary. This question is not resolved here, but from a narrower point of view the assessment is obvious. The results of work on the first five satellites created several industries and led to innovations on communications satellites worth billions of dollars. Even though only two satellites worked as planned, the experiments obviously justified the investment. (1991b, p.165)

Incrementality is clearly an issue. Did public support "create" several industries or merely speed up their creation? The mere creation of a new industry does not necessarily increase surplus. In fact, it may even reduce surplus if all it does is take business away from other industries in which resources are already sunk. Conceptually, a new industry is no different from a new product. It is beneficial only if it results in a net increase in consumers' and producers' surplus. This requires that at least some of the following occur:

- customers receive lower prices or better quality than existing industries provided;
- firms earn higher profits than in existing industries;
- employees make use of (earn a return on) hitherto unused skills.

There is also a tendency to argue that, if a project or a program is responsible for the creation of a new firm or industry and there is an increase in surplus, this increase should be attributed to the originating project or program in perpetuity. This is incorrect. The rents attributable to the original R&D decay over time and will approach zero in the absence of additional R&D spending. This limits the time horizon over which benefits can be attributed to the original project.

United Kingdom

Careful benefit : cost analyses of two major British government R&D projects, the Concorde and the Advanced Gas Cooled Reactor are reported in Henderson (1977). Henderson calculates the cumulative cost of these two projects as of March 31, 1976. Past expenditures are expressed in constant dollars and accumulated assuming a 10 percent and a 4.5 percent discount rate. For the Concorde, the discounted sum of anticipated additional costs and revenues from 1976 onwards is also estimated. Costs included further development costs and British Airways operating losses. Anticipated revenues were from sales to foreign airlines. The result is an estimated net program *loss* of £2,320 million at 10 percent and £1,670 at 4.5 percent.

Henderson then goes on to consider the external and intangible factors associated with the Concorde project. On the benefit side he considers: balance of payments effects, job creation, deviations between market prices and social opportunity costs, R&D spinoffs and national prestige. He rightly argues that balance of payments effects and job creation effects are simply examples of deviations between private and social costs. He finds that the balance of payment effect is negative (there is a net foreign exchange cost with a 20 percent premium on foreign exchange) and that the project did not employ any labour that would have been unemployed had it not been undertaken. (This is distinguished from a decision to cancel which would have entailed some adjustment costs.) With respect to technical spinoffs, Henderson speculates that they are not large in absolute terms and are even smaller if the spinoffs that might have been realized on other R&D are taken into account. He allows the project a £1 million annual credit for spinoffs and a £10 million lump sum credit for national prestige.

External factors considered on the cost side are: sonic booms, engine noise, high fuel consumption, undue luxury, ozone depletion, and the cost of overflying rights. Henderson rightly rejects fuel costs and undue luxury as factors. Fuel costs are already included in operating losses. Luxury is either paid for by passengers (thus reducing the operating loss) or not paid for at all, in which case it is considered consumer surplus (implying a credit to the project). He regards engine noise, sonic booms and ozone depletion as valid and assumes no ozone damage, no sonic booms *in Britain* and damage from engine noise to be £2 million annually. To obtain permission for the Concorde to overfly other countries, Britain had to grant additional landing rights in London, thus reducing the profits of British Airways. This is a transfer from a global perspective but a cost of £3 million annually from a British perspective. The net effect of all valid intangible and external factors is -£30 million in present value terms.

With respect to the advanced gas cooled reactor, Henderson compares the net benefit stream with that which would have been realized under a conventional light water reactor program. Ignoring externalities, he estimates a net program *loss* of £2,100 million at 10 percent and £1,640 million at 4.5 percent.

Experience with Government-Sponsored R&D

Evidence shows that rates of return on government agricultural R&D and on government infratechnology R&D have been good. This type of R&D usually deals with industry-wide problems and does not generally confer proprietary advantages on individual firms. As a result, project selection is less burdened by rent-seeking than is the case with the support of proprietary R&D, thus facilitating informed yet financially disinterested collaborative guidance. This point was made by Nelson (1982) and reiterated by the Council on Competitiveness (1991) in its advocacy of the support of *precompetitive R&D*. The results of precompetitive R&D can be shared among competitors with minimal distortion of and from commercial rivalry.[26]

The record of government-supported proprietary R&D is much less impressive. Guidance is frequently burdened by redistributive considerations and it is difficult to find informed yet disinterested sources of opinion. In addition, the organizational structures and incentive systems of government departments and government enterprises have simply been unsuited to either the conduct or the support of commercial R&D.

Some of the most serious problems have come with nuclear power and it is tempting to write this off as a special case. Experience in both Britain and in Canada (Lermer, 1987) has shown that nuclear reactor R&D has been a very poor investment. Canadian experience with other areas of energy R&D, including electrical transmission and crude oil recovery, has

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[26] The determination of the boundary between precompetitive and proprietary R&D is not an easy matter. It depends on the extent and nature of the competitive interaction among potential users as well as the their respective technological characteristics (see Cohen, 1993).

been more favourable (McFetridge, 1987). Again, these projects have tended to be characterized by the industry-wide applicability of their results.

Industrial Incidence of Spillovers

Mohen derives a number of generalized conclusions regarding the characteristics of R&D spillovers from the econometric evidence. They include:

- Inter-industry spillover benefits emanate from relatively few (two-digit) industries
- Inter-industry spillover networks are narrow, involving only a few receiving industries for each originating industry
- Inter-industry spillover effects are greater than intra-industry spillover effects
- Intra-industry spillover effects tend to be greater in the more R&D-intensive industries
- Inter-industry spillover effects tend to be greater in less R&D-intensive industries
- Social rates of return on industry-financed R&D may exceed social rates of return on government-financed industry R&D[27]
- Social rates of return on basic research may exceed social rates of return on applied research and development
- Spillover or indirect R&D is sometimes a substitute for and sometimes complementary to the own R&D of the recipient

Drawing on the work of Bernstein, Mohnen concludes that the two-digit industries in which the domestic spillover benefits of R&D are the largest are: primary metals, non-electrical machinery, chemicals, petroleum products, and rubber and plastic products. These conclusions are likely to change significantly in the light of evidence on spill-ins of foreign R&D

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[27] Poole and Bernard (1990) find that increases in the stock of defence R&D (the military innovation stock) reduce the growth of total factor productivity (ΔTFP) in the aerospace, shipbuilding, electronics and chemical industries. They conclude:

...the use of military production as a tool of economic development or political compensation can have harmful effects on the economic dynamism of the involved industries. ... Canadian defence expenditures play an important role in regional and industrial development, through offsets, industrial benefits and Defence Industry Productivity Program (DIPP) grants and loans, and are on occasion subject to pork-barrel type political interference. These factors may account for the negative impact on total factor productivity. (p.13) and spill-outs of Canadian R&D.

The use of patent citations as a measure of spillovers has yielded further insights regarding their incidence. The patented R&D of large corporations spills over proportionately *less* (is more appropriable) than the patented R&D of universities and small corporations.[28] Patented R&D of universities tends to spill over more broadly (in terms of industrial sectors) than patented corporate R&D. Patented R&D of universities is more important (in the sense of having more direct and indirect citations in other patents and thus having more spillover beneficiaries) than patented corporate R&D. (Trajtenberg, Henderson and Jaffe, 1992).

The extent of spillover benefits also depends on the characteristics of the technology, the characteristics of the business in which it is developed and the property rights regime in place. Levin *et.al.* have found that technologies susceptible to reverse engineering are especially vulnerable to imitation (see Table 1). Whether by reverse engineering or other means, new technologies become known to potential imitators more quickly in some industries than in others. Survey work by Mansfield (1985) shows that the incidence of this kind of leakage is particularly high in the instrument, electrical, and stone, clay and glass industries (see Table 2).

The spillover benefits of generic technologies may also be relatively large. Generic technologies are concepts, components, processes or investigations of scientific phenomena that have the potential to be applied by a broad range of products and processes. Generic technologies may make innovations or further research leading to innovations possible in a wide variety of industries. What constitutes a generic technology is likely to vary from industry to industry, however. In the science-based industries such as pharmaceuticals, generic technologies may arise from basic research. In the manufacturing industries such as electronics generic technologies are more likely to involve process and materials developments (Council on Competitiveness, 1991).

Insofar as line of business characteristics are concerned, businesses in which "co-specialized assets" such as reputation, market access and operational knowhow are important, are less vulnerable to imitation. Operations characterized by learning curves are also less vulnerable unless learning effects spill over. The existence of patent protection forestalls or at

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[28] Trajtenberg *et.al.* define the degree of appropriability in terms of the proportion of self-citations. Thus, a larger portion of the citations of patents held by large corporations are self-citations.

least slows down imitation but patent protection may not reduce spillover benefits if innovations would otherwise have been kept secret.

Are Spillovers Declining?

Much concern has been expressed in recent years that the productivity of resources devoted to innovation (R&D productivity) has declined. The principal sources of this concern are an observed decline in the patent : R&D ratio across countries and industries, a decline in the estimated effect of R&D on TFP growth (coefficient b in footnote 18) and a decline in the extent to which the more recent cohorts of patents are cited (Evenson, 1993; Griliches, 1994; Cabalerro and Jaffe, 1993).

Some scholars attach little significance to the decline in the patent : R&D ratio. Trajtenberg (1990), for example, regards patents more as a measure of innovative input than output and would thus not see the patent : R&D ratio as implying anything about the productivity of innovators. Griliches (1994) argues that the declining ratio of patents to *formal* R&D is not a recent phenomenon and cannot, in any case, be taken to imply that there has been a decline in the *value* of innovations per unit of innovative effort, *broadly defined*.

Evenson (1993) accepts that there has been a decrease in the propensity to patent but maintains that it is insufficient to explain the bulk of the decline in the patents : R&D ratio. Evenson's view is supported by non-patent evidence that R&D productivity has declined. An example is the finding by Hall (1993) that the stock market evaluation of R&D expenditures fell precipitously during the 1980s. The effect of R&D on TFP growth also declined during the 1980s, although Griliches (1994) attributes much of this to measurement error.

Evenson concludes that there has been a decline in R&D productivity and suggests two explanations, both of which assume that there is a stock of public knowledge or open science containing a finite number of ideas or invention possibilities.[29] The first explanation is that there has been an increase in the demand for inventions, which has drawn additional resources into inventive activity so that more inventors are working with a

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[29] This approach can be traced back to the debate surrounding "market pull" *vs* "technology push" debate. At issue was whether the pace of innovation is constrained by a lack of basic scientific knowledge (see Rosenberg, 1982).

given stock of scientific knowledge. The declining patents : R&D or patents : scientists and engineers ratio is then a reflection of the operation of the law of variable proportions or diminishing marginal productivity.

The second explanation is that the stock of invention possibilities has been drawn down and has not been replenished or recharged. Again, the law of variable proportions implies that the productivity of R&D would decline.

Evenson concludes that growth in demand for innovations is the more likely explanation. Kortum (1993) agrees, although he does not regard the demand growth explanation as sufficient. This leaves unanswered the questions of why the stock of invention possibilities was drawn down and how it might be replenished.

