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IMPACT AND EFFECTIVENESS OF PUBLIC SUPPORT FOR BUSINESS INNOVATION

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Contents

Introduction

As the 21st century unfolds, there is a growing recognition that the competitive global landscape is altering the context within which government support for innovation programs should be assessed. The primary justification for this area of public policy is the widespread recognition of the link between innovation and productivity growth and its impact on future income levels. Technological advance, broadly construed, is the most important source of productivity growth; but recent evidence suggests that those advances are concentrated among the leading firms in more technologically innovative sectors, while both lagging firms and sectors that experience a lower rate of productivity growth tend to reduce average productivity levels across the entire economy (Andrews, Criscuolo, and Gal 2015). The changing dynamics of innovation in the 21st century accentuates the need for a clearer understanding of what the current state of research tells us about the design, implementation and effectiveness of business innovation policies.

This report explores a number of conceptual and policy design issues that are relevant for the current Treasury Board Secretariat Horizontal Review of Innovation and Cleantech programs within the federal government. It provides an overview of some of the relevant conceptual frameworks used in leading industrial economies, as well as some that have experienced more rapid innovation-based (RIB) economic development. It provides an introduction to recent thinking in the academic and policy relevant literature on the nature of these design issues and summarizes some of the insights and findings of recent reviews that have been undertaken on program impacts. As such, it is intended to be a high level review of the current state of thinking on these issues and provide a guide to the more detailed literature, rather than an exhaustive review of the literature.

The report addresses several critical issues. First, it examines the conceptual and program models that exist for the design and implementation of government support of business innovation at different jurisdictional levels. It places this examination within the context of two broad approaches found in the literature, the traditional neoclassical approach to innovation policy and more recent evolutionary approaches. It explores the different policy approaches adopted in both leading economies, as well as several that have adopted a rapid innovation-based (RIB) approach to innovation policy and examines the relative merits of the respective approaches used by different governments.

The report goes on to examine the existing evidence on the impact of a range of policy instruments, drawing several recent reviews of both the academic and more policy oriented literature. It also draws upon concept of the “policy mix” for innovation that was introduced ten years ago in policy reviews undertaken for the European Union and OECD. It examines what value the “policy mixes” approach adds to our understanding of the design and implementation of government programs for the support of business innovation. Finally, it addresses the question of how the introduction of innovation programs within a federal system complicates the evaluation of their impact and creates a need for greater policy alignment. In this respect, it asks what value the concept of multilevel governance, developed initially in the EU, but adopted and widely applied in the scholarly literature on Canada, contributes to our understanding of how the effectiveness of policies is supported or constrained by the behaviour of other actors within the federal system.

Economic Rationales for Business Support Programs

Traditional neoclassical models and more recent evolutionary models of economics treat the rationales for policy support for technological innovation in significantly different ways, with attendant implications for the design and implementation of innovation policy. To a large extent, these two intellectual paradigms have operated in isolation from each other, with little direct comparison of the strengths and weaknesses of each approach. They have also tended to enjoy greater policy attention in different national contexts, which has also limited the degree to which the strengths and insights of each approach have been directly compared, thus limiting the ability to draw inferences for both policy design and evaluation. The following sections of this report provide a brief overview of the relevance of each approach for the design and evaluation of innovation policy. The focus on innovation as the basis for economic development represents a significant departure from more traditional approaches to economic development policy. While reliance on the neoclassical perspective limited the justification for government intervention to cases of market failure, an innovation-focused perspective shifts the rationale to examining how policies and programs will enhance a nation's future innovative capacity (Atkinson and Ezell 2012).

The Neoclassical Approach: Market-based Rationales

In the neoclassical approach, innovation is treated largely as an exogenous variable, operating outside of the properties of the general equilibrium models. Although Romer's work inserted the role of ideas into the framework, much of the neoclassical model remained the same (1986). The focus is on the static efficiency of an economy in allocating scarce resources at a single point, rather than its dynamic efficiency in generating increasing resources over time. The central question posed is whether the market will allocate sufficient resources to research and development for the creation of new products and processes if left to its own devices. The starting assumption of this perspective is that the unrestricted operation of competitive mechanisms based on the rational choices of individual agents interacting in the market will produce the optimal economic outcomes, both in terms of the microeconomic distribution of rewards and benefits to those agents and the optimal level of welfare for society as a whole.

The bulk of neoclassical theorizing about innovation policy is concerned with the factors that inhibit the achievement of optimal outcomes in the allocation of resources to research and technological innovation. This approach acknowledges that under certain circumstances, markets can and do produce suboptimal outcomes, usually in situations where they operate in imperfect fashion. The misallocation arises from the fact that the innovation process itself is inherently risky and uncertain and that market agents are constrained by information gaps, as well as their ability to capture the full value of the benefits arising from investments they make. Individual firms face a considerable uncertainty with respect to two critical factors – the extent to which their investments in leading edge research will result in commercial returns to the firm and the degree to which those results may leak from their firm to other ones in the ecosystem through knowledge or technological spillovers. This degree of uncertainty has led to the conclusion that rationale economic behaviour may result in a socially suboptimal level of investment in research and development. Among the conditions that can result in market failure, the most notable are: imperfect information (information asymmetries), imperfect markets (such as in the case of natural monopolies), risky or uncertain outcomes, significant discrepancies between the social and the private rates of return (knowledge spillovers) and the presence of public and indivisible goods. Some economists suggest that at the root of this dilemma are innovation and information asymmetries which lie at the core of the operation of market economies (Metcalfe 1995; Cimoli, et al. 2009).

One of the most significant of examples of these types of failure arises from the public good nature of new knowledge and the consequent difficulties encountered by private agents in capturing the full returns from their investments in basic or curiosity-driven research. The attendant problems that arise from the public good nature of knowledge creation, which include the problems of appropriability, cumulativeness and knowledge spillovers, provide the most commonly accepted rationale for government intervention to stimulate higher levels of spending on research to foster the creation of new knowledge and promote the socially beneficial effects of knowledge spillovers that arise from that spending. One of the most important aims of modern government programs to stimulate higher levels of investment in research and innovation is to counteract these kinds of market failures and produce higher levels of private investment in situations where the social rates of return are likely to be considerably higher than the private rates (McCann and Ortega-Argilés 2013). In these situations, interventions by government to stimulate or constrain business behaviour are justified in order to achieve a more optimal social outcome and a better distribution of economic welfare for society as a whole. This has provided one of the most important catalysts for government to stimulate higher levels of investment in R&D through a mix of tax incentives and direct subsidy programs.

The Evolutionary Approach: Neo-Schumpeterian Rationales

The evolutionary or neo-Schumpeterian approach to the analysis of innovation differs in many critical respects from the neoclassical perspective. The assumptions of the former about the presumed rationality of economic agents, the easily codified and undifferentiated nature of technical knowledge, and the largely symmetrical behaviour of identical firms in the innovation process, are all challenged by the body of literature associated with the latter perspective (Nelson 1994, 297–304; Lundvall 2006). A critical difference between the neo-Schumpeterian and neoclassical perspectives (including Romer's endogenous growth model) is their conception of the origins, nature and accessibility of technical knowledge. In the neo-classical perspective, technology is seen as information that is generally applicable, easy to reproduce and reuse, and is not always distinguished from the general base of scientific knowledge. Firms can produce and use innovations by drawing upon a freely available pool of technological knowledge (Dosi 1988, 1130). Technology is defined as, "the ability to carry out productive transformations . . . translating materials, energy and information in one set of states into another, more highly valued set of states" (Metcalfe 1997, 279). It thus consists of three key elements: knowledge; skills and artefacts; and from an evolutionary perspective, technological innovation which involves the process of applying knowledge and skills to combine an existing set of artefacts into novel combinations that fill a market demand and thereby create value (Arthur 2009).

The evolutionary approach to innovation and economic growth emphasizes the complex, uncertain and interdependent nature of technological change and places entrepreneurs and firms at the centre of the process. These individual agents and organizations are endowed with access to different knowledge bases, different sets of organization and technological capabilities, and even different risk profiles. They are confronted with a high degree of market uncertainty in which the potential for success or failure of a new innovation is unpredictable at best. Given the uncertain nature of technological innovation, firms or organizations rely upon their existing knowledge base in their efforts to solve new technological problems. Their knowledge base is highly structured and forms part of the cumulative memory of the organization. It is both codified, as in the case of scientific knowledge, and tacit. Individuals or groups working together for the same firm or organization often develop a common base of tacit knowledge in the course of their research and production activities (Nelson and Winter 1982, 76–82; Dosi 1988, 1188).

The evolutionary perspective also starts with the assumption that economic actors operate with bounded rationality and that innovation involves a constantly changing search process that is bounded by both limits of scientific and technological knowledge at any one point, as well as the strategic and managerial capabilities of the firms engaged in the search process (Dosi 1988; Cohen and Levinthal 1990). As such, the innovation process tends to move along a technological trajectory where the range of new possibilities is determined by the external knowledge base that firms can draw upon, as well as the internal heuristic search techniques that firms adopt to guide their innovation and new product development strategies (Nelson and Winter 1982). The result of this pattern of interaction is that innovation tends to progress along a path dependent trajectory, where past choices and past successes both limit and open up the possibilities for future technological development (Dosi 1984).

In this approach, firms are active agents who learn from their own experiences, as well as from their interaction with a broader network of customers, suppliers and the providers of specialized inputs and services they work with. Starting from this existing base of knowledge, firms employ a variety of search activities, routines and decision rules to guide their research efforts. The particular knowledge base of the firm, and the specific organizational practices associated with that knowledge base, contribute to what is termed the core competence of the firm, in other words, the things that it is good at. The extent to which firms rely on established routines and decision rules in their research efforts depends, in part, on the overall results of their past search activities and their capacity to learn from that experience. The process of innovation emerges out of the interactions between the cumulative increase in the knowledge base and the technological capabilities of firms in the development and diffusion of new technologies. The creation of new technologies and the learning processes associated with them follow their own unique path of development in the sense that the adoption of new routines and the acquisition of new capabilities build on what has gone before. From this perspective, the process of technological advance is seen as "a phenomenon of organized complexity that results in cumulative and irreversibly long-run change, in which successive events are uncertain, highly contingent and difficult to forecast" (David and Foray 1995, 17).

