The Use Of National Systems Of Innovation Models To Develop Indicators Of Innovation And Technological Capacity

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Introduction

For at least three decades governments have measured the input of resources to national R&D programs in the firm belief that R&D has a positive, if indefinable, effect on economic growth. More recently the development of the "new growth theory" of economics has provided the theoretical basis linking investment in S&T to economic growth. As Paul Romer (1) has pointed out:

". . . *there's another process underlying the business cycle - the process of discovery and invention. It is this process that generates long-run improvements in the standard of living. If you want to think of it as a picture, you can see economic growth as a long-run upward trend line, (with) the business cycle as little wiggles around that line. What determines how high we climb in the long run is the slope of that line, not the little* *wiggles"*

The first theoretical constructs of the benefits of S&T knowledge focused on the "linear" model of innovation where an investment in R&D would eventually lead to wealth creation or a social benefit. There were intervening steps where the technologies resulting from R&D were developed and commercialized, but the model suggested that resources expended on R&D would inevitably result in some good at the end of the chain, and that incremental R&D resources would result in incremental benefits. Current theories take a much wider view of the innovative process, and recognize that R&D is only one of several inputs to wealth generation and social progress.

The Problems of Not Using a National System of Innovation Model

Investment in S&T knowledge occurs primarily through three processes:

- domestic development of new S&T knowledge through R&D programs
- investment in intellectual property through the purchase of patents and licenses or by appropriating knowledge in the public domain
- acquisition of knowledge through the technology embedded in imported capital goods (e.g. usually "high-technology" products)

These investments, while usually thought of in financial terms also represent an investment in human capital. Thus measurement of these investments must not only include the financial resources devoted to them but also the human resources assigned to these efforts. However, analysts need to measure all three types of contributions to knowledge which contribute to economic growth, as economic structures vary widely. Most current S&T indicators focus on domestic R&D investments (either financial or human capital), based on the reasonable assumption that R&D performance is an indicator of innovation, and do not address the level of investment on other technological infrastructure. .

Most S&T indicators have been developed by, and for, analysts in developed economies, and may miss important policy areas for developing nations As an example, in a developing economy, the actual level of R&D activities may be quite low, but the level of investment in related science activities may be substantial. The United Nations Educational, Scientific and Cultural Organization (UNESCO), in its definition of S&T includes not only R&D but also national investments in S&T support services (such as libraries and statistical agencies) as well as scientific and technical education investments.

Similarly statistics on industrial investment on R&D miss those innovative industries are not R&D intensive Firms profit from the larger pool of external knowledge by absorbing and adopting some of it to their own needs; the source can be a competitor, another industry, government, universities or another country . Just as it is important to measure physical capital stocks, it is important to measure and follow the stocks of S&T knowledge or technological capital.

These issues were addressed by the Organization for Economic Cooperation and Development (OECD), in a recent report (2), which examined this issue and concluded that investments in technology embedded in capital equipment, whether imported or produced domestically were equally important and should be included in assessments of the knowledge intensity of nations. In addition, the authors noted that measuring these investments in technology (as opposed to investments in domestic R&D programs) was particularly important in small-industrialized nations and in developing nations.

Indicators as Policy Issues

Many nations have carried out or are carrying out major S&T policy reviews. All are struggling to develop 3;nalytic frameworks that meet their requirements. The issue facing S&T policy makers is, ultimately, what is the optimal level of investment of financial and human resources in S&T required to maintain economic competitiveness and quality of life? What is an appropriate distribution of S&T resources among the three major S&T performing sectors: government, industry and universities and what are the interactions among these three sectors? What is an appropriate distribution of S&T resources among basic research, applied research, development, technology acquisition, technology diffusion and training of S&T personnel? And finally, how can both the costs and benefits of these policy decisions be communicated to stakeholders and to the public at large without losing either their attention or their confidence?

The use of S&T indicators, and the choice of which indicators to use are important policy issues. Not only do they assist the policy maker, but they must inform the public, the taxpayers who ultimately support S&T programs. There is some evidence to suggest that the public are usually only well-informed about S&T when there is a problem (e.g. nuclear waste disposal or ozone layer depletion, as noted in Holbrook (3». At the 2nd Ibero-American Workshop on S&T indicators in Cartagena, Heman Jaramillo (4), in arguing the case for creating an S&T indicators unit in that country spoke of the need to regard information on S&T and innovation activities as a public good.

Nations need to acquire the capability to manage their investments innovation in an orderly manner consistent with their overall policy goals. Thus they need to develop policy machinery and quantitative analytical capabilities to inform themselves about their S&T activities and to allocate resources to them.