The Geography of Spillovers

Local Agglomeration Economies

The concept of external economies has been known since Marshall and Pigou. External economies occur when the expansion of an industry reduces the costs of all the firms in the industry. External diseconomies occur when the expansion of an industry increases the costs of all the firms in the industry.

External economies and diseconomies are frequently assumed to be localized hence the terms "agglomeration economies" and "diseconomies". This need not be the case. Indeed, the geographic incidence of external economies and diseconomies is not well understood.

Krugman's (1991) discussion of the sources of agglomeration economies relies on Marshall, who cites three sources of agglomeration economies:

- economies of labour market pooling
- economies in the provision of specialized inputs
- technological spillovers

A key question for Canada is whether technological spillovers are an important source of agglomeration economies. If they are, it means that innovation systems should be analyzed in regional or even local, rather than national, terms. It further implies that self-sustaining innovation systems or innovative clusters are unlikely to emerge in the many smaller, geographically isolated communities in Canada.[30] The localization of technological spillovers could also reduce the benefits derived by Canadian-based firms from developments occurring in various centres in the United States. Canadian-based firms may not be able to "tap into" the U.S. innovation system on equal terms.[31]

Krugman quotes Marshall on the nature of the advantages of labour market pooling. According to Marshall (1964, pp 225-6):

> Again, in all but the earliest stages of development, a localized industry gains great advantage from the fact that it offers a constant market for skill. Employers are apt to resort to any place where they are likely to find a good choice of workers with the special skill they require; while men seeking employment go to places where there are many employers who need such skill as theirs and where therefore it is likely to find a good market. The owner of an isolated factory, even if he has access to a plentiful supply of general labour, is often put to great shifts for want of some special skilled labour.

The advantages of labour market pooling derive from a less than perfect correlation of employers' demands for labour. Given this imperfect correlation, some employers will experience "good times" and so demand additional labour at the same time as others are experiencing "bad times" and laying workers off. These positive and negative employment shocks cancel each other out; if the labour market is large enough, there is no random variation in aggregate employment.

Of course, if wages are flexible and they adjust to clear the labour market, employment need not vary. In this case the economies of labour market pooling take another form. It can readily be shown that firms are better off (and workers are no worse off) paying workers a constant wage

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[30] Lacroix and Martin (1987) conclude that self-sustaining innovative clusters are unlikely to emerge in metropolitan areas of less than 400,000 in population.

[31] Porter (1991) contends that Canadian-based firms are likely to be at a continuing disadvantage in this regard. He cites differences in the type of development occurring in Seattle and Vancouver as evidence in support of his argument. If spillovers are localized, the ability of Canadian-based firms to compete is determined by the Canadian "diamond", which Porter regards as deficient in many respects, rather than the North American diamond.

than they are paying wage rates that vary but have the same average.[32]

Krugman (1991, pp.41-3) shows that, in the context of a simple model in which firms and workers must choose one of two locations, the advantages of labour market pooling will result in an equilibrium in which all production is located in the same place.[33]

On the economies of supply of specialized inputs, Marshall stated:

> ...the economic use of expensive machinery can sometimes be attained in a very high degree in a district in which there is a large aggregate production of the same kind even though no individual capital in the trade be very large. For subsidiary industries devoting themselves each to one small branch of the process of production, and working it for a great many of their neighbours, are able to keep in constant use machinery of the most highly specialized character and to make it pay its expenses though its original cost may have been high and its rate of depreciation very rapid (p.225).

Thus, the larger the market, the more likely it is to be able to support specialized input suppliers.[34] Again, this requires indivisibilities of some sort in specialized input supply; otherwise even the smallest demand could support a specialist. Economies of specialized input supply will be localized (i.e., they will result in agglomeration economies) if transportation costs of intermediate inputs are not too low relative to the transportation costs of final products. If transportation costs of intermediate inputs are relatively low, then specialized suppliers can serve customers in a variety of locations and there is no particular advantage to locations which happen to be large markets.

On technological spillovers, Marshall states:

> When an industry has thus chosen a locality for itself, it is likely to stay there long; so great are the advantages which people following the same trade get from near neighbourhood to one another. The mysteries of the trade become no mysteries; but are, as it were in the air, and children learn many of them unconsciously. Good work is rightly appreciated, inventions and improvements in machinery, in processes and the general organization of the business have their merits promptly discussed: if one man starts a new idea it is taken up by

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[32] See Currie, Murphy and Schmitz (1971) and the references therein.

[33] The requirement that firms choose one location is equivalent to assuming economies of scale hence an advantage to a single production location.

[34] Stigler (1968) used the same reasoning as the basis for a theory of vertical disintegration. In his model, the growth of the market gives rise to *independent* suppliers of specialized inputs.

> others and combined with suggestions of their own; and thus it becomes a source of further new ideas. And presently subsidiary trades grow up in the neighbourhood, supplying it with implements and materials, organizing its traffic and in many ways conducing to the economy of its material (p.225).

Porter (1990, p.154-7) emphasizes the importance of agglomeration economies as a source of international competitive advantage and while he attributes them to all three of the sources cited by Marshall, he stresses technological spillovers.

> A [geographic] concentration of rivals, customers and suppliers will promote efficiencies and specialization. *More important, however, is the influence of geographic concentration on improvement and innovation.* [italics added] Rivals located close to each other will tend to be jealous and emotional competitors. Universities located near a group of competitors will be most likely to notice the industry, perceive it to be important and respond accordingly. In turn, competitors are more likely to fund and support local university activity. Suppliers located nearby will be best positioned for regular interchange and cooperation with industry research and development efforts. Sophisticated customers located nearby offer the best possibilities for transmitting information, engaging in regular interchange about emerging needs and technologies and demanding extraordinary service and product performance. Geographic concentration of an industry acts as a strong magnet to attract talented people and other factors to it. ...
>
> Proximity increases the concentration of information and thus the likelihood of its being noticed and acted upon. Proximity increases the speed of information flow within a national industry and the rate at which innovations diffuse. At the same time, it tends to limit the spread of information outside because communication takes forms (such as face to face contact) which leak out only slowly. ... The process of clustering and the interchange among industries in the cluster also works best when the industries involved are geographically concentrated (p.157).

Whether geographic proximity makes for more "jealous and emotional" competition is difficult to say. Porter does, however, cite one plausible theoretical reason why technological cooperation may be facilitated by geographic proximity: there may be less scope for opportunistic behaviour when both parties to an agreement are located in the same community. There are a number of reasons for this. There may be constraining forces in the form of common membership in community organizations. Information asymmetries may be less severe in that the parties can observe each other's operations at lower cost. They may also face common local conditions, which make it less costly to verify assertions regarding unforseen contingencies. The gains from the redistribution of rents may also be smaller (i.e., if the parties use the same suppliers and draw from the same pool of specialized employees and input suppliers).

Krugman is rightly skeptical regarding the importance of localized technology spillovers. There is relatively little in the way of a "paper trail". Marshall asserts that these spillovers are "in the air". Porter's eclectic argument relies on professional labour market pooling, specialized input supply (including a supply of research services by local universities) and on the importance of face-to-face contact and direct observation for information transfer.

Many, indeed most, localized industries are not technology-intensive.[35] Porter cites the following Italian industries as being geographically concentrated: furniture, stonework, jewelry, wool textiles, food preparation, packaging machinery, food processing machinery, ski boots, woodworking machinery, knitwear, ceramic tiles, lighting, steel and factory automation equipment (1990, p.155). The implication is that they benefit from economies of labour market pooling or specialized input supply rather than from technology spillovers. Krugman argues that Route 128 and Silicon Valley, the most frequently cited examples of high-tech agglomeration economies, owe more to the economies of (professional) labour market pooling than they do to technology spillovers.

Evidence of the nature of the interaction among technology-intensive firms in close geographic proximity comes from the studies of science or research parks which are usually located near a university or a major research facility. The proliferation of science parks has been based on the assumption that geographic proximity is necessary to facilitate both technology flows and collaborative activity:

> Physical proximity would ease the flow of scientific/technological information and the creation of a network of collaboration among different science park tenants. Resident companies would gain privileged access to highly specialized manpower in the form of graduate students and university researchers. Thus, one of the fundamental premises in the justification for the growing number of science parks is that high technology industry benefits from its location alongside a university because of the enhanced information, collaboration and recruitment opportunities (Van Dierdonck, Debackere and Rappa, 1991, p.111).

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[35] Solway (1987) studied Toronto's fashion district. He finds that agglomeration economies are derived in part from the advantage of personal business relationships among specialists providing non-standardized services. Horizontal collaboration is facilitated by the differentiated nature of the final products. Individual firms do not see themselves as close competitors.

The many studies of science parks reach a common conclusion -- that being located in a science park does not materially enhance technological interchange with either the adjacent university or other science park tenants (Van Dierdonck *et.al.*, p.111).[36] A number of reasons are given. First, technology has a variety of sources, some of which may be distant and some of which may be local, but not necessarily in the park. Even if the requisite technological expertise is available within a science park, complementary business expertise may not be. Second, person-to-person networks can be spatial or professional (or both). Professional networks have no geographic boundaries; linkages are based on common training and interests rather than on geographic proximity. Face-to-face contact is not necessary.

Other studies have found evidence consistent with economies of agglomeration in *industrial* parks. For example, Rauch (1993) cites a number of studies showing that land prices in industrial parks in the United States increased much more quickly than the price of adjacent land. He concludes that:

> The most straightforward interpretation of the spectacular land price increases in these case studies appears to be ...[that]: later tenants are paying for the privilege of benefitting from economies of agglomeration as firms accumulate within the park allowing developers to recoup the costs they incurred in subsidizing early tenants (1993, p.858).

The nature of these agglomeration economies is not specified. It may have to do with the supply of business services, but it probably has little to do with technology spillovers.

Jaffe, Trajtenberg and Henderson (1993) offer evidence in support of local technological spillovers: the geographic distribution of patent citations. An existing patent is cited on a patent application if the applicant has made use of the information disclosed in it in her own invention. Since the applicant is not obliged to pay the owners of the cited patents for information derived from them, this is a spillover benefit. The authors investigated whether the probability of being cited is a function of geographic proximity to the applicant for the citing patent. Their method is to compare the respective frequencies with which a sample of cited patents

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[36] Kenney and Florida (1994, Table 7) have published contradictory findings for Japan. They find that proximity to universities is the second (of 14) most important determinant of the location of corporate basic research, while proximity to government labs is fifth.

come from the same geographic area (country, state, SMSA) as:[37]

(a) the patents which cite them and;
(b) matching patents which do not cite them.[38]

The authors summarize their results as follows:

> For citations observed by 1,989 of 1980 patents, *there is a clear pattern of localization at the country, state, and SMSA levels.* [italics added] Citations are five to ten times as likely to come from the same SMSA as control [matching] patents; two to six times as likely excluding self-citations. They are three to four times as likely to come from the same state as the originating patent; roughly twice as likely excluding self-cites. Whereas about 60 percent of control patents are domestic, 70 to 75 percent of citations and 69 to 70 percent of citations excluding self-cites are domestic. Once self-cites are excluded, universities and firms have about the same domestic citation fraction; at the state and SMSA level there is weak evidence that university citations are less localized. For citations of 1975 patents, the same pattern, but weaker, emerges for citations of university and other corporate patents. For top corporate [patents] there is no evidence of localization at the state or country levels, though the SMSA fraction is significantly localized. (1993, p.591)

Jaffe *et.al.* interpret their results as showing that an inventor has a higher probability of benefitting from the work of predecessors if they reside in the same community. The advantage of geographic proximity fades, however, over time. An implication is that direct observation or personal contact accelerates the diffusion of knowledge.