Despite the dynamic and unpredictable nature of the innovation process, it invariably develops along ordered paths defined by the economic and technical properties of past discoveries. This is one of its central paradoxes. The early stages in the development and diffusion of new technologies is marked by an increase in diversity, in terms of the range of products, processes and services associated with the technology — witness the number of different types and manufacturers of personal computers competing in the market place in the 1970s and 1980s. In this early stage of the technology, the design is still variable and there is no certainty about which products will dominate the market. However, the cumulative and irreversible character of technological change results from the tendency for markets to lock into particular technologies as their use becomes more widespread. Technologies become more useful and more attractive to end users as this occurs. This phenomenon is referred to as increasing returns (Arthur 1988). In other words, history matters; additions to technological knowledge are by nature cumulative and the ability to exploit new knowledge depends on the technological capabilities that already exist (Rosenberg 1994, 15). Adopting an evolutionary perspective thus shifts the lens through which innovation programs are assessed and reviewed and allows for the consideration of a broader range of programs in the overall mix of a government's Research, Development and Innovation (R,D&I) policy.

The Systems of Innovation Perspective

The increasing salience of knowledge and innovation in the global economy focuses attention on the fact that innovation and technical progress are generated by a complex set of structures that produce, distribute and apply various kinds of knowledge. While the actual process of creating novel combinations of existing artefacts or components is the purview of firms, enhancing the knowledge and skills needed to create these novel combinations is the responsibility of a much wider set of social institutions — hence the importance of the systems of innovation perspective for understanding and analyzing the nature of technological change. Over the past two decades, a growing number of policy analysts and government organizations have adopted the innovation systems approach, which focuses on the complex and interdependent role of institutional structures, to examine the relative capacity of national economies. The systems of innovation approach analyzes the nature of the systemic interactions between key actors and institutions that comprise an innovation system. The central tenet of the approach is that what appears at the macroeconomic level as technological innovations that are developed endogenously within the firm, actually emerges out of the complex interaction of a wide range of economic and social agents and organizations, and that many of the market forces which determine the success of these innovations are delimited by the operation of a complex set of non-market institutions (Soete, Verspagen, and ter Weel 2009; Edquist 1997; 2005).

The systems of innovation approach emphasizes the role of various institutional structures and social forces in influencing the innovation process. Studies of technological change have identified the complex interdependence between purely economic dynamics and the broader social and political factors that sustain the process. While innovation is primarily the focus of individual firms, virtually all of the authors associated with the systems of innovation approach stress the central role of the institutional infrastructures in providing much of the skills and knowledge, as well as the legal and regulatory frameworks that govern and support the adoption and diffusion of new technologies.

The innovation systems approach highlights the manner in which the discovery and diffusion of new technologies is facilitated, or impeded, by the prevailing ensemble of social, economic and political institutions at different spatial scales and levels of industrial organization. Innovation and technical progress are increasingly generated by the complex set of structures that produce, distribute and apply various kinds of knowledge and combine that knowledge into new products. These routines are developed in the context of the broader set of social and political institutions that provide many of the key inputs needed to support innovation in the firm — ranging from scientific research and highly qualified labour to the sources of finance and public policy supports that sustain the process. The innovative performance of individual countries, regions or industrial sectors is influenced by the way elements of this institutional mix interact with each other in the creation and application of knowledge (Wolfe, 2011). Central issues from the innovation systems perspective concern the degree of complementarity or fit between the various institutions which perform this role and the effectiveness with which they respond to rapid technological change.

The key elements that comprise the national and regional innovation systems include: the internal organization of firms; the network of inter-firm relationships; the role of the public sector; the institutional set-up of the financial sector; and the degree of R&D intensity and the nature of R&D organization in both the public and the private sector. The interactions among these elements of the innovation system are influenced by a variety of factors that include the macroeconomic and regulatory environment, the system of corporate governance, the nature of the education and training system, the state of the communications infrastructure, and prevailing conditions in individual factor and product markets. Interactions among the various institutions and actors that comprise the innovation system often operate across multiple levels of jurisdiction, from the national to the local, and take a variety of different forms (Nauwelaers and Reid 1995).

Building on the initial insights developed by some of the original theorists of the concept, Stan Metcalfe defines a national system of innovation as the

> . . . set of distinct institutions which jointly and individually contribute to the development and diffusion of new technologies and which provides the framework within which governments form and implement policies to influence the innovation process. As such it is a system of interconnected institutions to create, store and transfer the knowledge, skills and artifacts which define new technologies (Metcalfe 1997, 285).

The innovation systems perspective emphasizes the relative importance of the patterns of interaction between firms as part of a collective learning process in the acquisition and use of new technical knowledge, and their interaction with the broader institutional elements of overall system. This flows from their belief that innovation is increasingly tied to a process of interactive learning and collective entrepreneurship, especially in terms of the relationships between producers and users of new technology. The innovative performance of individual countries is therefore influenced by the way in which elements of this institutional ensemble interact in the creation and application of knowledge. Lundvall and his collaborators suggest it is helpful to think about two related dimensions of the innovation system. The first involves the structure of the system — what is produced in the system and what innovative competencies are involved in producing these; the second involves the institutional make-up of the system — the ensemble of non-market forces that shape and condition the way in which production and innovation occur (Lundvall, et al. 2002, 220).

Innovation Systems and Innovation Policy

The shift to a more innovation-based perspective necessitates a considerable rethinking of the government's overall approach to R, D & I policy. In the prevailing neoclassical paradigm that justifies government intervention in terms of correcting for market failures, the primary focus in R,D,&I policy has been on correcting for the most obvious case of market failures, particularly in the case of inadequate provision of public goods with extensive knowledge spillovers (basic or fundamental research), cases of imperfect markets, where the relatively smaller size of the domestic market may limit the scale of demand for high risk, technologically-intensive products or cultural products designed to reflect the unique experience of the local society and where there is a further risk of domestic producers being overwhelmed by a flood of overseas firms who enjoy the benefits of producing with larger scale economies.

The first major application of the innovation system concept to an analysis of national differences in innovation policies was the collaborative study of innovation across fifteen nations lead by Richard Nelson (1993). In his overview of the key findings of the study, Nelson identified the key elements of the innovation system that accounted for some of the differences in national configurations that it revealed. Among those elements identified were corporate research and development laboratories; the role of universities, or scientific and technical education structures more generally; and the role of governments, and in particular, their policies designed to influence the rate and pace of innovation. Overall, he concluded that the range of institutional structures supporting innovation varies across national systems as a result of the considerable differences in their respective traditions and their developmental trajectories (Nelson 1992, 373–74).

A comparative study of institutional differences across the innovation systems of European countries develops the notion of institutional coupling and illustrates how it shapes the national capacity for innovation (Lorenz and Lundvall 2006). It analyzes the complementary nature of the structure of labour markets, the education and training system, internal firm organizational patterns and the external sources of firm finance. These institutional structures are shaped and constrained by social and political processes across the diverse national economies in Europe, thus conditioning their potential for change. Public policies which fail to take these distinctive national features into account may suffer from a lack of fit with their existing institutional structures. The key institutional features affecting the success or failure of policies to promote technological upgrading are the effectiveness of interactive learning, within and between organizations, and the capacity for risk-taking. The skill structure and ability to acquire new skills, and the extent to which training and labour market systems are integrated with internal firm dynamics (organizational patterns) are also critical. The distinctive features of national systems strongly affects their capacities for innovation; both the nature and interrelatedness of these institutional subsystems affects how new and enhanced knowledge is absorbed and put to commercial use within firms. Interestingly, among the first countries to adopt the innovation systems (IS) approach in the design of their national agencies were Finland, seeking to recover from the economic crisis it experienced in the 1990s following the collapse of the Soviet Union, and Sweden, which established VINNOVA – the Swedish Government Agency for Innovation Systems – in 2001, formalizing a policy approach that the country had also been following since the 1990s (Weber and Truffer 2017).

The adoption of the innovation systems approach has prompted a shift to the broader conception of innovation policy among policy analysts. The innovation systems (IS) approach emphasizes the fact that while innovation occurs primarily within firms, the innovative capacity of nations or regions emerges from the complex interplay of wide constellation of different actors and organizations, including firms, research institutions, sources of finance, innovation intermediaries and civic associations at different levels of governance. It is the interaction between the different properties or capabilities of this mix of actors and organizations that determine the innovative potential of the nation or region, rather than the properties of an individual actor or institution; hence the emphasis in the IS approach is on the interaction of the various factors and how they develop over time This perspective draws the attention of policy makers to the need to review and redesign key linkages between the institutional components of the national innovation system. Weaknesses or failures in national innovative capacity are analyzed as system failures, rather than traditional market failures. The IS perspective therefore focuses its analysis and prescriptions on the configuration of core elements of the innovation system, particularly: "(i) capability failures if actors lack the appropriate skills and resources; (ii) coordination failures in the case of interactions lacking between actors, and (iii) institutional failures in cases where context conditions hinder the further development of innovations or when actors are unable to influence institutional structures in a way to support innovation . . ." (Weber and Truffer 2017, 112).

Governments concerned with promoting a more comprehensive approach to enhancing the innovative capabilities of their respective economies focus on a more integrated approach that sees R,D&I as part of a continuum to promote the continuous upgrading of innovative capabilities in a national or regional economy. Work on innovation systems includes both the national and the regional levels. This shift grows out of the recognition that innovative capabilities are sustained through local and regional communities of firms and supporting networks of institutions that share a common knowledge base and benefit from their shared access to a unique set of skills and resources. The regional innovation system, like the national, can be conceived in terms of both the demand and supply side for innovation.

On the supply side are the institutional sources of knowledge creation in the regional economy. Closely linked to these are the institutions responsible for training and the preparation of highly qualified labour power. The demand side of the system subsumes the productive sector – firms that develop and apply the scientific and technological output of the supply side in the creation and marketing of innovative products and processes. Bridging the gap between the two is a wide range of organizations, which play a role in the acquisition and diffusion of technological ideas and know how. These may include technology centres, technology brokers, business innovation centres, organizations in the higher education sector that facilitate the interface with the private sector and mechanisms of financing innovation, such as venture capital firms (Nauwelaers and Reid 1995).

While the innovation systems approach has generally gained greater currency in Europe, policy analysts in the US have favoured the innovation ecosystem approach which reflects more of a business and bottom up approach. From this perspective, innovation ecosystems consist of a complex web of relationships between a variety of individuals, communities, organizations, material resources, rules and policies that work together to facilitate knowledge production, knowledge transfer and industry-driven commercialization activities (Wessner and National Research Council 2007). These ecosystems embody a bottom-up approach to economic development and are capable of achieving short-term outcomes and longer-term economic and social impacts. Each regional or local ecosystem also has its own set of operational rules and an organizational style that aligns with its unique entrepreneurial culture and fosters its knowledge-based competitive advantage. Furthermore, the structure of innovation ecosystems will vary considerably due to the differences in regional priorities, local economic and political conditions, historical contexts, and the agency of local research and innovation actors. In turn, each innovation ecosystem will have different knowledge production processes and commercialization strategies to support its members and their activities. As a consequence, there are a number of variables that influence the interaction of innovation ecosystem members, the strength of the relationships formed, and more broadly, the ecosystem's capacity to innovate. The innovation ecosystem approach was recently adopted in the Council of Canadian Academies report on *Innovation Impacts: Measurement and Assessment* (Council of Canadian Academies 2013a).