Another interpretation of the Jaffe *et.al.* results is that citing and cited inventors are more likely to reside in the same community for reasons other than spillovers. One reason could be economies of professional labour market pooling. Inventors with similar backgrounds and interests may be more likely to locate in the same geographic area for reasons of employment stability and it may be their common interests rather than observational advantages that lead them to cite each other more frequently.

To the extent that they do imply localized technology spillovers, the Jaffe *et.al.* results do not support the argument that spillovers stem from concentrations of particular lines of business. The authors find that the

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[37] SMSA means Standard Metropolitan Statistical Area.

[38] A matching patent is one in the same patent class and with the same application year as the citing patent.

incidence of localization of within-patent-class citations is no greater than the localization of across-class citations. Thus, geographic proximity does not facilitate imitation *per se.* The technological agglomeration economies identified by the authors are external not only to the firm but also to the product line if not the industry. It appears that the ability to innovate is enhanced by the presence of other innovative firms regardless of whether their activities are closely related.[39]

A study by Jaffe (1989) admits to a similar interpretation -- that interstate differences in corporate patenting activity are a function of technologically-related university R&D spending in the state. Jaffe finds that this spillover effect is greater in states in which university and industrial R&D activity have the same geographic distribution. This implies that within-state geographic proximity matters. He determined, however, that while this result holds for corporate patents in aggregate and in the case of chemical patents, it does not hold in the cases of drugs, electronics or mechanical arts patents, respectively. One implication is that corporate patentees are benefitting from generalized rather than specialized university expertise.

The findings of Rauch (1993) also attest to the generalized spillover benefits derived by communities from their well-educated residents. Rauch finds that, given their individual characteristics, the incomes of individuals are also increasing functions of the average education levels in the Standard Metropolitan Statistical Areas (SMSAs) in which they reside. The means by which the highly educated individuals increase the productivity of others in the community are not well understood.

In sum, it is clear that agglomeration economies exist and that their most likely sources are labour market and infrastructure (especially transportation) specialization. Porter's arguments notwithstanding, there is little to indicate that firms located at a distance from their rivals are technologically disadvantaged. In general, therefore, Canadian-based firms should not experience significant "natural" disadvantages in accessing

[39] Glaeser, Kalal, Scheinkman and Shliefer (1991) find that, over the period 1956-87, individual industries tended to grow faster in cities where they are under-represented relative to the national average and in cities where employment is more evenly distributed across industries. This implies that agglomeration economies do not arise from concentrations of similar activities in the same location. Similarly, Kenney and Florida (1994) find insofar as the location of basic and applied corporate research and production engineering in Japan is concerned, proximity to or distance from competitors is never an important factor, while quality of life, transportation linkages and availability of engineers always rank near the top.

technological developments in major U.S. centers.[40] Although communities derive spillover benefits from the presence of human capital-intensive individuals, these individuals need not be concentrated in a particular industry or area of technological specialization. Indeed, there appears to be a dynamic benefit from diversity.

Smaller communities are not likely to attract industries requiring specialized skills or professional qualifications.[41] It should be emphasized, however, that the threshold at which local demand is sufficient to support specialization varies from specialty to specialty. It has been argued, for example, that smaller Canadian metropolitan areas have a better chance of attracting the R&D end of high technology businesses than they have of attracting the marketing and financial end.

International Spillovers

International technology transfer is a much-studied phenomenon. Much less is known about the extent to which the benefits of innovation spill over internationally. The existence of international spillovers has important implications for public policy. From a national point of view, the social rate of return on innovation depends on the magnitude of domestic spillover benefits. From a national income point of view, there is no payoff to encouraging innovative activities with large international but small domestic spillover benefits. Moreover, if spillovers do not flow readily across national borders, Canadian-based firms will be at a disadvantage in participating in the North American innovation system.

There are many channels through which the benefits of technological innovation can spill over internationally. New technologies may be embodied in goods that are traded internationally. If the prices at which those goods trade do not fully reflect the value of the new technologies embodied in them, a spillover benefit in the form of consumers surplus will be realized by users in the importing country.[42] Prices of new product innovations may not reflect their

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[40] Artificial barriers to technology flows include the exclusion of Canadian-based firms from R&D consortia and other networks.

[41] An exception would be the "lone eagles" who are able to work for employers in many different locations using telecommunications links.

[42] There can also be a negative pecuniary externality due to "creative destruction." Innovations in one country may reduce the quasi-rents accruing to specialized resources producing substitute products in

(continued...)

value to users because of competition or the threat of competition from imitators. If those imitators are foreign, any profits they realize also constitute an international spillover benefit. Foreign imitations which infringe the innovator's intellectual property rights have become known as piracy.[43] Intellectual property rights are created by national governments and in some countries these rights have been weak or non-existent. Piracy is also said to occur when a foreign imitation or copy would have infringed on the innovator's intellectual property if it had occurred in the innovator's home country. The United States has claimed that huge losses have been suffered by its nationals at the hands of foreign pirates. (McFetridge and English, 1990)

Technology is also transferred internationally in disembodied form. Historically, this has occurred within two broad classes of institutions (governance structures), arm's-length (market) and intra-firm (internal). Spillovers may occur because these governance structures do not enable the innovator to capture the entire benefit of his innovation. One form of international spillover occurs if an innovation in one country increases the productivity of R&D resources in another and no compensation is paid. Examples include the facilitation of a follow-on innovation in another country and the generation of knowledge that is complementary to knowledge existing in other countries.

The respective characteristics of technologies transferred by the market and internal modes have been the subject of much study.[44] In general, the greater the investment required to make the transfer, the more likely it is that the transfer will be internal. This has been associated with novel, complex and noncodifiable technologies. The institutions or governance structures within which technology is transferred are, however, now sufficiently varied that the market-internal distinction is simply one of many that can be made.

Spillovers occur in arm's-length international technology transactions if license fees and royalties paid by licensees are less than the value of the

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(...continued)
another.

[43] Unauthorized use of a trademark is called counterfeiting. The term piracy is most frequently used in connection with unauthorized copying of copyrighted material.

[44] Reddy and Zhao (1990), McFetridge (forthcoming, 1995).

technology to them. This is generally the case.[45] Again, it is attributable to competition or the threat of it, most notably from the potential licensee. Licensing can be viewed as a means by which imitative R&D by the licensee is avoided and the benefits of this saving are shared.

Spillovers also occur in internal technology transfers when employees in foreign subsidiaries realize learning benefits for which they do not pay (in the form of lower wages) or when host country customers or suppliers are able to realize surplus from spinoffs resulting from collaboration with foreign subsidiaries. Of course, benefits of host country customers and suppliers need not be at the expense of home country customers or suppliers. Foreign subsidiaries may find opportunities for collaboration that do not exist in the home market. Studies of host-country spillover benefits often find that they take the form of demonstration effects wherein local firms learn a variety of organizational and operational techniques rather than from the imitation of specific technologies.

Issues of international technology transfer and spillovers have historically been addressed from the perspective of an innovating country (the United States) which transfers technology to other countries either in embodied or disembodied form. The process of innovation is itself becoming increasingly internationalized, which is manifest in the internationalization of the R&D function in multinational enterprise and in the emergence of international R&D networks.

The internationalization of the R&D function in multinational enterprises has taken two general forms. The first is market-oriented R&D, which supports operations in a foreign market. This occurs in idiosyncratic markets or where the market is large and interaction with customers is required. The host country may realize spillover benefits in the form of learning by professional employees, surplus on R&D collaboration between the subsidiary and local customers, and professional labour market agglomeration economies. Some of these benefits may be realized at the expense of the home country.

The second form of internationalization is knowledge-oriented. It may take advantage of expertise accumulated by the subsidiary or of other sources of knowledge in the host country. This form of intelligence

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[45] The licensing literature refers to the two-thirds-one-third rule under which the licensee receives two-thirds of the benefits of a licensed technology and the licensor, one-third (see McFetridge and Raffiquzzaman, 1987).

gathering has been noted in connection with the decisions of firms in the electronics and biochemistry industries to locate R&D operations in the United States (Dalton and Serapio, 1993; Grandstrand, Hakanson and Sjolander, 1993). Such "listening post" R&D increases international spillovers to the detriment of the host country. It facilitates imitation of proprietary innovations and also harvests the host country's stock of "open science" for use at home.

R&D may be coordinated internationally through network arrangements. The R&D may be proprietary or nonproprietary ("open science"). Alliances frequently involve contributions of complementary knowledge by each of the participants. International barter of knowledge is taking place as alliances, consortia and networks reduce duplicative research and internalize both domestic and international externalities.

The means by which knowledge may flow to foreign users, whether imitators, follow-on innovators or innovators in unrelated fields, are the same as the channels available to domestic imitators. These are cited earlier in this study as imitative R&D, reverse engineering, licensing, employee mobility, technical publications and meetings, patent disclosures and revelations by employees of innovating firms.

Evidence of the realization of spillover benefits by foreigners engaged in follow-on research is reported by Jaffe, Trajtenberg and Henderson (1993). These authors used citations of U.S. patents in patents with foreign inventors as a measure of spillover of U.S. technology abroad. They find that borders *do* matter; that is, that U.S. patents have a higher probability of being cited by another U.S. patent than by a foreign patent. Nevertheless, the difference in probability is modest and largely transitory, implying that the bulk of the difference between domestic and international spillovers takes the form of a short international diffusion lag.[46]

Nelson and Wright (1992) argue that the international diffusion of

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[46] The probability that a 1975 U.S. patent will be cited in subsequent U.S. patent applications of U.S. corporate inventors is not different from the probability that a 1975 U.S. patent will be cited in the subsequent U.S. patent applications of foreign corporate inventors. There is about a three percentage point difference between the respective probabilities that U.S. and foreign university applications will cite a 1975 U.S. patent and this is marginally significant statistically. The probability that a 1980 U.S. patent will be cited in subsequent patent applications from U.S. inventors is about ten percentage points higher than in the U.S. patent applications of foreign inventors and this difference is statistically significant. Some but not all of this difference is due to the shorter period in which citations of 1980 patents are observed.

knowledge in technical publications and other media has become increasingly widespread as more countries develop the capacity to make use of scientific and technological publications, date and plans. This increases the probability of a foreign spillover and advances its timing as well as increasing its magnitude. Nelson and Wright attribute the decline in U.S. "technological leadership" to these spillovers.

There is some econometric evidence on the productivity effects of international technology spillovers. The studies of the benefits of Canadian government agricultural R&D allow U.S. government agricultural R&D to have an effect on Canadian production costs. They find that U.S. R&D reduced Canadian production costs in one case (laying hens) and had no effect in two others (beef cattle and sheep).