National Styles of Science, Technology and Innovation Policies

Most observers agree that World War II was the critical watershed in the development of national science and technology policies. The experience gained in financing and managing large scale science projects during the war, particularly in the development of radar, electronics and atomic weapons, and the highly visible contribution they made to the Allied victory, carried over after the war into a surge of new investments in science and technology that surpassed anything undertaken before (Hart 1998). The successful outcome of these focused research efforts generated support for substantial increases in government procurement and research funding for high technology industries, especially those perceived as critical for national defence. This lesson was strongly reinforced by the successful launching of Sputnik in 1957 and the ensuing space race which it triggered in the 1960s. In the later part of the twentieth century, many new and emerging technologies in areas such as microelectronics, robotics, biotechnology, nanotechnology and the exploration of the human genome, have been the outcome of this increased funding (Wessner and National Research Council 2003, 50–51).

While in the early years after World War II the focus was primarily on the creation and funding of national science policies, over the course of the following decades, national technology policies emerged as an extension of science policies, with a focus on the development of new technologies and the promotion of industrial sectors. They are "policies that are intended to influence the decisions of firms to develop, commercialize or adopt new technologies (Mowery, 1995, 514)..." Technology policies can include those intended to increase the supply of scientific knowledge, through support for basic research, technology development, and the development of applied civilian technologies. The role of the research infrastructure is critical for policies designed to enhance the supply of technology in a national economy. This includes the role of publicly financed research institutes and research universities. It also includes efforts to support university-industry research partnerships, to promote the transfer of technology from the research laboratory to industry, and to support industrial technology development (Teubal, et al. 1996). However, the field of innovation policy is marked by continuing debates over the precise role the government should play in supporting research and innovation, the choice of the appropriate policy instruments for government to use, and the relevant point for government to intervene along the spectrum from basic or curiosity driven research to more applied types of technology development closer to the commercialization end of the spectrum.[1]

Mission Oriented versus Diffusion Oriented Innovation Systems

In addition to policies to increase the supply of technology, a range of other policies target the adoption and diffusion of technology more widely throughout the economy. In broad terms, analysts have made a distinction between two broad policy approaches to support science and technology: mission-oriented

[1] For more detailed discussions of the distinction between basic, or curiosity, driven research and applied research, cf. (Stokes 1997) and Branscomb (Branscomb 1997; Branscomb and Florida 1998; Branscomb and Auerswald 2001).

and diffusion-oriented policies. In national systems dedicated to the mission-oriented approach, the emphasis is placed on substantial investments in achieving radical innovations to reach clearly established national goals. In contrast, diffusion-oriented policies emphasize the effective diffusion of technological capability throughout the industrial structure to facilitate the incremental adoption of new technologies across a wide range of industries. In the initial phase of the postwar period, public policies to support science and technology were strongly influenced by the US lead, with the predominance of public investment in the nuclear, military and space programs. This pattern was particularly true of the UK and France which most closely followed the mission-oriented model. Furthermore, the actual pattern of policy in these countries tended to emulate the 'big science' approach that was established by the wartime Manhattan Project and continued to be favoured in the US. In contrast, policies in other industrial countries, such as Germany and Sweden, more closely approximated the diffusion-oriented approach. Diffusion-oriented policies tended to be more decentralized, focusing on improving the technological capabilities of small and medium-sized enterprises through vocational education programs, establishing a strong system of industrial standards and promoting cooperative R&D (Ergas 1987). There is not a strict correlation between the economic rationales provided by the neo-classical and the evolutionary perspectives for supporting investments in science and technology. However, at a broad level, the mission-oriented approach tends to be guided by the neo-classical rationale for subsidizing the social returns to investments in basic or fundamental research that may lead to breakthrough discoveries, while the mission-oriented focus on the need to diffuse technologies more broadly across the economy is more closely aligned with the evolutionary systems perspective. In more recent years, however, the distinction between these national styles has tended to blur as more countries have adopted elements of both the mission-oriented and diffusion-oriented approaches.

Japan was unique among the industrial countries in adopting a highly strategic approach to the design of its postwar science and technology policies. The Japanese system was directed towards the challenge of rebuilding its industrial structure after World War II and catching up with the US and other industrial leaders. One of the hallmarks of its innovation system from 1945 to the 1980s was the critical role played by government agencies in guiding that process. During this period, government ministries pursued long-term strategic objectives to guide the acquisition and development of technology by Japanese industry and to shape the overall structure of the economy. From the early 1950s to 1975, the major goal of policy was to encourage the importation of technologies that Japanese industries needed to compete with those in other industrial countries. The Ministry of International Trade and Industry (MITI) gave priority to technology needed to produce intermediate goods, such as chemicals, and suppress demand for consumer goods (Kodama 1995, 26–30; Johnson, Tyson, and Zysman 1989). In the subsequent period, from the mid–1970s onwards, the focus shifted towards an emphasis on supporting industrial research for long-term economic growth. Industrial and technology policy was reoriented towards perceived ‘sunrise’ industries – those that were less energy and materials intensive and more knowledge-based. These industries were perceived to be ‘strategic-transformative’ ones, such as information technology, that held the potential to transform both products and production processes across a wide range of other sectors. In the reorientation of the early 1970s, government efforts targeted a number of new technologies and industrial sectors, including electronics and computing, new materials and biotechnology, which were perceived as the sectors that would lay the basis for economic growth across a wide range of the broader economy (Tyson and Zysman 1989). The success of Japan in aligning its institutional structures to gain a competitive advantage over leading European economies and the US in some of these key technologies provided the impetus for initial development of the IS approach in the late 1980s (Freeman 1987).

The US is generally characterized as having pursued a mission-oriented approach and recent analyses of US science, technology and innovation policies have documented the extent to which government initiatives, often in the name of space and defence objectives, were instrumental in seeding the growth of entirely new economic sectors associated with the emerging post-industrial economy. Over the course of the postwar period, the US government underwrote between one-half and two-thirds of total R&D spending. Financial support for the expanded US research effort was readily available not only from the extensive programs of the National Science Foundation and the corresponding National Institutes of Health, but also from a host of mission-oriented programs sponsored by specific agencies, such as Defence, the Atomic Energy Commission and later NASA. At the centre of this innovation system was the US Air Force, which “. . . exercised significant influence over the atomic energy program and academic research in a range of physical science and engineering disciplines as well as over an array of large and small contractors in aviation, electronics and a host of lesser industries” (Hart 1998, 214). This was complemented by a rise in private corporate R&D, funded in some industries, such as electronics, jet engines and space systems, by the same federal agencies. A much underappreciated fact is the extent to which the US Air Force was responsible for establishing the academic discipline of computer science in postsecondary institutions in the 1960s to meet the rapidly growing need for well-trained computer programmers versed in the programming languages starting to gain greater application in the military, space programs and the broader economy as well (Mowery and Langlois 1996). The substantial and continuing nature of these investments propelled the US into a position of world leadership in scientific research and in developing and implementing some of the key technologies that drew upon this research (Nelson and Wright 1992; Weiss 2014).

In the later part of the twentieth century, many new and emerging technologies in areas such as microelectronics, robotics, biotechnology, nanotechnology and the exploration of the human genome, have been the clear beneficiaries of this increased funding (Wessner and National Research Council 2003, 50–51). In a far ranging study of the impact of government support on the development of new technologies, the US National Research Council documented critical components of the computer revolution that benefited from US government support programs. Government support was essential for the development of most of the early digital computers in the US and enabled critical breakthroughs in areas ranging from computer time-sharing and the Internet to artificial intelligence and virtual reality. Federally supported research concentrated in particular in areas that private industry had limited incentive to pursue: “long-term fundamental research; large system building efforts that require the talents of diverse communities of scientists and engineers; and work that might displace existing entrenched technologies” (National Research Council 1999, 5).

Rapid Innovation-based Strategies

Some of the most successful examples of effective innovation policy over the past four decades are found in the case of a number of countries that have used a range of policy levers to effectively accelerate the technological development of key sectors of their economy, most often in the field of information and communications technologies. This form of policy intervention has been justified on the basis of the different elasticities of demand associated with various technologies and the implications that shifting the developmental trajectory of a national or regional economy can have for long-term growth rates of the economy and the long-term trend in per capita incomes. The potential benefits that flow from an individual set of technology and production choices are strongly determined by the potential demand for those technologies or products in world markets – or what economists refer to as the income elasticities of demand. The faster the demand increases in world markets for a country’s products, the greater will be the net benefits, in terms of growth, that flow to that country. The choices made individually by firms, or collectively through public policy, about the product mix that a country specializes in will strongly affect its future well-being (Dosi, Tyson, and Zysman 1989, 15).

A key characteristic of those economies that have successfully industrialized, from the earliest cases to more recent examples, has been mastery of the ability to manipulate and produce more technologically complex products and production processes and to develop and sustain the economic forms of organization necessary to produce these goods. As the pace of technological change has accelerated, there appear to be a number of critical technologies “whose domains of application are so wide and their role so crucial that the pattern of technological change in each country depends to a large extent on the national capabilities in mastering production/imitation/innovation in such crucial knowledge areas . . . .” As a result the ability to master those capabilities disproportionately tends to influence the long-term growth prospects of individual countries (Cimoli, et al. 2009, 23). It is the potential benefits that can arise from the long-term growth potential of these kinds of income elasticities that have been used to justify targeted government support for specific sectors in the contemporary economy, such as information technology, biotechnology or nanotechnology.

Dan Breznitz has analyzed the innovation strategies pursued by a number of lagging countries to alter their economic development trajectory through focused support for what he terms rapid innovation-based (RIB) industries. In these cases, a conventional development strategy that relies on imitation of leading economies and technology transfer is no guarantee of success. In the successful cases analyzed, including Israel, Taiwan and, to a lesser extent, Ireland, critical factors in the effective of the innovation strategies have included: a focus on the ways in which knowledge is acquired at the national level and disseminated to relevant institutions and firms within the innovation system; policy interventions to reduce the degree of risk to encourage private firms to enter the industry; and actions by the national government to support the linking of local firms to multi-national enterprises (MNEs) embedded in global production networks (GPNs) beyond the national boundaries (Breznitz 2007, 6).