The effect of American R&D on Canadian manufacturing productivity has been investigated by Mohnen (1992) and Bernstein (1994). Bernstein used the cost function approach. Specifically, he estimates average variable cost functions for Canadian and U.S. two-digit industries respectively. Domestic and foreign spillover effects are inferred from the respective effects on average variable cost of the stock of R&D in other domestic manufacturing industries and the stock of R&D in the same two-digit industry in the other country. An industry realizes positive *intranational* spillover benefits if an increase in the stock of R&D in other domestic manufacturing industries reduces its average variable cost (holding output, input intensities and input prices constant). An industry realizes positive *international* spillover benefits if an increase in the stock of R&D in the same two-digit industry in the other country reduces its average variable cost.

Bernstein found that statistically significant *intranational* spillover benefits are realized by three of eleven Canadian industries (electrical equipment, food and beverage and petroleum products).[47] R&D spillovers among two-digit industries *within* Canada thus appear to be less important than Bernstein's earlier work implied. Bernstein also found that seven Canadian industries (electrical equipment, fabricated metals, nonelectrical machinery, nonmetallic minerals, petroleum products, primary metals and transportation equipment) realize *international* spillover benefits from the stock of R&D in the same industry in the United States. Two U.S. industries (food and beverage and paper and allied) realize spillover

[47] These inferences are drawn from Bernstein (1994, Tables 4-14). Spillover benefits were inferred if the direct average variable cost elasticity is negative and twice its standard deviation.

benefits from R&D in the same industry in Canada.

Bernstein's results would appear to weaken considerably the case for government support of industrial R&D. Statistically significant domestic spillover benefits are realized in only three of the eleven Canadian industries studied.[48] International spillovers are more important. Of course, Canadian firms must invest in R&D in order to realize spillover benefits but there is a private incentive to do so (An increase in U.S. R&D stock increases the desired Canadian R&D stock in eight cases.) The externality rationale for public support is not there. This result could change, of course, if the analysis were extended to allow for intra-industry spillovers.

In sum, the existence of international spillovers complicates prescriptions for efficient resource allocation. Policy should favour activities with large *domestic* spillover benefits. While it is purely a matter of conjecture, the type of innovations that generate the largest domestic spillover benefits might be those that add value to unique domestic resources.[49]

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[48] Four U.S. industries realize statistically significant intra-national spillover benefits.

[49] An example that comes to mind is tar sands and heavy oil R&D. Whether the pattern of conventional crude prices has been such that this R&D has yielded a good rate of return is another matter.

PART 3
INCREASING APPROPRIABILITY: THE PATENT SYSTEM

The Intellectual Property Bargain

A patent is a property right in a new invention granted by a national government. It allows the owner (the patentee) to exclude others from making, using or selling the patented invention in the country granting the patent for up to 20 years from the date the application is filed. In return for the *right to exclude*, the patentee must *disclose his invention*. Disclosure involves the provision of a clear and complete description of the invention on the patent application. The description must be sufficient to enable anyone with average skill in the technology to make or use the invention. Patent applications are published eighteen months after they are filed.

Patents apply to new (novel) technologies. To meet the novelty requirement, an applicant must be the first to apply (file) except in the United States where the patent is granted to the first to invent. A patent will not be granted on an invention that has been in the public domain for more than a year.

In order to qualify for a patent an invention must be useful and operational; also, the invention must be nonobvious. Patents can be granted on a new product, a new apparatus, a new chemical composition or a new process. Patents are not granted on ideas, scientific principles, theorems, organizational forms or methods, computer programs or medical treatments.

Patents are granted on microbial life forms including bacteria, yeast, moulds, fungi, actinomycetes, algae, cell lines , viruses and protozoa, provided that the usual standards of novelty, utility and nonobviousness are met. Processes for manipulating or utilizing microorganisms can also be patented but patent protection does not extend to the microorganism as it is found in nature. Plants and animals have not been patented in Canada but the processes for producing plants and animals that require significant human intervention may be patentable.

The right to patent has been characterized as a limited monopoly. Its purpose is to allow inventors to capture a portion of the social value of their inventions and thus to help to overcome the inappropriability problem discussed in Part 1. The power to exclude allows the patentee to require that users of the invention pay for its use and thus to recover the inventor's R&D cost.

Once a new technology exists, it is efficient that it be used by anyone who is willing to pay the marginal cost of its use. Marginal cost may be much lower than average cost, which includes the R&D cost of the invention. For a new process, marginal cost might be the cost of reproducing plans or instructions. For new software it might be the cost of copying it on a diskette. For a CT scanner it would be marginal manufacturing cost.

The cost of the patentee's R&D effort can be recovered only if (at least) some users are charged prices in excess of marginal cost. If all users are charged a price in excess of marginal cost, use of the patent may be restricted.[50] Thus, there may be tension between two social objectives. In order to increase the incentive to innovate, dissemination of an innovation may be restricted by pricing it above marginal cost for a period of time. This is the essence of the intellectual property bargain. But society does not want to restrict the use of an invention, once it has been introduced for any longer than is necessary. The objective is to minimize the restriction on use required to provide a given incentive to invent. This creates an optimization problem. It is in society's interest to structure each dimension of the patent right so that the surplus from additional inventive activity induced by a more restrictive right is just equal to the surplus foregone due to restricted use.

The Patent as an Incentive to Invent

Patents are intended to increase the extent to which the benefits of an invention can be appropriated by the inventor and thus to provide an incentive to invent. An inventor can discourage would-be imitators in a number of ways. These are listed in order of importance in Table 3. While such ranking varies from industry to industry, the most important means of appropriating the returns on an innovation overall are:

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[50] It is important to understand that patents can also encourage dissemination of knowledge. First, an invention is disclosed after the filing of a patent application. The knowledge so disclosed is then freely available to all non-infringing (i.e., non-imitating) users. Second, the patentee has an incentive to publicize his invention and thus to build up the demand for it. This may encourage more widespread use once the patent has expired than would have been the case had the patentee relied on secrecy as a means of appropriating the returns on his invention.

- having access to unique co-specialized assets
- having an R&D lead
- moving down the learning or experience curve

Table 3
How Do Innovators Protect Themselves From Imitation?

Method of Appropriating Benefits	Effectiveness (Rank Order) Products	Processes
Superior Sales or Service	1	3
Having an R&D Lead	2	1
Moving Quickly Down the Learning Curve	3	2
Patents to Prevent Duplication	4	5
Patents to Secure Royalties	5	6
Secrecy	6	4

Source: Levin et.al. (1987).

Co-specialized assets include production knowhow or facilities, marketing experience or facilities, or reputation. The inventor is protected from imitation when exploitation of an invention requires unique complementary assets to which the inventor has access while imitators do not.

Inventors with an R&D lead have a period of monopoly power before imitators are able to enter the market. Inventors relying on the learning curve take advantage of their early entry into the market to accumulate production or marketing experience which reduces their unit costs and discourages potential imitators.

As Table 3 indicates, patents rank behind co-specialized assets, R&D leads and the experience curve, but ahead of trade secrecy as a means of appropriating the returns on inventive activity. This implies that patents do not provide much in the way of additional incentive to invent for some firms and, perhaps, in some industries. As Table 4 indicates, however, the patent system does provide a significant additional incentive to invent in the pharmaceutical, chemical and petroleum industries. It also provides a modest additional incentive in the machinery, fabricated metals and electrical products industries.

Table 4
The Importance of the Patent System as an Incentive to Invent

Industry	% Innovations That Would Not Have Been Developed in the Absence of Patent Protection
Pharmaceuticals	60
Chemicals	38
Petroleum	25
Machinery	17
Fabricated Metal Products	12
Primary Metals	01
Electrical Equipment	11
Instruments	01
Office Equipment	00
Motor Vehicles	00
Rubber	00
Textiles	00

Source: Mansfield (1986, Table 1)

The Patent System and the Disclosure of New Technological Information

The patent system is intended to encourage inventors to publicize their inventions rather than to keep them secret, and the description of the invention in the patent application is intended to assist others in developing non-infringing applications and improvements. The evidence is, however, that patent applications are not one of the more important sources of technological information. Earlier in this study, Table 1 showed that patent disclosure ranks sixth out of seven sources of technical information. Independent R&D, reverse engineering, licensing, hiring employees of the inventing firm and publications and trade fairs are all more important.[51]

Table 5 shows the examination of patent applications to be among the least important sources of information for Canadian high technology firms, although it is a more important source of information for medium and low technology firms. This may reflect a difference in the industrial composition of these two groups. It may also be the case, however, that for many high technology firms, the pace of change is such that by the time a patent application is published the technology described in it has been superceded.

It is possible that patent applications are a potentially more fruitful source of information for so-called medium technology firms. Paul David has argued that, in general, access to the existing stock of technical information is becoming increasingly important as innovation becomes more a matter of integrating and recombining existing scientific and technological findings. David emphasizes what he calls the "distribution power" of an economy, which is simply the ability of innovative organizations to make use of the existing inventory of scientific and technological findings. This partly a matter of awareness and partly a matter of negotiating terms of access when the knowledge involved is proprietary.

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[51] It is arguable that information would not be obtainable via license agreements if there were no patent protection.

Table 5
Sources of Information

Source	**Firm Type** High Technology	Medium/Low Technology
	Percent Reporting Use of Each	
Affiliates	71	100
Trade Shows, Conferences	70	56
Literature	68	46
Discussions with Other Firms	32	26
Reverse Engineering	08	01
Examine Copyrighted Material	03	07
Examine Industrial Designs	03	07
Examine Plant Breeder's Rights	03	01
Examine Patents	02	13
Examine Integrated Circuit Designs	02	03

Source: Industry, Science and Technology Canada (1989) Exhibits 5.2.3 and 6.2.4

The Role of Secrecy

Trade secrecy is an alternative to patenting. A trade secret is not a property right although it can be protected by contract. Parties to a trade secret agree not to divulge valuable technical knowledge and can be enjoined from so doing. If a trade secret is inadvertently divulged, however, it is no longer protected. The less susceptible an invention is to imitation by reverse engineering, the more likely it is to be kept secret.

Table 3 suggests that trade secrecy is the least used alternative for protecting new product innovations. It ranks somewhat higher as a means of protecting process innovations (which are generally less readily reverse engineered). The ranking in Table 3 understates the role of trade secrecy in that other means of protection, such as unique complementary production knowhow and the maintenance of an R&D lead, presumably rely, at least in part, on trade secrecy. Even so, it appears that in most industries, when an innovation is patentable it is, in fact, patented (Table 6).

Table 6

Propensity to Patent

Industry	**% of Patentable Inventions Patented**
Pharmaceuticals	82
Chemicals	81
Petroleum	86
Machinery	86
Primary Metals	50
Electrical Equipment	83
Office Equipment and Instruments	75
Motor Vehicles	65

Source: Mansfield (1986, Table 2).

Occasionally, trade secrets are referred to as tacit or uncodified knowledge. Transmission of tacit knowledge requires instruction and observation, that is, it requires direct interaction between those with the knowledge and those seeking it. Transmission of codified knowledge requires no such interaction. Knowledge may be kept secret by keeping it in tacit form. Henry Ergas has suggested that the increased importance of computer simulation as a means of conducting experiments brings with it increased formalization and codification and thus further diminishes the role of trade secrecy.

The Optimal Patent Right

Much of the economic analysis of the patent right has been focused on its duration or term. The optimal patent term is a period such that the surplus derived from the additional inventions that would accrue with a longer term is equal to the surplus foregone by further restricting the use of inventions that would have accrued at shorter patent terms.