In more recent work, Breznitz and Ornston have suggested that RIB strategy requires the establishment of a Schumpeterian Developmental Agency (SDA) charged with identifying and refining new policy approaches to transform the key sectors of the economy. Radical innovation is more likely to be stimulated by agencies situated at the periphery of the public sector, which operate with relatively limited resources. This peripheral location facilitates policy innovation due to the fact that they are less likely to be targeted for political interference by established public sector interests and are less vulnerable to lobbying by special interest groups. This enables policy makers to experiment with novel and risky initiatives. An additional factor critical to the success of these agencies is the willingness of governments to support them over a long period that allows the strategies refined and implemented by the agencies to effect significant long-term change in the target sectors of the economy, as was the case in Finland, and Israel (Breznitz and Ornston 2013).

The case of Taiwan provides another striking example of RIB development in the recent past. In this case, the government's strategy deployed a public research laboratory, the Industrial Technology Research Institute (ITRI), to promote the diffusion of technology sourced from abroad into the Taiwanese marketplace. ITRI's role was to scan the globe for useful technologies and develop the capability to exploit these technologies in its own laboratories. The Taiwanese government decided to enter the integrated circuit industry in the mid-1970s. ITRI was established to derisk the process of adopting technology from abroad and transferring it to local firms. ITRI's mission was to scan for technologies of interest to Taiwanese industry, import that technology (through license and joint collaborative development), and to absorb, adapt, and transfer that technology to Taiwanese firms by providing trained personnel, equipment, and know-how to Taiwanese firms who could exploit the technology for commercial development (Matthews 2002). Revenues for the first few years came exclusively from government contracts through a series of public R&D projects in the 1970s and early-1980s (Breznitz 2007).

This strategy ultimately led to the spin-off of two anchor firms from ITRI. The first was United Microelectronics Company (UMC), which became the first foundry for silicon wafer manufacturing in the country. UMC was heavily supported by the government with the transfer of personnel, technology, equipment, and IP from ITRI into UMC (Hsu 2004). The second key anchor firm was Taiwan Semiconductor Manufacturing Company (TSMC), which was created from the original ITRI lab. With UMC and TSMC, the key suppliers of silicon wafers for integrated circuit manufacturing were established. This same process of ITRI licensing technology, developing manufacturing procedures in its laboratories, and passing them along to local firms was repeated in the early 1990s with CD-ROM technology, in the mid-1990s with Ethernet switch technology, and in the late-1990s with thin film transistor liquid crystal display (TFT-LCD) technology. ITRI's relationship with Taiwanese firms has changed as those firms have matured. ITRI is moving away from the paradigm of method and knowledge transfer of technologies invented in other places, and is beginning to conduct original industrial research in conjunction with Taiwan's universities and in collaboration with international partners (Yeung 2016).

Relevance for the Canadian Case

Recognition of the importance of shifting the technological trajectory of new and emerging sectors of the economy has been singularly lacking in most Canadian approaches to innovation policy. One notable exception is Richard Harris' seminal study for the Macdonald Royal Commission. Harris was concerned with a specific market imperfection that has received inadequate attention in most analyses of innovation policy: the unique challenge faced by firms in small, open trading economies, where the size of the domestic market may generate insufficient demand to sustain firms and industries in leading edge technologies or products. Theories that link international trade with technological innovation argue that shifts in leadership are not randomly distributed across industrial sectors or between countries. Reflecting this perspective, Harris argued that much of technological competition tends to be cumulative and that the nature of that competition contains a large degree of irreversibility. There are substantial advantages to being first. Trying to adapt industrial and technology policy on the principle of catching up to the technological leaders may prove difficult. Technological competition tends to be pre-emptive and produce irreversible results. The benefits of technological leadership allow a firm to recover its research and development costs, as well as realize a higher than average return on its investment. In effect, 'success breeds success', or "being successful today raises the probability of success in the future" (Harris 2015, 99). This may greatly reduce the chances for competing later on, which will open up a significant gap between the technological leaders and technological laggards resulting in significant differences in national incomes between the two types of economies and a significant trade surplus or trade deficit in high technology products.

Harris suggested that there is a bias in small, open economies against Schumpeterian or technology-based industries. The entry barriers associated with technological innovation affect smaller firms to a greater extent than large ones. And to the degree that smaller economies are characterized by a larger number of smaller indigenous first firms, this places the entire economy at somewhat of a disadvantage with respect to technological competition, "the Schumpeterian industries in small economies suffer from a relative disadvantage in industrial structure. As a consequence he suggests "the social incentive to subsidize Schumpeterian industries is greater in a small open economy than in the large closed economy" (2015, 105). The reason for this is that the relatively smaller size of firms in the smaller economies leads to a suboptimal industrial structure with respect to competing in Schumpeterian-based industries.

Harris also noted that subsidizing small firms to engage in greater levels of R&D spending does not automatically ensure that the firm will grow to sufficient size in order to overcome the barriers to entry in world markets. He concluded that market failure in the industrial R&D process within Schumpeterian industries disadvantages firms in a small open economy, resulting in the need to design technology policy with this fact in mind. The policy implications of Harris' insights were largely overlooked in the recommendations advanced by the Royal Commission and have been absent from much of Canadian innovation policy for the past thirty years. As will be noted in subsequent sections of this report, there is substantial evidence to suggest that both direct and indirect innovation policies, targeted at individual firms, can increase the volume of research and innovation activity within specific sectors of the domestic economy, at both the start-up phase of growth and for more established technology-based firms. However, the continuing underperformance of the Canadian economy with respect to many of the key indicators tracked by the Council of Canadian Academies, the Science, Technology and Innovation Council and the Science, Technology and Innovation Outlooks published by the OECD, all indicate that the absence of a longer term strategic perspective may be a contributing factor in this persistent problem (Council of Canadian Academies 2009; 2013b; Science Technology and Innovation Council 2014; OECD 2016) .

Building Strategic Capabilities across Sectors and Clusters

The evolutionary perspective suggests that innovation policies and programs need to be assessed from a different perspective than that suggested by the traditional neoclassical emphasis on market failure. It provides a broader lens through which to assess the overall effects and impacts of the complex mix of policy measures adopted by governments to support R,D&I. The innovation systems approach also suggests a need to shift the focus from support for individual firms to viewing the innovative performance of the firm in a broader context that sheds light on how the firm's performance is conditioned by the broader sector or cluster within which it operates.

The development of productive capabilities in a national or regional economy frequently generates technological spillovers from one firm to another in the same sector and sometimes across firms in related sectors. Sometimes these spillovers follow the lines of traded input-output relationships in the economy, but often they occur along lines that are not traded. These technological spillovers are tied to knowledge and practices that are not always codified or explicit. They are frequently shared among firms or transferred from firm to firm through various forms of networks, such as user-producer relationships, strategic alliances, R&D consortia, collaborative training and marketing schemes, and supportive public infrastructure, such as educational institutions. They may also derive from other institutional arrangements, such as the particular norms and rules governing the functioning of local labour markets. These forms of collaboration and networking give rise to the existence of 'untraded interdependencies' within a regional economy, which represent important regional assets and capabilities (Dosi 1988; Storper 1995).

The implication of this perspective is that policy needs to focus not just on building the innovative capabilities of individual firms, but also a broader sectoral capacity to support new technology platforms in emerging areas such as alternative fuel technologies or cloud-based and data analytic capabilities for the information technology and advanced manufacturing sectors. While the federal government has not always been explicit about its adoption of a sector-based approach to innovation policies, a detailed examination of the history of science, technology and innovation policies in Canada over the past half century suggests that specific sectors have been singled out for focused policy attention, principally the aerospace, automotive and telecom sectors.

Dating back to the introduction of the Defence Production Sharing Agreements in 1958 and down to the recent collapse of the SADI program into the new Canada Innovation Fund, the aerospace sector has consistently been targeted as a sector of strategic importance. For most of this period, the most important federal spending program in this area was the Defence Industry Productivity Program (DIPP). Created in 1959, on the heels of the Joint Defence Production Sharing Agreement between Canada and the US, DIPP provided support for Canadian firms in their competition with their larger US counterparts for a share of the lucrative continental market in defence contracts. Modified in 1968 and placed under the control of the federal Department of Industry, the program continued to provide strong support for the Canadian aerospace and defence-related sector industries, overwhelmingly located in Ontario and Quebec. Under the terms of DIPP, firms were able to obtain conditional grants for the eligible costs of R&D projects, to cover the costs of acquiring advanced production equipment for modernizing or upgrading manufacturing facilities, to cover the costs of establishing qualified Canadian suppliers of defence related products (source establishment assistance) and to carry out market feasibility studies. DIPP funding averaged between $150 and $300 million annually during the course of its existence, but was continuously the main source of support for R&D and innovation in the aerospace industry (Botham and Giguère 1993, 82).

Despite its success and the critical role it played in supporting innovation in the key aerospace sector, the program was terminated in the 1995 budget, as part of a general reduction of business subsidies. This action sparked a firestorm of protest from the affected sectors of industry and it was subsequently replaced by Technology Partnerships Canada, which was eventually replaced by the Strategic Aerospace and Defence Initiative (SADI) in 2007 (Smardon 2014, 371). Aerospace has not been the only sector singled out for technology support; the automotive sector has also received consistent support from both the federal and the provincial governments since the early 1980s, which was formalized with the introduction of the Automotive Innovation Fund (AIF) in 2008 and subsequently the Automotive Supplier Innovation Program (ASIP) introduced in 2015 (Doern, Castle, and Phillips 2016, 203–05). Historically, the federal government has also adopted focused policies to support the restructuring or technological development of other key sectors, including textiles, telecommunications and pharmaceuticals (Atkinson and Coleman 1989).

Most of the current sector focused programs, including SADI, AIF and ASIP were wound up in the 2017 federal budget and their funding transferred into the more broad-based Canada Innovation Fund. This raises a fundamental question about the relative value and importance of sector specific innovation policies versus the sector neutral approach adopted in the most recent federal budget. While an evolutionary systems perspective would suggest there are some virtues to adopting a sector focused approach, this trajectory of program evolution is consistent with the general pattern across OECD countries observed in the review of the direct program support for R&D and innovation undertaken by researchers at Manchester University. They noted that large technology development programs focused on specific sectors, such as aerospace, the nuclear industry, telecommunications and the computer industry, were a more common feature of the innovation policy landscape in OECD countries in the 1960s and 1970s. The majority of these programs have either been wound down or in the case of the EU, they have been rolled over into more collaborative research programs through the Eureka or EU Information Society programs, or become a less significant part of the overall mix of policies in their respective countries. However, the report also notes that they have undergone something of a revival in the past decade in the form of new programs targeted at strategic technologies or building technology platforms that may cut across several traditional industrial sectors (Cunningham, Gök, and Laredo 2013, 12).