The optimal patent term depends on a number of factors. The first is the responsiveness of inventive activity to changes in the patent term.[52] The more responsive inventive activity is to changes in the patent term, the longer the optimal term. The second factor is the extent to which the patent monopoly excludes users who are willing to pay marginal cost. The surplus lost (foregone) as a result of prices exceeding marginal cost during the patent term is known as *deadweight loss*. The greater the deadweight loss from foregone use, the shorter the optimal patent term. If patentees are able to discriminate, and thus to recover their R&D costs from infra-marginal users while not excluding marginal users, the optimal patent term can be very long.

The third factor to consider in determining optimal patent term is the extent of rivalry among potential inventors. For example, several inventors may be competing for the same patent. While rivalry can be beneficial in that it allows a variety of strategies to be pursued and increases the probability that someone will be successful, it may also proceed beyond that point and become largely duplicative. By increasing the potential profitability of the winner of the patent "race" a longer patent term draws more rivals into the race or induces existing rival inventors to speed up their R&D programs. To the extent that this leads to duplicative and hurried R&D, it militates against a longer patent term.

The fourth factor is the perspective of the jurisdiction involved. An optimal patent term can be derived from a global perspective or from the perspective of a single country. The two differ. A single country may have an incentive to "free ride" on the innovative efforts of other countries. Free riding may involve a short patent term, compulsory licensing or no patent at all. Users in the free riding country benefit from lower prices for products and processes that are still subject to patent protection in other countries. Patentees lose but if the free riding country accounts for a small share of world inventive activity, most of these losses are borne by inventors in other countries. Therefore, the smaller the proportion of world inventive activity accounted for by the country involved, the greater the incentive to

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[52] The importance of the existence of patent protection as an incentive to invent is examined below.

free ride.

There is considerable theoretical literature on the optimal patent term. Kotowitz (1986) provides an excellent overview. He finds that from a global perspective, when there is rivalry among inventors, the optimal patent term is likely to be shorter than six years. Optimal patent terms are considerably longer if there is no rivalry (unique inventors). The intuition behind this is that with rivalry, a longer patent term or, indeed, a stronger patent right, results in the use of more resources in R&D but not necessarily more or better or more timely inventions.

Kotowitz also confirms results obtained by Tandon (1982) to the effect that a longer patent term coupled with provisions for compulsory licensing at royalty rates below the monopoly level is preferable to a short patent term in that it provides the same incentive to invent with a smaller deadweight loss to potential users.[53]

The optimal patent term is shorter when viewed from the perspective of a small country than when viewed from a global perspective. The reason for this is that the longer patent term increases the amount domestic users must pay for patented inventions without materially affecting the global output of inventions. This can be viewed as a transfer from domestic users to foreign inventors. If, as Kotowitz suggests, the global patent term is too long, this transfer does not increase the profitability of foreign inventors. Rather, it is dissipated in increased rivalry. Indeed, under conditions of rivalry the optimal Canadian patent term is much shorter than the (20 year) term now prevailing internationally *even if Canada wishes to maximize global rather than national welfare (surplus).*

These conclusions must be qualified if there are local introduction costs which include modification, testing or promotion. In this case, domestic patent protection is necessary if inventions from abroad are to be made available in Canada. The strength of the protection required depends on the magnitude of these local costs. Again, it is preferable to have these costs recovered in small amounts over a longer period than in large amounts over a shorter period.

The breadth of the patent claim allowed is determined by the Patent

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[53] This result is extended by Gilbert and Shapiro (1990) who show that welfare (surplus) can also be increased by measures which reduce the patentee's profit per period while extending the term of the patent.

Office and by the courts. A broad patent claim gives the patentee the right to enjoin the invention of close substitutes for his invention. A broader patent claim gives the patentee more monopoly power.

The determination of the optimal breadth of a patent is subject to the same considerations as the determination of the optimal term. Indeed, the two should be determined simultaneously. Given the term, the narrower the patent claim allowed, the greater the amount of competition the patentee will face from non-infringing substitute inventions. With closer non-infringing substitutes available, the value of the patent monopoly is reduced. If the definition of the patent is sufficiently narrow, the inventor has no monopoly power and the patent provides no incentive to invent. The more narrowly defined the patent claim, the longer the term required to provide a given incentive to invent. This raises the question of whether a broad claim with a short term is socially preferable to a narrow claim with a long term.

This issue turns on the different distortions associated with narrow and broad claims, respectively. With a narrow claim, the distortion is the result of substitution by those preferring the patented brand in favour of lower priced close substitutes. With a broad claim, a patentee who finds it profitable to provide several varieties will also find it profitable to price them so that the users' choice among them is not distorted. The only distortion is from substitution outside the broad class covered by the patent. A narrow, long-lived patent is preferred if the deadweight loss from substitution in favour of distant substitutes exceeds the deadweight loss from substitution in favour of close substitutes. (Klemperer, 1990)

An additional argument in favour of a broad claim is that with a broad claim, the patentee controls the introduction of close substitutes. Resources are not wasted providing "me too" substitutes which merely shift profits. It has also been argued, however, that the patentee may not have sufficient knowledge to determine which substitute inventions are wasteful and may therefore rule out productive lines of research. (Merges and Nelson, 1990)

An invention must be novel or nonobvious in order to be patentable. The novelty requirement and the breadth of the patent claim are related. A weak novelty standard implies a narrow patent claim. Scotchmer and Green (1990) argue that a weak novelty requirement is preferable to a strong one in that it encourages inventors to disclose minor improvements, the results of which can be used by other inventors. With a strong novelty requirement such minor improvements are kept secret, requiring others to do duplicate research. Of course, inventors still have the option of keeping minor improvements (or major improvements for that matter) secret. With a first-to-file system (patent granted to the first to apply for it), however, there is an incentive to file rather than risk having the improvement patented by someone else.

Conclusions

The patent system helps to encourage innovation by increasing the extent to which innovators can appropriate the social benefits of their efforts. The limited available survey evidence implies that the patent system has a significant effect on the incentive to invent in relatively few, albeit important, industries. There is also evidence that patent disclosures are not particularly important as sources of information on new technologies. Even in the most well designed survey, however, it is difficult to infer the full effect of something as fundamental and pervasive as a system of property rights. Respondents might attribute greater incentive effects to patents if they had experience operating without them.

The optimal patent literature is very complex and highly abstract. If nothing else, it demonstrates that the patent right must be analyzed in its entirety. Judgements regarding duration, scope, compulsory licensing and novelty and disclosure requirements cannot be made in isolation. Nor can they be made independently of the structure of industry or, indeed, of the economy. That said, the persistent theme of the optimal patent literature is that the right as it is now configured is, on balance, probably stronger than is necessary.

This conclusion runs counter to the trend of public policy in Canada and elsewhere, which has involved stronger patent rights and copyright and a high level of concern with infringement, especially international infringement. This is a contrast to earlier Canadian concerns which appeared to identify Canadian interests with the bargaining power of domestic licensees of foreign technologies. While they are myopic, existing theoretical and empirical studies of the patent system imply that, historically, Canadian concerns with the terms of access, though frequently misguided, are not without some validity and perhaps should be accorded greater weight.

PART 4
OFFSETTING INAPPROPRIABILITY:
TAX INCENTIVES, SUBSIDIES AND PROCUREMENT

Tax Incentives

Canada has accorded favourable tax treatment to industrial R&D expenditures for more than 30 years. This has involved allowing R&D expenditures to be expensed rather than capitalized as well as a variety of credits and special allowances. A description of these measures can be found in McFetridge and Warda (1980) and in Warda (1990, 1994). A number of other countries have experimented with R&D tax incentives. The incentives presently in place are described in Warda (1994).

The current Canadian federal tax regime for scientific R&D includes:

- 100 percent deductibility for current R&D expenditures
- 100 percent deductibility for expenditures on machinery and equipment
- 20 percent R&D (taxable) tax credit except for the Atlantic provinces (30 percent) and companies eligible for the small business tax rate (35 percent and refundable)

The provinces of Nova Scotia, Ontario and Quebec provide R&D tax incentives in addition to the federal incentives. Nova Scotia provides a 10 percent credit against provincial income taxes for R&D expenditures made in the province. Quebec provides a refundable tax credit of 20 percent of salaries of R&D employees in Quebec (40 percent for companies eligible for the small business tax rate). In addition, there is a 40 percent tax credit on payments for university R&D and the federal R&D tax credit is not subject to Quebec provincial tax. Ontario provides a superallowance (i.e., deduction from taxable income) equal to 25 percent of R&D expenditures in excess of the federal R&D tax credit claimable (37.5 percent of expenditures in excess of an average of the preceding three years).

A number of questions have been raised with respect to R&D tax incentives; the most frequently asked is do they work? This question is usually phrased in terms of the amount of R&D induced per dollar of tax revenue foregone ("bang for a buck"). This question is important because a goal of these tax incentives is to encourage additional R&D. There are a number of other instruments available to do this (subsidies, contracts). Among the factors to be considered when choosing instruments is the incremental effect of each instrument.

It has been argued that concern with incrementality is distributional and that the receipt of windfalls (rents) by some R&D performers does not imply that resources are being allocated inefficiently. This is not correct. Transfers to R&D performers must be made from current or future tax revenues. Taxes distort the allocation of resources and thus involve a deadweight loss which is also known an excess burden.[54] Thus, transfers are costly. An incentive program that does not induce resources to move toward higher valued uses is necessarily wealth-reducing for the economy as a whole. Moreover, the firms receiving transfers may be owned by foreign nationals. In this case, the beneficiaries of any transfers would be foreign shareholders. From a strictly domestic viewpoint, the transfer is a cost to the economy.

The responsiveness of R&D spending to R&D tax incentives is difficult to measure because there are so many other factors that influence the desired level of R&D spending, and these factors also change over time. It is generally agreed that the substitution effect of R&D tax incentives is quite small.[55] That is, making R&D more financially attractive on an after tax basis does not make existing R&D performers significantly more R&D intensive. It does not induce much in the way of substitution of R&D capital for other inputs (physical capital, labour). The bulk of the response of R&D spending to tax incentives appears to come through the output or scale effect. A reduction in the "rental price" or "user cost" of R&D reduces unit production costs. This ultimately results in lower prices, greater demand, greater production and a greater demand for R&D capital. The magnitude of the output effect is subject to question. It ultimately turns on the extent to which the tax incentive leads R&D-intensive industries to expand their share of national production and this, in turn, depends on the elasticity of substitution between R&D-intensive and other products. Conclusions regarding the responsiveness of R&D to tax incentives depend

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[54] Of course, in second best world a tax distortion may offset another distortion and thus increase allocative efficiency. An example would be funding an R&D incentive by taxing the emission of noxious pollutants.

[55] Bruce (1987, p.50)

crucially on the assumed magnitude of this elasticity.

After surveying the existing studies of the responsiveness of R&D spending to tax incentives in various countries, the (Australian) Bureau of Industry Economics (1993) concluded that these incentives result in between 60¢ and $1 for every dollar of tax revenue foregone.[56] With respect to the Australian incentive (a 150 percent allowance), the Bureau concluded:

> Despite the fact that there is some possibility that one dollar of tax revenue foregone is inducing one dollar of additional R&D, the findings make clear that there is a substantial transfer element in the current scheme - the tax concession appears to support proportion of R&D expenditure (perhaps up to 83 percent) that may have taken place anyway. (p.105)

A second question regarding R&D tax incentives is whether they are efficiency-enhancing. This depends in part on whether they are incremental, in part on the deadweight loss (excess burden) associated with raising the taxes to finance the incentive, and in part on the social rate of return on the induced R&D. A related question is whether the incentive should be larger or smaller. This depends on whether the incentive is large enough to increase R&D spending to the point at which its marginal social rate of return is just equal to the marginal social rates of return on other types of investment.

In its study, the Bureau of Industrial Economics (1993, Table 8.2) finds that under the assumptions that the R&D externality is 78 percent of the marginal private rate of return, the excess burden of taxation is 32.5 percent and 20 percent of the incentive goes as a transfer to foreign shareholders, the Australian 150 percent allowance is wealth-increasing for Australia if it increases R&D spending by (roughly) 70¢ or more per dollar of tax revenue foregone. A similar calculation for Canada would probably not differ much in terms of the conclusions it reached. The implication is that the existing tax incentives are likely socially beneficial, but there is no compelling case for making them more generous.

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[56] In an earlier survey, Inland Revenue in Britain (HM Treasury, 1987) concluded that tax incentives increase industrial R&D spending by roughly half of the tax revenue foregone by the government. A study of U.S. tax incentives by Cordes (1989) concluded that U.S. incremental credit stimulated between 35 cents and 93 cents per dollar of tax revenue foregone.

The magnitude of the R&D tax incentive that is appropriate for Canada should be determined in the light of the magnitude of the R&D externality, the incremental effect of the incentive, the excess burden of taxation and the proportion of the incentive that becomes a transfer to foreigners. This may differ from the incentive that is appropriate for the United States or other countries. It is not essential that Canada be "in line" with other countries. Given the uncertainty regarding the magnitudes of the parameters that determine the socially optimal incentive rate, however, some comfort may be derived from having incentives of roughly similar magnitude to those of countries with similar characteristics to Canada.

The tax treatment of R&D in Canada has been compared with that of other countries by Warda (1990, 1994). He finds that Canadian incentives are the most generous of the ten countries he examined. Bruce (1992) makes a more general comparison of the after-tax cost of capital for R&D in Canada, Japan and the United States respectively. The after-tax cost (or neoclassical rental rate) of R&D capital depends on both the tax treatment of R&D and the after-tax cost of finance. He finds that the after-tax cost of R&D capital in Canada is somewhat lower than in the United States but that both countries have a much higher cost than Japan implying that, other things being equal, a company located in Japan would do more R&D than a company located either in the United States or Canada.[57]

It is frequently argued that tax incentives are inferior to subsidies in two respects. First, unlike subsidies, tax incentives may not be available to firms with no taxable income. Of course, this problem can be remedied by making tax incentives refundable as has been done with the present R&D tax credit in Canada. The present tax regime makes credits on the first $2 million in current R&D expenditures fully refundable for all firms eligible for the small business tax rate (taxable income less than $200,000) and partially refundable for companies with taxable income between $200,000 and $400,000.[58] Canada has also experimented with allowing unused tax credits to be flowed through to individuals or companies with taxable income. The federal experiment in this regard, the Scientific Research Tax Credit (SRTC) of 1984-5 had the design flaw of allowing the transfer of a

[57] According to Bruce (1992, Table 3), the implicit annual rental rate on a $1000 R&D asset which did not depreciate would be $39 in Canada, $52 in the United States and $18 in Japan.

[58] Credits on R&D buildings and equipment are 40 per cent refundable. The amount of R&D eligible for the refundable credit declines by $10 for each dollar by which taxable income exceeds $200,000 reaching zero at a taxable income of $400,000.

credit on R&D that had not yet been performed. In many cases the R&D was never performed and the federal government lost nearly $2 billion in tax revenue during the short life of the scheme. The province of Quebec has also experimented with flow-through schemes but has recently announced their termination.

A second argument is that subsidies may come with informed professional advice attached while tax concessions do not. Recipients of such subsidies, it is argued, are likely to choose better projects and complete them successfully. The implications are that these "informed" subsidies are more likely to be incremental and may generate higher social rates of return than tax concessions. The National Research Council's IRAP program has been cited as a possible example. It is said that an IRAP dollar is a "high powered dollar.' The alternative view is that government influence on R&D project selection and conduct is not necessarily positive and that a major advantage of tax incentives is that they do not involve the government in commercial decisions. The available evidence on R&D subsidies is considered below.

Subsidies

Subsidies for Innovation in Perspective

The magnitude of industrial subsidies in Canada has been estimated by Ronayne (1993). He finds that direct industrial aid (i.e., subsidy payments to business) has been declining as a percentage of GDP, although much of this decline has been due to the termination of subsidies for petroleum exploration and for petroleum imports.[59] Indeed, of the $14.2 billion in operating subsidies paid in 1991, nearly $4 billion is accounted for by agricultural and housing subsidies and subsidies to the national broadcasting network and the post office. Ronayne also finds that provincial governments are accounting for an increasing proportion of direct aid to business.

Relative to other OECD countries, Canada appears to rank roughly in the middle in terms of subsidy intensity. Ford and Suyker (1990) find that non-agricultural subsidies accounted for 2.6 percent of non-agricultural GDP in

[59] Until 1985 the price of petroleum produced in Canada was held below the world price. Importers were paid a subsidy equal to the difference between the world price and the Canadian price.

Canada in 1985 versus 0.5 percent in the United States, one percent in Japan, 1.7 percent in Germany, 2.9 percent in the Netherlands and 7.6 percent in Sweden (1990, Table 3).

The stated objectives of Canadian industrial assistance programs most frequently involve innovation, small business development or employment and training, although 28 percent of the programs (by number) have the stated objectives of "general investment", "sector-specific assistance" and "regional aid" and could be providing assistance to a variety of activities. Ronayne (1993, Table IV-5) finds that, of 127 federal and provincial assistance programs listed in a published guide to industrial assistance programs in Canada, 22 percent have support of R&D or innovation as their principal objective, 21 percent have small and medium-sized business development as their principal objective and 16 percent have employment and training.[60]

The nature of Canadian industrial assistance programs has changed in recent years (Doern, 1992, p.56). Grants are being replaced by repayable loans.[61] Support is focused more on "pre-competitive" or "pre-production" activities such as feasibility studies, technology acquisition, R&D and modernization and on the provision of so-called "value added services" to firms by the granting department. Support is either not targeted or is targeted on broad classes of products such as microelectronic components and systems, advanced materials or biotechnology. Program criteria emphasize inter-firm cooperation, alliances and networking. Alliances may include foreign firms or non-profit institutions. In sum, Industry Canada's industry support programs are being configured to be broadly available, to afford national treatment to foreign firms, to tend toward infrastructure rather than production and to contain a smaller element of explicit subsidy. This configuration may also reflect the influence of Porter and others on the role of leverage, the past failures of targeted subsidies and the importance of innovation systems or clusters as well as concerns about U.S.

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[60] The guide is *Industrial Assistance Programs in Canada*, CCH Canadian Ltd., Don Mills, Ontario, 1991.

[61] This change in policy was announced in the February 1990 budget (Department of Finance, Canada, 1990, p.12). In the April 1993 budget, the Minister of Finance stated that the policy of requiring repayment of most grants and contributions to business by federal departments "...reinforces the government's efforts to orient its business assistance towards investing in economic development rather than the subsidization of the private sector" (Department of Finance, Canada, 1993, p.53).

countervail.

Subsidy Programs Supporting Innovation

Federal government agencies spent $977 million on scientific activities in Canadian industry in 1993-94, including grants (some of which are repayable) and contracts. This amounted to 16 percent of federal science and technology expenditure. The distinguishing feature of contracts is that the government retains the rights to any new technologies developed under contract. The support element in an R&D contract comes from spin-off innovations or learning-by-doing.

The agencies or departments accounting for most of the expenditure are: the Canadian Space Agency, Industry Canada, the Canadian International Development Agency, the Department of National Defence and the National Research Council. Grant programs are administered primarily by the Department of Industry and Science, and the National Research Council, with the other departments and agencies primarily engaged in contracting.

The largest grant program administered by the Department of Industry, Science and Technology is the Defence Industries Productivity Program (DIPP). In operation since 1960, this program supports R&D, technology acquisition and feasibility studies as well as source establishment, and provides capital assistance for modernization and upgrading in the aerospace and defence-related industries.[62] Contributions made under DIPP are now repayable. Roughly 60 percent of DIPP disbursements are for R&D. Affiliates of major U.S. companies such as Pratt and Whitney and Litton Systems, Boeing and McDonnell Douglas have been continuing recipients of funding. Major recipients operate under the terms of Memoranda of Understanding (MOU) which commit them to specified performance objectives for their Canadian operations.

The other major innovation support program is the Industrial Research Assistance Program (IRAP). Expenditures under IRAP amounted to $76 million in fiscal 1991-2. IRAP provides both financial assistance and technical advice and information. In this respect it is regarded in some quarters as a model innovation support program. It has received numerous

[62] Source establishment is the qualification of a new Canadian source of supply.

positive appraisals over the years[63] and is one of the few programs to have had its budget increased in the face of continuing federal budgetary cuts.

IRAP is administered by the National Research Council (NRC) which operates Canada's national research laboratories and has, as a result, considerable expertise in research management.

The following kinds of support are provided under IRAP:

- *Field Advisory Service* The NRC contributes to the maintenance of a staff of over 250 field advisors to provide assistance to industry in solving local problems. These field advisors are based in provincial research councils, industry research associations, specialized research institutions and consulting firms and are experienced in the management of technology in smaller firms. Technological information is provided by the NRC's Canada Institute for Scientific and Technical Information (CISTI).

- *Short-term projects* Small firms with technical problems or testing requirements are eligible for grants of up to $5000 per project (up to three projects per year) for up to 65 percent of the cost of laboratory or consulting services.

- *Medium-term projects* Firms with under 200 employees are eligible for assistance of up to $100,000 to pay salaries of personnel engaged in applied R&D and new product or process engineering.

- *Long-term projects* The NRC provides assistance (maximum not specified) to firms in taking advantage of technology or expertise that exists in government, university or foreign laboratories. The firm develops the technology, the NRC covers project costs and licenses the firm in the event that the technology proves to have commercial value.

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[63] The 1985 report of the Task Force on Program Review concluded that "IRAP works" and suggested that the government consolidate its technology transfer efforts within IRAP (p.429). The National Advisory Board on Science and Technology (1992) concluded that IRAP "...has an excellent record of collaboration with federal, provincial and private sector agencies and as such should be the technology network foundation upon which government program consolidation and delivery should be based." (p.18) The Board cites a study by the National Research Council in support of its conclusion.