The policy rationale for this shift in program focus towards an emphasis on the development of new technology platforms may be found in an evolutionary perspective on the evolving nature of technology-based competition. Firms may encounter specific forms of market or system failure associated with the development of new technologies. These potential failures include the greater degree of risk and higher level of uncertainty associated with the development of new technology platforms, the lack of standards for new and emerging technology platforms, as well as the proprietary technologies that are the proper realm of inter-firm competition. The shift in focus by the majority of R&D performing firms to more applied R&D spending in order to remain competitive in the latter stages of technology life cycles, means there is even greater need for government to support the quasi-public good stages of research and technology development. The broader implications of this are that,

> (m)any economies are now compensating for these 'market failures' by establishing public-private research partnerships to pool risk, improve the efficiency of R&D, and diffuse new technology platforms more rapidly within domestic supply chains. These economies are also investing increasing amounts in supporting technical infrastructure (infratechnologies and standards) to increase efficiency across the R&D, manufacturing and commercialization stages of technology-based economic activity (Tassey 2013, 307).

Recognizing the strategic significance of technology platforms, as well as the R&D spending levels or innovative practices of individual firms, has two critical implications for the objectives of innovation policy more broadly: it requires a broader and deeper integration of the links between individual programs designed to support the research and development capabilities of research institutions, especially in the public sector and the integration of those research capabilities with the absorptive capacity of domestic firms (Cohen and Levinthal 1990); 2). The need for this integrated perspective has been reflected in the development of the policy mix approach discussed in more detail below.

It also requires that the effectiveness of R,D&I programs be assessed within a broader context of the competitiveness status of firms in the global economy, which affects their strategic position in rapidly evolving global production and innovation networks and global value chains (Chaminade, et al. 2016; Cantwell 2009; Cantwell 2017). The significance of these points was underscored in the *OECD Innovation Strateg*y released in 2010. The strategy highlighted the predominant role played by multinational firms in the globalization of innovation. Fewer than 700 global firms account for close to half of the world's total R&D spending and these core firms have played a central role in the emergence of global innovation networks – widely viewed as the next step in the progression beyond global value chains and global production networks. These multinationals are sourcing their innovation activities on a global scale in order to both gain access to new markets and reduce their costs. Increasingly, however, they are also situating these global innovation activities in new locales where they can tap into local centres and clusters of knowledge, as well as gain access to the highly qualified workers that anchor the labour markets in those clusters of expertise. The OECD strategy went on to underline the central role that knowledge networks play in integrating local firms and research capabilities into these global connections,

> But knowledge networks are so far much less developed than product, labour and financial markets . . . (and t)heir development is important for stimulating innovation and improving its efficiency by reducing transaction costs. Public policy should therefore support the formation of knowledge networks and markets. This can be done through policies that encourage the development of knowledge brokerages (OECD 2010a, 18).

Key Policies and Programs to Promote Innovation

Basic Research and Technology Transfer

Public policies to support innovation and economic development have been introduced in a layered fashion over the past 60 to 70 years since the end of World War II, leaving a complex legacy of overlapping and interacting policies. This legacy reflects the gradual evolution of these policies over the period and, in particular, the shift in focus from science to technology to innovation policies discussed above. In the early postwar period, the primary emphasis was placed on expanding public investments in basic research; this focus initially reflected the legacy and impact of major research initiatives to support the development of radar and atomic weapons during the war and was strongly reinforced by the launching of the first Sputnik satellite in 1957, triggering the space race with the West. In the ensuing decades, the focus shifted to promoting technology adoption and diffusion throughout the economy and supporting the commercialization of basic research. The challenge from an evaluation perspective is the frequently overlapping and sometimes conflicting program objectives associated with specific policies. This leaves those charged with responsibility for program evaluation with the challenging task of unravelling the multiple objectives of specific programs and determining the most appropriate criteria to apply in individual cases.

Social Returns to Investment in Basic Research

Nowhere is this problem more evident than in the case of public funding for basic research. The traditional view of the economic benefits derived from government support for basic or fundamental scientific research argues that government action serves to correct a market failure. As noted at the outset, the rationale behind public support for research focuses on the role of information in economic activity. Drawing on the work of Kenneth Arrow, it underlines the informational properties of scientific knowledge, suggesting that this knowledge is non-rival and non-excludable (1962). From this perspective, the result of government-funded scientific research is economically useful information, freely available to all firms in a non-exclusionary fashion. By increasing government funding for basic research, it is deemed possible to expand the pool of economically useful information available for industrial firms to draw upon. This information is seen to be durable, freely available, and costless to use. Government funding overcomes the reluctance of firms to fund their own research (to a socially optimal extent) due to its non-appropriability; new packets of economically useful information are created; and the distribution of this information enhanced through the tradition of public disclosure in science. [2]

In contrast, the evolutionary approach suggests that the informational view of knowledge substantially undervalues the extent to which knowledge is embodied in specific researchers and the institutional networks within which they conduct their research. As Rosenberg states, the information–based view tends to regard scientific knowledge as being "on the shelf, costlessly available to all comers" (1990, 165). This view fails to appreciate the extent to which scientific or technical knowledge requires a substantial investment and capability on the part of the user. Often this capacity is expensive or difficult to acquire and maintain (Patel and Pavitt 1994, 112). In an influential survey, Cohen and Levinthal suggest that one can characterize the R&D of firms as having two faces: R&D both allows the firms to create new pools of knowledge and it enhances their ability to assimilate and exploit existing knowledge. They refer to this second dimension as the firm's *absorptive capacity* (1990). In the evolutionary view, firms have no direct and costless access to this kind of knowledge, other than to that which they are currently using,

> . . . technology is not a free good, but involves specific, often idiosyncratic, partly appropriable knowledge which is accumulated over time through specific learning processes, whose directions partly depend on firm–specific knowledge and on the technologies already in use (Dosi and Orsenigo 1988, 16).

Over the years, a number of methodological approaches have been employed to estimate the social returns to investments in basic research. Most studies of the social and private rate of return to publicly funded research stress the positive rates of return. By lowering the costs incurred in developing new technologies or products through investing in the inputs, publicly funded projects generate a broader social benefit; conversely estimates of the private rate of return to research and development tend to be lower than those for the social rate of return (Mansfield 1995). This difference underscores the necessity of estimating the social rates of return for investments in scientific research, despite the

[2] I have explored this issues at greater length in two previous reports (Wolfe and Salter 1997; Wolfe, D. A. 2006). The following section draws on the discussion in those reports.

methodological problems involved. Estimates of social and private rates of return to privately funded R&D vary between 20 and 50 per cent (Griliches 1995).[3] One line of research into the benefits of publicly-funded research has investigated the spillovers from government funding to other types of activities, such as industrial R&D. The existence of these spillovers augments the productivity of one firm or industry by expanding the general pool of knowledge available to it. "[I]t is assumed that the level of productivity achieved by one firm or industry depends not only on its own research efforts but also on the general pool of knowledge accessible to it" (Griliches 1995, 63).

Mansfield has also made an interesting contribution to the attempts to measure the economic benefits of investments in basic research. Based on a sample of 75 major American firms in seven manufacturing industries (information processing, electrical equipment, chemicals, instruments, pharmaceuticals, and metals and oils), he obtained estimates from R&D managers about the proportion of the firm's products and processes over a ten year period could not have occurred without the results of the academic research. The survey results suggest that about 11 per cent of these firms' new products and 9 per cent of their new processes could not have been developed, in the absence of the academic research, without substantial delay. These percentages of products and processes accounted for 3 per cent and 1 per cent of sales respectively for the firms concerned. Mansfield concluded that the economic benefits of academic research are spread over seven years. By the eighth year, the firms themselves would have realized such research. These benefits accrue only to American firms and they provide benefits to only the innovating firm. Using these figures, Mansfield estimates the benefit from academic research to be 28 per cent. The figure represents "the present value of the stream of benefits associated with the research equal to costs. (In other words, it is the annual profit rate on society's investment in academic research)" (Mansfield 1991, 10).

In a study conducted in Germany, Beise and Stahl replicated Mansfield's methodology using a larger sample of firms to assess the effects of publicly funded research at universities, polytechnics and federal research laboratories on industry innovations. In surveying 2300 companies, they found that less than one tenth of product– or process–innovating firms introduced innovations between 1993 and 1995 that would not have been developed without the benefit of public research. These new products amount to approximately five per cent of all new product sales. The primary variable determining the success of technology transfer was the degree of movement of qualified academics between the research centres and industry. Firms also tended to cite research institutions located close to the firm and the firm's own R&D activities as support in the ability to absorb the findings of public research and

[3] A more detailed discussion of the various methods used to estimate the social and private rates of return to investments in R&D and the specific results of individual studies can be found in (Wolfe and Salter 1997); cf also (Salter and Martin 2001).

turn them into innovations. Additionally, firms with high R&D intensities cited remote public research institutes more frequently than less R&D-intensive firms (Beise and Stahl 1999).

Another approach to evaluating the benefits of publicly funded research is (Mansfield 1991, 10) found in the work of Narin et al. using a citation analysis of the US patent data base. They measured the academic citations in US patents to conclude that over a seven year period, there was a tripling in the knowledge flow from US science to US industry. Based on an analysis of the front pages of over 400,000 US patents issued between 1987 and 1994, they traced the 430,000 non–patent citations contained in these patents. Of these 430,000 non-patent citations, 175,000 were references to papers published in the 4000 journals covered by the Science Citation Index (SCI). Based on an analysis of these papers, they demonstrated a secular increase across countries (UK, France, German, and Japan) in citations of science in patent records. Patents also tend to cite their own country's papers two or three times more often than expected, when adjusted for the number of a country's scientific publications. Large US funding agencies were also highly listed as sources of funding for the citations included in the patents. The authors suggest that this indicates a strong reliance by US industry on the scientific results of research funded by the public sector (Narin, Hamilton, and Olivastro 1997).

A substantial body of research on the impact of government investments in research has been undertaken by the US National Institute of Standards and Technology. NIST has been conducting economic impact studies on a regular basis to: inform the policy and budget communities of the economic returns to society from NIST projects; and fulfill the reporting requirements of the US Government Performance and Results Act (GPRA) for performance evaluation data. In general, economic impact measures, such as the benefit–cost ratio (BCR) and social rate of return (SRR), provide useful and informative outcome data for the agency. Most of NIST's impact analyses have focused on firms and/or industries in the supply chain that benefit most directly from their output. Collectively, the entire set of economic impact studies conducted demonstrates that the rates of return on NIST infratechnologies consistently match or exceed rates of return to private investment in technology. In addition, these studies and other economic analyses suggest that public investment in infratechnologies complements private investment in proprietary technologies, which in turn generates higher rates of economic growth (Tassey 1999).

Technology Transfer and Commercialization

Much of the basic research analyzed in these studies is conducted in universities. While the studies may provide some indication of the macro-impact of funding basic research on innovation, they do not provide much insight into the precise mechanisms by which this knowledge is transferred. Yet the task of transferring knowledge from universities to industries has proven to be more complex, and the role of universities in economic development is much more varied, than the linear conception of the innovation process allows. Successful knowledge transfer depends on the type of knowledge involved, and how it is employed. As Mowery et al. have recently argued, "Any assessment of the economic role of universities must recognize the numerous, diverse channels through which university research influences industrial innovation and vice versa" (2004, 179).

The nature of knowledge transfer, and the actual substance of what firms draw from basic research, varies significantly across industrial sectors. Several large-scale surveys of industrial R&D managers have probed for the extent and implications of inter-sectoral differences in the way that firms in different industry sectors deploy scientific knowledge in the innovation process. A pioneering study conducted at Yale University queried 650 R&D managers in US firms, representing 130 lines of business. it distinguished between two roles that science plays in supporting innovation: one as an expanding pool of theory and problem-solving techniques deployed in industrial R&D; the other as a direct source of new technological possibilities pointing the way towards new solutions to old problems. Overall, university-based research in a field is reported as being much less important to recent technical advance in industry than is the overall body of scientific knowledge in the field. In most fields, what academic research provides are not pilot inventions, but the broad understandings and techniques that industry can employ for a variety of different purposes. Industrial R&D managers value the scientific background and training of their R&D staff more highly than the current research activities of university-based researchers. The Yale researchers also noted that advances in fundamental scientific knowledge influence the pattern of innovation in industry through a second, more indirect route – through their incorporation in the applied sciences and engineering disciplines and their impact on research in those fields. The disciplines with the highest relevance scores of university research for the largest number of industries were computer science, materials science, metallurgy and the engineering disciplines (Klevorick, et al. 1995).

Both the research methodology and the findings of the original Yale survey were replicated in a subsequent survey of industrial R&D managers conducted at Carnegie Mellon University. Public research is significant in addressing previously identified needs or problems, rather than suggesting new lines of innovative activities, with the exception of a select few industries, such as pharmaceuticals, that draw directly upon the public research base. An additional finding was that the most important mechanisms for communicating research results from public research institutes to industry are the traditional ones of publication and conferences, strongly complemented by informal exchanges and private consulting arrangements between firms and researchers (Cohen, Nelson, and Walsh 2003, 139–41).

The Carnegie-Mellon study underlines the multifaceted ways in which research conducted at universities contributes to industrial innovation and economic development. In addition to generating new knowledge through the conduct of basic research, universities provide both formal and informal technical support, as well as specialized expertise and facilities for on-going, firm-based R&D activities. A study by the National Academy of Engineering documented the multiple ways in which universities contribute to the development and expansion of local industry: through the provision of skilled graduates who become key players in local industry; through the conduct of long-term fundamental research that contributes to the science base and understanding available to private firms; through the promotion of an atmosphere of intellectual diversity that tolerates different approaches to the solution of technical problems; through direct collaboration with industry both on specific projects and in longer term relationships; by serving as test beds for new technologies and research instrumentation that are ultimately transferred to industry, and finally as the nuclei for start-up companies that spin-off from universities to become the seeds of new business (National Academy of Engineering 2003, 46–48; Grossman, Reid, and Morgan 2001; Mowery et al. 2004). As national innovation systems become more interconnected and as the knowledge base required to support the production of 'complex technologies', university research becomes increasingly important to local firms not just for the transfer of knowledge generated through its own research activities, but also as a conduit enabling firms to access knowledge from the 'global pipelines' of international academic research networks (Bathelt, Malmberg, and Maskell 2004).

Overview of Policy Instruments to Support Innovation

There is a substantial body of work in the literature on innovation policy regarding the relative merits and effectiveness of different policy instruments, particularly tax incentives versus direct support, as well as policies to support networking and collaboration, policies to promote entrepreneurship and policies to stimulate the growth of a venture capital industry and provide additional sources of funding to technology-based firms. In general, these surveys distinguish between four major instruments: government sponsored R&D, direct government procurement of new technologies, direct subsidies, loans and repayable contributions to businesses, universities and not-for-profit organizations, and tax incentives (Finance Canada 1997).

Direct Measures to Support R&D and Innovation

A fundamental distinction made in the literature that reviews the effectiveness of innovation policy instruments is between those policies that target the supply side of the innovation process and those that target the demand side. Given that the majority of the policy instruments covered in this review focus on supply side instruments, the following discussion is restricted to those instruments. Virtually all supply side instruments target the objective of increasing the volume of R&D spending in a national economy as their key objective. The primary rationale for this form of intervention is the neo-classical arguments concerning the likelihood that, if left to their own devices, private firms will fail to invest in the socially optimal level of R&D due to the inability to fully capture all of the social returns to their investment. A further assumption that frequently lies behind government support for R&D is the belief that increased investment will generate new products, increase exports and sales and result in higher level of employment (Edler, et al. 2013).

Fiscal measures to support increased levels of R&D can be delivered both through the tax system and through direct subsidies. The relative advantage of using tax policy instruments includes their ease of use for firms in terms of the lower cost of compliance and administration given that they are applied through the existing tax administration structure. There is also a higher degree of predictability of the results, although this can clearly vary with the complexity of the tax administration process involved with a particular set of tax incentives. Another advantage is their wide applicability across a broad range of industrial sectors, firms or investments. Criticisms of the use of tax policy instruments usually focus on the lack of openness, transparency and accountability from a public policy perspective as the actual tax decisions are subject to the confidentiality requirements of the Income Tax Act. Another criticism that has been levelled by some governments is that the focus on providing support to individual firms through the tax system undermines the ability of the government to promote cross-firm linkages and collaboration of the kind that would be suggested by the IS approach. A final criticism is the open-ended nature of tax expenditures which make them more difficult to predict from the perspective of revenue forecasting in the fiscal framework.

Although tax policy instruments to support R&D lies outside the scope of the current review, there is an extensive body of literature that examines its impact. The majority of studies focus on the impact of R&D incentives on input additionality, i.e. the increase in levels of R&D spending that can be attributed to the effect of the tax incentive. In general the studies reviewed reported positive effects for different types of R&D tax incentives. In the US case, the results indicate a positive and significant effect for the tax credit in terms of increasing R&D expenditure in the US by $1 for every $1 of foregone revenue (Köhler, Larédo, and Rammer 2013; OECD 2010b). More recent studies have also looked at the impact of tax incentives on output additionality and have found positive effects in terms of increases in the probability of firms introducing new products and new processes. A widely cited Canadian study found a positive correlation between the R&D tax credit and the frequency of new product development, the introduction of products that are new to the market and the share of sales derived from new products, but did not find positive impacts on firm profitability or market share (Czarnitzki, Hanel, and Rosa 2011).

The comprehensive review of the literature by the OECD Economics Directorate looked at the effect of R&D tax credits on total factor productivity. While the economic analysis shows that tax credits increase productivity in OECD countries and that they do stimulate growth, they found relatively modest effects. The analysis also showed that the positive effects are greater for those industries that are structurally more R&D intensive. The results tend to support a greater targeting of R&D tax incentives at firms that are more highly innovative and industry sectors with a higher propensity to conduct R&D (Palazzi 2011, 47).

Given that the use of tax policy instruments lies outside the mandate of the current review of innovation and Cleantech policies, the following discussion focuses on the other instruments. There is an extensive literature on the advantages and drawbacks of direct spending programs to support innovation. Direct spending amounts for specific programs can be established within the parameters of the fiscal framework and grants can be awarded on the basis of more selective criteria to individual firms or business intermediaries within specific sectors who satisfy the requirements of specific programs. The disadvantage of direct grants is the higher compliance costs involved for the firms who must apply to government administrators for the grants and undergo a stringent due diligence process before being awarded the funds. A further limitation is the budget envelope can be expended before the applications of all eligible firms have been evaluated, as has happened in recent years with some federal programs, such as IRAP. While this may constitute effective program management from the perspective of the fiscal framework, it generally undermines the impact of a specific program in achieving its targeted goals.

Reviews of the effects of direct measures of support on increased levels of R&D generally find that the support stimulates higher levels of investment in R&D and innovation activities but that the specific results of different programs depends to a great extent on the particular features of the program design and the broader national context in which they are implemented. A comprehensive review of the impact of direct support programs conducted by University of Manchester researchers with support from NESTA noted that they had become much more sophisticated in combining their primary objectives with additional ones that aim to encourage greater collaboration or knowledge transfer between firms or between private firms and public sector research organizations. Direct support programs in a number of countries have also become more targeted, with a specific focus on high technology SMEs and start-ups. As noted above, the key advantage of the direct spending policy instrument as opposed to tax policy instruments is the ability to target specific categories of firms or forms of collaboration for public support.

The comprehensive review of the evidence from studies on the impact of direct support program assessed that evidence in terms of three criteria: evidence that government support created additional inputs with respect to R&D and innovation; evidence that the government programs created additional outputs, in the form of increased sales, exports or higher levels of employment, without the government subsidy; and evidence that the government intervention generated observable changes in the firm's organizational behaviour (Köhler, Larédo, and Rammer 2013). In general, the survey of the evidence concluded that government support tended to generate additional private levels of activity with respect to inputs to the R&D process. In the vast majority of the cases covered by the review, the projects investigated would not have been started, or they would have proceeded at a slower pace, with a lower level of technological input and output in the absence of the support. There is further evidence that the effects on input additionality are more noticeable in smaller firms (although this is not universally the case in all studies, in low technology sectors and in lagging regions. The evidence on output additionality for R&D and productivity improvements was less straightforward, although some studies found positive effects with respect to job creation. While the number of evaluations of impact on firm behaviour is more limited, the evidence shows that the direction of the effects is almost universally positive. More importantly for this review, a number of the studies reviewed suggest that the effectiveness of direct support programs can be increased through the adoption of rigorous selection processes, combined with ongoing monitoring of the impact of the support, regular interaction between program administrators and recipients of the support and prolonged duration of the programs (Cunningham, Gök, and Laredo 2013, 40–43; OECD 2011).

A further observation worth noting concerns the "halo effect" of direct funding from so-called prestige programs, such as the Advanced Technology Program (ATP) program in the US, on firm performance. The comprehensive review of impact of direct support noted that there was an input additionality effect associated with these programs, which allowed the firms receiving funding to successfully raise additional rounds of external finance (Cunningham, Gök, and Laredo 2013, 33). A study of the ATP program conducted in the early 2000s concluded that the ATP program had a distinctive "halo effect"; winning an ATP award significantly increased a firm's chances of accessing other sources of funding for their R&D activities, ". . . the ATP award appears to send a market signal that certifies that the firm and technology are promising" (Feldman and Kelley 2001, 207).