The Department of Industry and Science administers a variety of smaller programs designed to support industrial innovation. These include:

- *The Technology Outreach Program (TOP)* This program is intended to improve the technology infrastructure by covering a portion of the initial operating costs of non-profit organizations providing technology development, diffusion or critical skills training in support of industry. Sustaining assistance covering a portion of operating costs may also be provided.
- *The Microelectronics and Systems Development Program (MSDP)* This program pays a portion of the costs of R&D projects intended to apply advanced microelectronics and software in manufacturing, processing or service industries. Repayment of contributions in excess of prescribed ceilings is required. Preference is given to firms which collaborate with Canadian and foreign partners.
- *The Strategic Technologies Program* This program supports leading edge, pre-commercial R&D alliances and technology application alliances in the areas of information technology, biotechnology and advanced industrial materials. Preference is given to projects that create extensive linkages in Canada for rapid diffusion of technology and knowhow, build on key Canadian resources, involve technologies that are new to Canada and have significant commercial potential. Technology application alliances can include users or developers. Assistance covers a portion of percent of project cost.
- *The Forest Industries R&D and Innovation Program* This program supports pre-commercial R&D alliances and technology application alliances in the forest and related machinery industries. Criteria for support are the same as those of the Strategic Technologies Program.

Evaluation of Subsidy Programs

Systematic economic evaluations of innovation subsidy programs in Canada are dated. Recent discussions of industrial innovation programs do not assess their economic contribution. The assessments that have been carried out are largely organizational in nature, and suggest program consolidation, better coordination and more mission statements.

The earlier evaluations were skeptical of the economic benefits of the innovation subsidy programs. An examination of the subsidization of *proprietary* innovation projects by the federal government concluded that, with respect to the oldest and largest program, the Defence Industries Productivity Program (DIPP), "...there is reason to doubt whether Canada has received adequate value for the monies disbursed under its aegis" (Tarasofsky, 1984, p.66). With regard to the IRAP, the question of effectiveness was regarded by Tarasofsky to be "open".[64] Other evaluations have been more favourable to IRAP (Task Force on Program Review, 1985; National Advisory Board on Science and Technology, 1992).

In his evaluation of federal energy R&D programs, McFetridge (1987) concluded:

> Energy R&D shows up well in relation to other R&D supported by the federal government. There are several reasons for this. It has been aimed at the solution of specific technical problems faced by various industries. For the most part, it has not been used to support new firms or struggling firms or firms in disadvantaged regions. It has not been used to enable individual firms to develop proprietary technologies to sell in foreign markets. The focus has been on industry-wide or multi-industry technological problems. Research has been guided jointly by industry experts and government scientists. Research has largely been contracted out.
>
> In essence, unlike other federal R&D programs, energy R&D funding has not been used to assist individual firms. It has been used to solve industry-wide technological problems especially those associated with the exploitation of unique Canadian resources.[65] (pp.72-3)

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[64] Both programs have a high degree of support from their beneficiaries. Repayments under DIPP remain relatively modest ($13 million in 1991, $10 million in 1992), which may imply limited financial success of projects supported by DIPP. Early evaluations of IRAP were correctly regarded by Tarasofsky (1984, p.60) as having serious methodological flaws. These flaws included sampling successful projects only, excessive
attribution of sales to IRAP assistance and use of "multipliers" that ignore opportunity costs.

[65] McFetridge went on to argue that while the development of proprietary technologies by individual firms should not be a primary goal of federal energy R&D, commercial success is not unwelcome. He noted that the rechargeable lithium molybdenum disulphide battery developed by Moli Energy Ltd. is often cited as an example of a commercially successful proprietary innovation developed with government support. Four years later Globerman (1991) picked up the Moli story. He wrote:
When a fire broke out in a portable telephone that used Moli's batteries, a financial crisis was precipitated that ended Moli's hopes of forming the nucleus of a provincial high technology industry. ... At the time of writing Moli's assets were in the process of being sold at a drastic discount to their book value. (p.259)

Most of the evidence on the incrementality of subsidies is dated. Tarasofsky (1984, p.79) found that R&D subsidies awarded under the Enterprise Development Program (EDP) between 1977 and 1980 increased the R&D spending of recipients by between 47¢ and 63¢ per dollar of subsidy awarded in the electrical products and machinery and equipment industries respectively. Remembering that the responsiveness of R&D spending to tax incentives has been estimated at between 60¢ and $1 per dollar of tax revenue foregone, this implies that R&D spending is at least as responsive to tax incentives as it is to subsidies.

The experience with respect to the incrementality of modernization studies may also be instructive. Assistance has been provided to the pulp and paper industry (1979-84), the shipbuilding industry (1975-85) and the footwear, textile and clothing industries (1981-86). Subsidies to the pulp and paper, and footwear, textile and clothing industries were for equipment modernization; the shipbuilding industry received vessel construction subsidies. Virtually all this industry's current business is from government orders.

After examining the operation of these subsidy programs, the Economic Council of Canada (1988) concluded that:

> Subsidies granted to firms and industries to modernize their capital equipment have not promoted adjustment, despite their aims. Although it is theoretically possible to promote incremental private sector investments through subsidies, our review of capital subsidies led to the following conclusions: 1) in general, the expenditure of modernization subsidies was not incremental - that is, the subsidies did not typically encourage firms to undertake extra investment; and 2) the subsidy programs could not be justified on either efficiency or equity grounds (p.29).

Procurement

Public procurement policy is regarded as a potentially effective device for supporting innovation under certain circumstances. There do not appear to have been any formal evaluations of the efficiency of procurement policies as a means of supporting innovation. This would involve a comparison of the premium paid relative to "off-the-shelf" purchases (plus the excess burden on the premium) for product or process innovations induced by government demand with the domestic spillover benefits resulting from these innovations.

Procurement has been an effective instrument in the more restricted sense of inducing or accelerating innovation in instances where the public sector is a large and serious customer for the new products involved (Nelson, 1982; Porter, 1990, 1991; Dalpé, DeBresson and Xiaoping, 1992). When the government is a marginal, indifferent or indecisive customer, the procurement lever has not worked.

Dalpé *et.al.* find that the public sector in Canada has been a relatively important first user of innovations in a number of industries. They also find that the importance of the public sector as a first customer increases with the novelty of the innovation. The authors identify nine industries where procurement leverage may have exerted a significant effect on innovation: office furniture, other paper, aircraft, railway rolling stock, shipbuilding, other transportation equipment, telecommunications equipment, pharmaceuticals and scientific instruments.

Québec is seen as a pioneer in the use of "strategic" procurement for industrial development purposes. According to the Ontario Premier's Council, a number of large, successful Québec computer systems companies owe their existence to Québec's decision to contract out its health care and education system computer services requirements (1988,III, p.67). The contracts were large, long-term and demanding in their specifications. The procurement policies of Hydro Québec have also been credited with the development of a consulting engineering industry and an electrical distribution industry in Québec (Ontario Premier's Council, 1988, II). Some of Québec's procurement strategy reflects the best of what Michael Porter and others recommend -- large, competitive, long-term and technically demanding contracts awarded to independent suppliers that are better placed than government departments and public enterprises to exploit economies of scope and spinoff innovations.

Concessionary Financing

There has been an increased appreciation in recent years of the role of the financial system (or "financial infrastructure") in facilitating innovation. The financial system allocates capital, supervises the use of capital and provides information to investors. National financial institutions vary in the effectiveness with which they perform these functions. Throughout the 1980s, writers on industrial policy were fascinated by so-called bank-centred financial systems.[66] More recently the flexibility, adaptability and resilience of equity market-based financial systems have been recognized. In particular, there has been a recognition of association between the existence of well-functioning equity markets and the importance of spin-off and start-up businesses in an economy.

The efficiency of a financial system depends on many factors, the examination of which is beyond the scope of this report. While it is very easy to identify "imperfections" in the way innovative activity is financed, it is very difficult to find persuasive arguments why government programs and financial institutions have any advantage in overcoming them. Recent institutional innovation in government lending may have remedied some of the defects of earlier programs.

Governments may or may not have an advantage over the market when it comes to risk spreading and risk pooling. Accepting their mandate as one of concessionary risk-bearing, some government lenders, such as Quebec's SDI, have attempted to develop more appropriate (incentive compatible) instruments for this purpose.

There has also been a recognition that the financing of innovative enterprises is handicapped more by lack of expertise among borrowers and lenders than from a lack of capital. A recent Quebec financial innovation, Innovatech, addresses this issue. It is a high-tech investment fund specializing in the greater Montreal area. This fund is administered by an independent board of directors drawn from industry and operates in cooperation with other investment funds. Much of its portfolio is devoted to equity in start-up ventures. It is said to operate with a high level of expertise and with a minimum of bureaucratic interference. (Research Money, April 28, 1993, pp.1-2; November 24, 1993, p.3)

Ontario has recently attempted to respond to the perceived shortage of informed, "patient" equity capital for knowledge-intensive companies

[66] The National Advisory Board on Science and Technology (1991) advocated that German-style ownership links between the chartered banks and the "real" sector be allowed in Canada.

with its Ontario Lead Investment Fund.[67] The government and six private sector partners are contributing $70 million to a fund that will be invested by "expert investment corporations" (EICs) formed by investment managers, venture capitalists and others. The EICs are expected to contribute a further $140 million. A financial incentive for private sector participation is limited participation by government in any profits on investments made by the fund. (Research Money, November 24, 1993, p.2)

[67] The "patient capital" issue has been largely resolved. Equity markets turn out not to be biased against long-term investment and R&D as some industrial policy commentators asserted. Costs of capital have tended to equalize internationally as countries such as Japan have eliminated controls on capital flows. The cost of capital in Canada may still be higher than in the United States. The National Advisory Board on Science and Technology (1991) saw this as being a consequence of government deficits rather than a lack of patience on the part of Canadian lenders.

PART 5
MODELS OF INNOVATION AND PUBLIC POLICY

The Linear and Feedback Models of Innovation

The linear model of innovation characterizes the innovative process as a flow beginning with basic research and proceeding to applied research and then to development and commercialization. The flow of causality is from basic science to technological innovation. Scientific discovery is regarded as largely exogenous.

This linear model was questioned in a series of papers by Nathan Rosenberg, who made the essential point that the innovative process is cumulative and interactive. Participants in the process benefit from contact with each other. Rosenberg contended that the process is not linear; rather, it is characterized by feedback.

One example is the so-called exogeneity of basic science. Rosenberg provided historical examples of cases in which developments in basic science were facilitated by technological innovation. In some cases, developments in applied research provide insights to those engaged in basic research. An example of this is the discovery of star noise and ultimately radio astronomy arising out of research on the causes of interference in radio telephone transmissions.

In other cases, basic research was facilitated by technological improvements in scientific instruments and calibration and measurement methods. In some cases it was simply a matter of better manufacturing techniques. Calibration and measurement methods and standards have recently become known as *infratechnologies* and their contribution to the productivity of basic and applied research as well as commercial activity is now widely acknowledged.

A second example is the role of "users" in the innovative process. In the stylized linear model, users were simply at the end of the pipe accepting whatever came out. Rosenberg provided examples of cases in which users were responsible for ideas leading to innovations and participated in the innovative process itself. More pervasive, however, is the participation by users in the cumulative process of making small improvements in existing technologies such as the steam engine or the passenger jet. Rosenberg called this process *learning by using*. He emphasized both its collaborative nature and its quantitative importance. It is this accumulation of small modifications and improvements that is responsible for most of the productivity gain resulting from the introduction of a new technology.

Rosenberg pointed out many other instances in which the assumptions of the linear model do not hold. He gave examples (metallurgy, petroleum refining) in which technological innovation occurred in advance of the understanding of the basic scientific principles underlying it.[68] Rosenberg also noted that technological innovations often draw their scientific underpinning from developments in technologically distant fields.[69] Thus, the development of related basic science is sometimes neither necessary nor sufficient for technological innovation.

Many scholars have elaborated on Rosenberg's work. New issues have also emerged.

The linkage between science and technology is increasing. Computer-assisted research and engineering has compressed development periods; scientific discoveries more frequently have immediate commercial applications; engineering is becoming increasingly science-based; and technological innovations are more likely to have immediate scientific relevance. The distinctions both between science and technology and among the stages of the innovation process are blurred.

Paul David maintains that research and development personnel are no longer distinguished on the basis of what they do but rather on the basis of the economic incentive system under which they work. The categories of basic R&D and applied R&D are no longer useful. A more workable

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[68] Mowery and Rosenberg (1989, p.33) write:
The sequence of technological knowledge preceding scientific knowledge has by no means been eliminated in the twentieth century. Much of the work of the scientist today involves systematizing and restructuring in an internally consistent way the knowledge and practical solutions and methods previously developed by the technologist. Technology has shaped science in important ways because it acquired some bodies of knowledge first and, as a result, provided data that in turn became the "explicanda" of scientists, who attempted to account for or to codify these observations at a deeper level.

[69] Rosenberg (1982,p.75) writes:
Often, however, an innovation from outside will not merely reduce the price of the product in the receiving industry but will make possible wholly new or drastically improved products or processes. In such circumstance it becomes extremely difficult even to suggest reasonable measures of the payoff to the triggering innovation because such innovations open the door for entirely new economic opportunities and become the basis for extensive industrial expansion elsewhere.

distinction is between open access and proprietary (restricted access) knowledge. Thus, there is a stock of "open science" or common property scientific and technological knowledge. This stock is augmented by applied research and development as well as by basic or fundamental research.[70] The stock of open science is also augmented by what has become known as precompetitive R&D. This is R&D that is applicable to and can be shared by a variety of users, even though they may be in competition with each other. Precompetitive R&D may be confined to basic research in some industries but may extend through applied research to development in others.

Another useful distinction is between codified and tacit knowledge. Codified knowledge is more readily accessible than tacit knowledge. What is codified and what remains tacit is partly a matter of economic incentives and partly a matter of technological possibility. Knowledge may be kept in tacit form to increase its appropriability, that is, to keep it out of the stock of open science.

Henry Ergas argues that the increasing use of computer-aided design, experimentation and testing facilitates formalization and codification of an increasing portion of the knowledge stock. An implication is that knowledge is becoming increasingly transferrable. Diffusion is faster and less costly. Secrecy is becoming a less viable option and the degree of appropriability may be declining as a consequence.

Successful innovations more frequently involve recombination or integration of existing knowledge from diverse sources. The linear concept of in-house R&D followed by commercialization is increasingly inappropriate characterization of the innovative process. Indeed, the period of dominance of the innovative process by the corporate R&D lab may be coming to an end, superceded by networks, alliances and other cooperative arrangements involving what was formerly called "basic" research institutions.

The change in the nature of the innovative process has been accompanied by many institutional changes. There are increasing linkages between universities and other "basic" research institutions and commercial

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[70] This characterization raises the question of whether this "intellectual common" can ever be over-grazed. Evenson (1993) has suggested that if the ideas embodied in the stock of public knowledge are being exhausted faster than they are being replenished, the productivity of resources devoted to proprietary research will fall and that this what did, indeed, occur during the 1980s.

enterprises. Government laboratories are taking on an increasing commercial orientation (Niosi and Manseau, 1994).

New collaborative institutions have emerged. The most widely discussed is the strategic alliance. These alliances and their membership reflect the increasingly diverse sources of technology on which innovators rely.

Within existing innovative organizations there is increasing emphasis on access to "outside" sources of knowledge. Applied research and development is valued for its "swap" value in a strategic alliance as well as its internal commercial potential. Research, including basic research, is valued for the insight it gives those involved into the possible applications of the ideas of others.

Public Policy Implications of the Linear Model

The stylized linear model, together with the public good approach to the economics of innovation, implied that basic research would be done largely in universities or, when national security was involved, in government laboratories. Applied research and development would be done in the private sector largely in corporate laboratories or, in atomistic industries, by industry associations.

There are three methods by which governments can encourage innovation. The first is to define and enforce intellectual property rights. These rights allow innovators to appropriate a portion of the social value of their innovations and thus provide an incentive to engage in innovative activity. Second, the government can subsidize innovative activity either through direct subsidies to institutions (universities, non-profit organizations, industrial corporations) engaged in such activity or, in the case of the business enterprise sector, through either the tax system or concessional lending. Third, the government can purchase innovation services. These services can be procured from independent suppliers (contracting out) or it can provide these services for itself.

It is generally accepted that it is difficult to define and enforce property rights in basic scientific knowledge. The linear model implies that there is virtually no private incentive to engage in basic research, which is defined as having no apparent commercial application. Where and when economic value will be realized is not readily predictable. The linear model therefore implies that any basic research that does occur will have to be heavily subsidized or procured outright by the government.

The linear model defines applied research and development as having possible commercial application. Intellectual property rights and the law of contract (trade secrecy) make it possible for innovators to realize some of the commercial value of their innovations. There is a private incentive to engage in applied research and development. This implies a more modest and in some cases non-existent role for government subsidization and procurement.

In sum, the linear model implies not only a progression from basic to applied science and then to development and commercialization but also a progression from substantial direct government support at the early stages to limited direct support at the later stages.

Public Policy Implications of the Feedback Model

The feedback model emphasizes the cumulative and interdependent nature of the innovative process. According to the feedback model, so-called basic research may have commercial potential and, as a consequence, there is some private incentive to engage in it. Business enterprises have an incentive to perform basic research themselves and to enter alliances with universities and non-profit institutions. The feedback model implies that support of basic research will increasingly come from sectors other than the government. The simple rule that basic research is the responsibility solely of the government no longer applies. The task will be to develop the type of institutional arrangements which will allow for commercial support and application of fundamental academic research without compromising the choice of projects or peer evaluation of research work.[71]

The feedback model also implies that the pay-off to applied research and development includes the creation of opportunities in technically unrelated sectors of the economy and the provision of insights, methods and

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[71] Feller (1989) concludes his description of state advanced technology programs in the United States with the observation that:

> In each case, the state strategy is predicated on the widely shared belief that the lags between advances in "fundamental" and "commercial" knowledge have been compressed, and that the race to economic success will be won by that unit (nation, firm, state) best able to form "partnerships" or "strategic alliances" among the relevant players. (p.12)

better tools to those engaged in basic research. Generic technologies which are widely applicable may result from applied research or development as well as basic research. Thus, the feedback model argues that the externalities in applied research and development may be greater and more widespread than is implied by the linear model. The case for government support of applied research and development via either subsidization or procurement is correspondingly greater. This may involve greater participation by government laboratories in applied research and development projects or greater subsidy or tax support for applied research and development by business firms, consortia and industry associations. It also suggests a need to consider the role of intellectual property in facilitating a more widespread dissemination of new technological information.

PART 6
ECONOMICS, POLITICAL ECONOMY AND MODELS OF INNOVATION

The analysis of the role of the public sector in the innovation system requires the integration of three streams of thought or "models”. The market or (allocative) efficiency model has the normative implication that "the government” should direct resources into the activities with the largest spillover benefits. It further suggests that, due to its public good properties, technological innovation is likely to yield large spillover benefits. It has been rather vague, however, as to the categories of innovative activity that might yield the largest spillover benefits. The economic theory of democracy explores what constitutes “the government”. It predicts that the government is not likely to act as a social planner, maximizing present and future national income. Rather, government policy is likely to reflect the interaction of contending interest groups. In some cases the alignment of interest groups may be such that the government is able to reallocate resources in the direction of activities with high spillover benefits. If these spillovers exceed the (deadweight) losses due to the distorting effects of the requisite taxation, national income increases. There is reason to believe that effective coalitions of interest groups supporting technological innovation may not form frequently and that some of what has passed for support of innovation may have been motivated principally by redistributive considerations.[72] Even where there is an effective coalition in favour of supporting innovation, the design and administration of that support can be burdened by rent-seeking. This result is more likely the greater the commercial or proprietary interests at stake. For this reason, it is frequently argued that public support of innovation should be confined to precompetitive R&D and generic technologies.

Models of innovation attempt to explain how innovation occurs. Historically they have emphasized the cumulative and interactive nature of the innovative process. More recently they have emphasized that the type of generic new knowledge that has widespread and enduring applicability and is thus likely to entail significant spillover benefits is not solely the product of basic scientific research.

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[72] To the extent that they find it advantageous, those engaged in rent seeking activity will claim that they provide large spillover or spinoff benefits. Thus, the investment of public funds in luxury skyboxes or convention centres is said to "create" new jobs and the wages paid are claimed as "benefits".

The caricatured linear model of innovation equated precompetitive R&D with basic research and generic technology with science. Since the institutions engaged in basic scientific research were readily identifiable (universities and non-profit institutions), this made for a simple support rule. It also minimized political problems arising from conflicting commercial interests.

The feedback model of innovation emphasizes the ubiquity of externalities. The feedback model stresses that spillover benefits may be generated by applied research and development as well as basic research and by technological improvements as well as scientific findings. What is generic and precompetitive depends on the industry. Indeed, it could depend on the line of business within an industry. This complicates the allocation of government support. No one set of institutions can be identified as the principal source of spillovers. The application of simple rules is likely to involve the government in proprietary innovation in some industries and to leave generic R&D unsupported in others. Coming up with more refined rules will be difficult. Indeed, in a context of interest group politics and bureaucratic self-interest, the prospect of allocating government support on the basis of the divergence between social and private rates of return would appear to be remote.[73]

There are some grounds for optimism. Institutional evolution is rapid and decentralized. Overarching government plans are not necessary. In many cases governments may be merely participants in this ongoing evolution. For example, the feedback model recognizes a community of interest between the business sector and the universities and implies increasing collaboration between the two. The feedback model sees the business sector as an important potential source of support for university research. The role of government is to accord universities the flexibility to participate in these arrangements.

To take another example, the feedback model recognizes that research conducted in government laboratories may have commercial applications either by itself or in combination with other technologies. It motivates the participation by government laboratories in cooperative

[73] For example, the Council on Competitiveness (1991) was able to identify generic technologies but then goes on to define a subset of "critical" technologies in which the United States had lost market share to the Japanese.

research involving contracting-out, contracting-in, alliances or consortia.[74] It suggests, as the National Advisory Board on Science and Technology has recognized, that the internal organization and incentive structure of government research institutions may have to be altered if they are to interact effectively with other components of the innovation system.

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[74] The feedback model explains why collaboration between government laboratories and the business sector is potentially productive. This is not the same as requiring that government laboratories earn enough commercial revenue to break even. A break-even requirement may be seen as a solution to the accountability problem in that it may help to ensure that government laboratories are performing useful research. Meeting a break-even requirement is, however, neither necessary nor sufficient to ensure that useful research is being performed.

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