Access to Finance and Venture Capital

The available evidence on the impact of government programs to provide greater access to financing and venture capital is more limited than the research on the impact of fiscal (tax) incentives and direct subsidies. However, the available evidence does indicate that the schemes are more likely to generate output effects in terms of higher levels of employment and sales. The available studies underline the importance of design criteria in the overall effectiveness of these programs, particularly with respect to the way in which risks are shared between the funds receiving public support and the firms in which they invest. The review also noted the need for clarity in the operation of the funds, shorter time lags and a limited amount of bureaucracy to result in improved performance (Edler, et al. 2013, 16).

A number of related studies highlight the value of linking public programs designed to provide access to sources of finance with additional sources of advice. This research indicates that innovation support delivered through intermediary organizations has the potential to have a greater effect on companies than purely financial support. Work done by Statistics Canada for the Business Development

Bank of Canada shows that funding and advice in combination has a greater impact on venture performance than either funding or advice alone (Business Development Bank of Canada 2013). The insufficiency of providing venture funding alone to startup firms is strongly reinforced in a series of studies conducted by Barber and Crelinsten over the course of a decade in the early 2000s. They discovered a consistent pattern in both an initial set of interviews with the CEOs of 30 startup firms and in a subsequent study of 18 high technology firms that had survived between 3 and 20 years and collectively raised almost $500 million on financing. The culture of science and technology is strong in Canada and these firms were frequently staffed with technical personnel with world-class skills. What they lacked was sufficient staff with a deeper understanding of what they label the "culture of commerce" — namely, the importance of sales, marketing and management skills for growing and retaining in Canada successful technology firms (Barber and Crelinsten 2005; 2009). Somewhat depressingly, this observation is consistent with the findings of a comprehensive review of the state of the management of innovation research in Canada conducted in the 1980s (Wolfe 1990). While the provision of technology and business advisory services would not be sufficient to overcome this deficit by itself, the evidence presented in the next section suggests that it does constitute a valuable compliment to the more conventional forms of providing financial assistance to technology firms.

Impact of Complementary Services

A key objective of innovation policy in a number of industrial countries has been to provide more effective technical expertise to firms to support their growth through the various stages of technology development. The most common form of this support is through technical advisory services that provide information, consulting, mentoring and technical advice to assist firms. The majority of these services are targeted at SMEs, but this is not exclusively the case. The organizations providing these services will often engage with companies on an individual basis as well as through more collective forms of interaction, such as cluster organizations. The assistance can be provided through extension staff, such as IRAP's Industrial Technology Advisors (ITAs), field offices and dispersed technology centres, such as the Manufacturing Extension Partnership offices in the US, some of the Catapult Centres in the UK, or the Fraunhofer Institutes in Germany.[4] While the precise nature of the services and the forms they take vary considerably across countries, there is a growing body of evidence to demonstrate their effectiveness as key innovation intermediaries.

A recent comprehensive review of the existing evidence on the effectiveness of these technical advisory services concluded that they provide positive benefits to the firms that participate. The nature of the benefits that result can include reductions in the cost of technology development programs,

[4] For a survey and overview of some of the national differences in the approach to these organizations, cf. (Hepburn and Wolfe 2014).

improved quality in the resulting products or processes, higher productivity levels for the firm and success at the introduction of new products or firm-based innovations. While the immediate benefits found by existing studies have been modest, the comprehensive review of existing evidence concluded that the cumulative effects of these services can be significant, particularly in the case of SMEs and that they can often make the difference between the survival or decline of firms affected (Edler, et al. 2013, 22–25; Shapira and Youtie 2013).

More significantly, the review also found substantial evidence to support the conclusion that direct subsidy programs worked more effectively when they were combined with some form of complementary advisory services, such as expert advice, training on various aspects of business and management practice, and support for marketing. The reason identified for the greater effectiveness of the subsidy in combination with the complementary service is the contribution made to developing increased managerial and technical capacity in the firms receiving support to take full advantage of all aspects of the project being funded. The evidence also suggests that the transfer of these kinds of enhanced skills to firms is likely to have longer term impacts on the firm's future R&D and innovation projects because the skills developed can be transferred from one project to another. There is also evidence to suggest that the combination of direct support involving the use of advisory services with fiscal incentives represents a desirable policy mix for programs aimed at enhancing industry R&D efforts (Cunningham, Gök, and Laredo 2013, 27–28).

It is worth noting that these conclusions draw upon a number of Canadian studies that have investigated the impact of combining direct subsidy programs, such as IRAP grants, with the SR&ED tax credits. These studies find strong evidence for the conclusion that firms which were recipients of both forms of support performed better on most measures of innovative behaviour than firms that were just recipients of indirect tax supports. The reasons attributed by the authors to this result was the combination of advisory services in the IRAP program with the direct subsidy (Bérubé and Mohnen 2009; Bérubé and Therrien 2016).

Support for Collaborative R&D

The relationship between the generation of new knowledge and its successful adoption and use in the developed economies has become infinitely more complex in recent decades. The changes that have occurred include greater reliance by established firms on external sources of R&D through research consortia and collaboration with focused technology firms; the global outsourcing of R&D through expanded performance of R&D in foreign countries; and the proliferation of university-industry collaboration and research centres. This shift has been driven by increased competitive pressures, difficulties in firms' ability to capitalize on the benefits of internal research and changes in government policy to promote collaborative research with universities. Interdependence among networks of institutions has increased as fewer firms or public sector actors are able to innovate on their own. As partnerships and collaborations between companies, organizations and the public sector have become a more critical part of the innovation landscape, a wide range of new policies and programs have been introduced by governments to promote, networking, clusters and R&D collaboration. The range of programs and policy instruments to support collaboration include science-industry research centres, collaborative research and exchange programs, such as publicly supported R&D consortia, and collaborative knowledge exchange initiatives. Recent public initiatives also involve an expansion of the role of public research institutions to promote more extensive forms of networking and interaction with private actors.[5]

Collaborative R&D programs aim to compensate for both market and system failures by linking research personnel across private sector organizations or between public and private research organizations. In so doing, these initiatives attempt to reduce the risk inherent in undertaking complex research programs with uncertain outcomes, facilitate knowledge exchange and skills transfer among the participants, and accelerate the pace of research and the diffusion and application of the resulting knowledge. Since the 1980s, a wide number of collaborative research institutions, such as provincial and national Centres of Excellence in Canada or Engineering Research Centers in the US, have been established to support interaction and facilitate knowledge flows between public research institutions and private industry (National Academy of Engineering 2003, 59–60).

A leading example of a successful and much studied program in the US involved the Engineering Research Centres (ERCs), created in the 1980s to foster greater university-industry collaboration. Individual centres were co-sponsored by the National Science Foundation, universities and industry. The ERCs were designed to develop basic knowledge in areas critical to the competitiveness of US firms in world markets by concentrating on research areas of major industrial importance that cut across disciplinary boundaries. A study of 355 firms participating in 18 different ERCs, using both surveys and interviews, found that firms participating in the centres were more interested in gaining access to upstream forms of knowledge, rather than developing specific products and processes, a finding consistent with the results of the Yale and Carnegie Mellon surveys of industrial research managers cited above. Consistent with their original motivation, the most commonly reported benefits included access to new ideas, know-how and technologies through interaction with the ERC (Feller, Ailes, and Roessner 2002, 462–64).

The recent review of evidence on the impact of innovation policies and programs assessed the results of a wide range of policy studies and academic articles on collaborative R&D initiatives. The

[5] A fuller discussion of the wide range of initiatives introduced by governments that fall within this category can be found in (Wolfe, Bramwell, and Munro 2011).

results of the studies confirm the positive impacts that they generate increased collaboration between research institutes and firms in terms of a greater investment of resources, time and attention to the research projects undertaken. While the output effects were harder to quantify, the studies noted that the effects included enhancing learning among participants, a change in orientation, increased creativity and greater involvement in international activities. The studies also reported positive economic benefits for the firms involved in terms of higher employment levels and more value added products, as well as direct R&D outcomes observable in increased patenting. The available studies also identify some of the factors that make for successful collaborations, including a suitable program design, effective management for the collaboration, a flexible approach to the interaction and the need to build long-term relationships and trust among the partners (Edler, et al. 2013, 26–30; Cunningham and Gök 2013). A Canadian study of collaboration between university and industry researchers concluded that a critical factor in the success of the collaborations was the amount of time and resources invested by the private sector partner to the collaboration (Wolfe and Lucas 2001).

The Concept and Role of Policy Mixes

Recent work undertaken for the European Union (EU) and the OECD has introduced the concept of the "policy mix" which provides an added dimension to our understanding and analysis of the impact of R&D and innovation policies. The idea behind the concept is that evaluations of the impact and effect of individual policy instruments on a firm or sector's R&D and innovation performance will fail to capture the effects that may arise from the interaction among several different policy instruments. As such, they may attribute a change in firm performance to the impact of a single policy instrument, rather than recognizing that the observed effect results from the interaction of a number of different instruments. For this reason, they define a policy mix as "the combination of policy instruments, which interact to influence the quantity and quality of R&D investments in public and private sectors" (Nauwelaers 2009, 3). The policy mix approach was also introduced and discussed extensively in the OECD's 2010 Innovation Strategy (OECD 2010a).

While the concept of the policy mix adds an important dimension to our understanding of the way in which multiple policies can affect the behaviour of an individual firm or economic actor, it defies easy application from a program or policy evaluation perspective. The complexity of R&D and innovation systems and the high degree of variety that exists across national systems makes it challenging to identify and isolate the particular elements of the system, as well as external programs that influence firm performance. For purposes of a policy mix analysis, relevant programs are deemed to include: all economy-wide and sectorally-specific policies aimed at stimulating higher levels of R&D, including both direct (subsidy) instruments and indirect (tax incentive instruments); skills and training policies targeted at increasing the available supply of high qualified labour for R&D and innovation related activities; a wide range of policy instruments targeted at increasing R&D and innovation activities; and policies that aim to increase linkages among actors in the R&D and innovation domain, including programs to support collaborative R&D and policies to stimulate increased usage of intellectual property and standard setting regimes. The study cited above provides a comprehensive typology of relevant policies for the policy mix approach (Nauwelaers 2009, 7–8). The policy mix approach highlights the need for more effective coordination across a diverse range of policy fields that are often the responsibility of different government line departments or ministries in a complex public administration. The policy mix approach also recognizes and attempts to take account of the complexities of analyzing the interacting effects of the policy mix across multiple, and sometimes competing, jurisdictions within a federal system or a multilevel governance regime, such as the EU.

A central focus of the approach is the need for the public authorities responsible for the overall performance of the innovation system to monitor and assess the potential impact of new and emerging technologies on existing industries and sectors through the acquisition of strategic intelligence concerning developments in other parts of the world and the periodic use of technology foresight and technology roadmap exercises. Some governments have made effective use of system-wide policy initiatives to support the development and adoption of new and emerging technologies. Noteworthy examples include the US National Nanotechnology Initiative and the Germany High-Tech Strategy, which is a comprehensive policy approach, refined over a long-term period by the federal government to enhance public and private R&D efforts in the federal republic. A key insight derived from the policy mix approach is the need to identify and address potential imbalances within the national innovation system between different components of the system. These imbalances can lead to system mismatches between the allocation of resources among public and private sector actors or across divergent industrial sectors within the national economy. Reviews of the effectiveness of the policy mix within an individual country suggest that it is highly dependent on the overall governance mechanisms that are in place for the research and innovation system and the degree of coordination that they provide across the range of both public and private actors who populate the system. High level Science and Innovation Councils, with responsibility for overseeing and assessing the effectiveness of the innovation system and advising the elected executive are viewed as one mechanism for improving coordination across the policy mix. The analysis of policy mixes can also focus on different strategies that can be adopted to promote industrial restructuring in older industrial economies, rapid-innovation based development in economies that are catching up or R&D intensification in economies that are focused on raising the levels of R&D and innovation activity across a range of economic sectors (Nauwelaers 2009, 32).

The Compendium of Evidence on Impacts of R&D and Innovation compiled by University of Manchester researchers for NESTA also contains a review of the existing evidence on the effectiveness of the innovation policy mix and the interaction of policy instruments. It surveys a number of aspects of this concept, including evaluations that examine how individual policy instruments interact, studies or reviews that assess the existing policy mix at an individual country or system level, and cases where individual instruments have deliberately been designed as part of a policy mix across several different innovation-related institutions or the portfolios of relevant operating agencies. A key finding of the review is that the vast majority of policy and program evaluations that are undertaken examine individual policies in isolation from each other; it is rare to see a conscious attempt in these studies to assess or evaluate the interaction effects among them. Among the notable exceptions to this rule are the kind of studies noted above that evaluate the complementary effects of both fiscal incentives and direct subsidies on the innovation performance of individual firms or the benefits to firms of drawing upon advisory services in combination with other forms of R&D support. However, from a country-wide perspective, no analyses were found that deal directly with the overall effects of policy mixes. The reviews also failed to find evidence of any common or converging patterns for typical examples of policy mixes, as the particular patterns observed in individual countries "appears to be highly path dependent and results in quite diverging trends" (Cunningham, et al. 2013, 18). This finding is consistent with a long standing observation about the variation in regional innovation systems, namely that "one size does not fit all" (Tödtling and Trippl 2005).

The one approach that was repeatedly singled out for discussion in various reports from the Manchester Compendium of Evidence was the German High Tech Strategy originally adopted in 2006 as an initial step towards developing a comprehensive approach to R&D and Innovation policy. In the initial phase of the program, a substantial proportion of funding from the federal Ministry of Research and Education was channeled through the strategy which achieved greater coordination of existing activities and a number of new initiatives. For this reason, the Strategy is frequently singled out as an example of a national policy approach that produced a more effective degree of coordination among the activities of a range of different federal ministries (Cunningham, et al. 2013, 22–23).

While the policy mix approach has not been widely applied in Canada, it is worth noting that as part of the original study conducted for the EU Policy Mix project, two individual country reviews were commissioned for Canada. The first report provided a country overview of the existing policy mix in Canada and the second focused on the governance aspects of the innovation system in Canada and presented a detailed case study of the range of federal and provincial programs targeted at an individual sector in a specific region — what the approach called a "mini-mix". The country review surveyed some of the key challenges confronted by the innovation system in Canada — the relatively low of R&D intensity, especially in the business sector, the smaller share of R&D-intensive sectors in Canada compared to other leading OECD countries, the weak survival rates for innovative Canadian firms and start-ups and the lower level of patenting than other countries. It noted that there were limited studies of the interaction effects of Canadian R&D and innovation policies from a broader perspective (Hansen 2007; Creutzberg 2007).

Policy Alignment across Levels of Government

A key challenge for evaluating the effectiveness of innovation policies within a federal system of government is the need to take account of the overlapping and sometime duplicative effects of both federal and provincial policies. Nowhere is this more evident in Canada than in the funding of research in the higher education sector where both jurisdictional levels share responsibility for policy (Wolfe 2005). This is also increasingly the case with respect to the provision of complementary services, where several of the provinces or regional agencies have developed extensive networks of organizations, such as Ontario's Network of Entrepreneurs (ONE) or Springboard funded by ACOA in Atlantic Canada, aimed at supporting entrepreneurship and the transfer of research from its postsecondary institutions into the hands of firms that can commercialize and apply it.

An expansion and intensification of the formal ties within the European Union since the early 1990s have led to a deeper investigation into and understanding of the challenges that arise in policy regimes with multiple interacting jurisdictions. Multilevel governance is a term developed to reflect a new model of political architecture where political authority and policy making influences are dispersed across the different levels of the state as well as to non-state actors. The concept emphasizes cooperation among different levels of government in the EU, where the creation of a third tier of policy making, the European Union, and the adoption of the principle of subsidiarity as a central tenet of the Single European Act of 1992, had a profound impact on the relative powers of both national and subnational or regional levels of the European states. Hooghe and Marks argue that the core of the idea of multilevel governance is that the national level no longer monopolizes policy making and instead engages in collective decision-making with other levels of government and relevant actors, and in so doing, cedes control of the policy-making process. Decision-making competencies are therefore shared among all actors with no one level exercising monopoly over another. Accordingly, subnational levels are said to be interconnected to national, and at times, supranational arenas rather than nested within the national state (Hooghe and Marks 2001, 4).

In the North American context, where three tiers of government is the norm, the concept of multilevel governance helps us recognize the interdependent nature of their respective roles and jurisdictional responsibilities. Regional and local actors are a necessary source of knowledge in local learning networks, assisting in the process of collective learning that is vital to the innovation process in knowledge-intensive firms. This point is reinforced in recent work from the OECD. Maguire and Nauwelaers (2009) outline several trends evident in recent policy approaches to regional innovation. Concerns about policy fragmentation and incoherence is driving increased emphasis on the process of taking stock of policy instruments delivered by all levels of government in order to analyze and fill in gaps in national and regional policy mixes. These concerns have resulted in a growing emphasis on providing policy support at different stages of the innovation value chain to improve the ability of firms to capitalize on both public and private investments in emerging technologies, and priorities are shifting from building stocks of knowledge to promoting flows of knowledge in regional innovation systems and the absorptive capacities of firms. There has also been a policy shift from the tendency to import best practices from other regional contexts towards developing context-specific solutions from the ground up that are targeted specifically to different regional innovation systems, and from standard policy-making to policy-making as an iterative learning process supported by strategic regional intelligence.

A key challenge for evaluating innovation policy in systems with multiple levels of jurisdiction is to ensure a better integration and coordination of available programs and policy instruments. Increasingly, no one level of government has a monopoly on the policy instruments that comprise the overall R,D & I strategy of federal and provincial governments. Multilevel governance is no longer an interesting academic concept, but has become highly relevant to the challenge of economic development in the Canadian federation. One illustration of this dilemma is the Canada Foundation for Innovation, which makes major infrastructural investments in expanding the research capacity of post-secondary institutions and hospitals across the country with little regard to the integration of these important new facilities into the existing or emerging industrial structure or local clusters of those regions. This raises the critical policy question of whether efforts by the two levels of government reinforce and support each other or whether they create an unnecessary level of duplication and spillovers that reduces the overall policy effectiveness. Effective evaluation of innovation policy must not be conceived as the exclusive responsibility of one level of government jurisdiction or the other, but rather, must assess the interacting effects of the complex policy mix that exists in ten different jurisdictions across the country.

Conclusion

The preceding analysis provides a high level overview of some of the recent thinking and analysis on the rationale for, the design of and evaluation of a wide range of policy instruments deployed across both industrial and more recently developed countries to promote their R,D & I strategies. Most of the innovation policies considered within this review continue to be framed within the rationales provided by the two distinct paradigms considered at the outset — the neoclassical approach with its emphasis on information asymmetries and market failure and the evolutionary systems approach with its emphasis on the importance of developing cumulative capabilities within the firm and identifying and filling gaps that arise from system failures. While there is a certain amount of tension between the two approaches from an analytical perspective, they both continue to play an important role in terms of framing and designing specific policy instruments. The policy evaluation process will benefit from from paying closer attention to when the rationale for a specific policy instrument has been provided by one paradigm or the other and assessing its effectiveness in terms of the economic problem the policy instrument is designed to address.

The review also paid particular attention to incredible range of variation that exists across distinctive national innovation systems, ranging from mission-based to diffusion-based to rapid-innovation-based approaches. The distinctive national styles identified in this part of the report focuses attention on the relative degree of emphasis placed on different policy instruments within these national systems. It also draws attention to the need to evaluate the effectiveness of particular policy instruments within the context of the overall national approach to R,D & I, rather than to evaluate the policy in an isolated frame of reference. It also highlights the importance of assessing the way in which different national approaches to R,D & I have been successful or have failed to alter the trajectory of technological development within their economies. It also draws attention to the impact that different administrative structures or delivery agencies can have on the effectiveness of policies. The review then summarizes some of the latest findings from both the academic and policy research literature on the effectiveness and impact of a range of policy instruments, including tax incentives, direct subsidies, support for venture capital and other forms of financing, advisory or complementary services and collaborative research initiatives. The balance of evidence surveyed supports the conclusion that on the whole, the majority of these instruments contribute to an increase in input, output and behavioural additionality, but that it may not be sufficient to consider their effectiveness in isolation from each other.

For this reason, the review introduced the more recent concept of the policy mix which underlines the need to look at the effectiveness of a range of policy instruments in terms of their relation to each other and, in particular, look at the interaction effects among a range of policy instruments. In this respect, the policy mix concept is more consistent with the evolutionary and innovation systems perspective in its emphasis on the need to evaluate the effectiveness of policies from a broader systems perspective. Finally the review concludes with a brief discussion of the need to consider the challenge of policy alignment within a federal system with some degree of multilevel governance. The existence of multiple levels of jurisdiction with sometimes overlapping and duplicating policy efforts suggests the need to identify not only which specific policy is generating the observed outcome or impact, but also whether potential system gaps that arise in the policy mix result from a failure to adequately coordinate policy efforts across two levels of jurisdiction, rather than from a gap in the policy mix at one level or the other. Finally, the review suggests the need to take a long-term perspective in evaluating policy impact. Those countries that have been most successful in influencing the trajectory of their technological development have been the ones which have refined and pursued a consistent approach over a considerably longer time frame than a single electoral cycle.

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