In the public policy context S&T indicators fulfill several functions. As van Steen (5) has argued, these include:

- **Signaling or monitoring:** giving insight to and calling attention to developments and trends in the S&T system and its environment
- **Accountability, evaluation and allocation**: setting and justifying S&T budgets and giving insight into the performance of the S&T system against the goals established by policy- makers and planners
- **Legitimization;** support for existing policies
- **Awareness:** providing information to set aside prejudices and incorrect perceptions of the performance of the S&T system

Governments, whether national or regional, must develop sets of indicators to quantify the progress of their S&T programs and to make those programs more transparent to the taxpayer in their own right, and not just an adjunct to other policy initiatives.

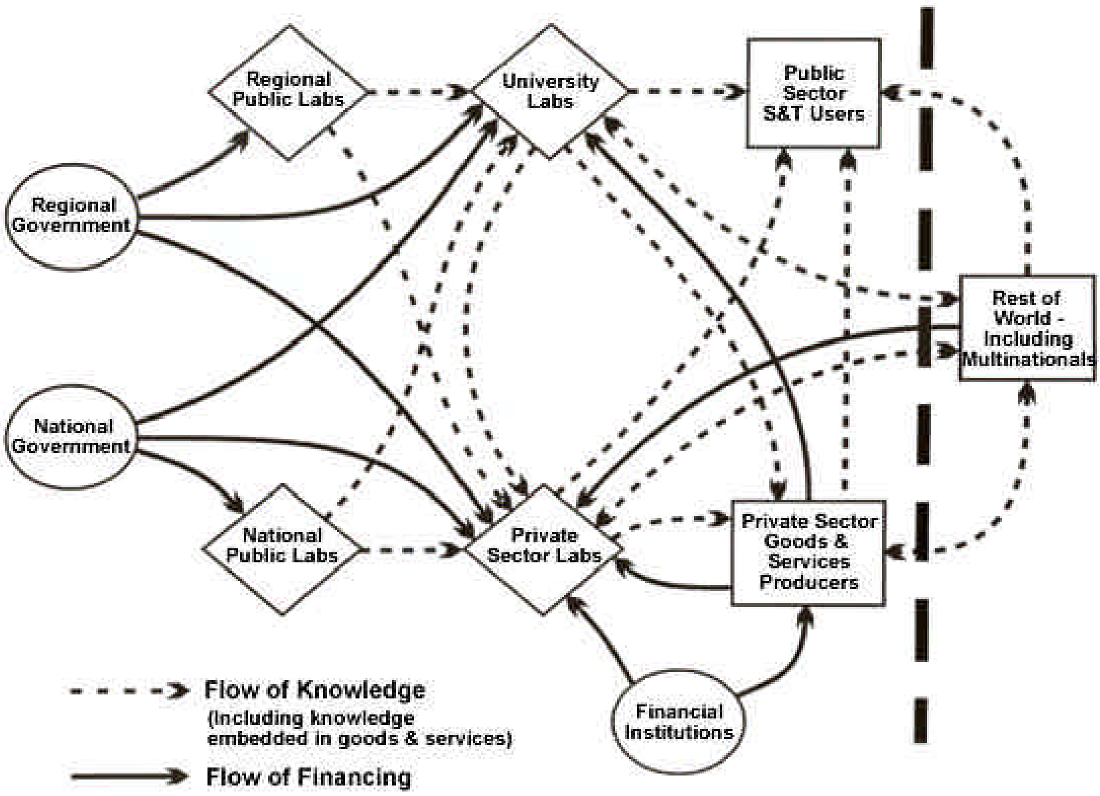
National Systems of Innovation

It is convenient, when analyzing the stocks and flows of knowledge in an economy to describe the process of innovation in an economy as a system. Chris Freeman (6) has noted:

"The rate of technological change in any country and the effectiveness of companies in world competition in international/ trade in goods and services, does not depend simply on the scale of their R&D... It depends on the way in which the available resources are managed and organized, both at the enterpr ise and national /eve/. The national system of innovation may enable a country with limited resources.... to make progress through appropriate combination of imported technology and local adaptation and improvement "

Figure 1 shows a simplified national system of innovation (NSI). The purpose here is not to define all of the elements and their inter-relationships, but to give an idea of the major linkages. Ideally one should be able to measure the investment in knowledge by each element and the flows of knowledge among the elements; in practice it is necessary to delete some of the smaller linkages. For example, not shown are the links from regional and national government labs to the outside world; these usually take the form of exchanges of intangible and unpriced intellectual property.

Figure 1



The characteristics of a national system of innovation (NSI) can be summarized as:

- Firms are part of a network of public and private sector institutions whose activities and interactions initiate, import, modify and diffuse new technologies
- An NSI consists of linkages (both formal and informal) between institutions
- An NSI includes flows of intellectual resources between institutions
- Analysis of NSIs emphasizes learning as a key economic resource and that geography and location still matter

The emphasis on institutions is the cornerstone of NSI analysis. Charles Edquist (7), in the introduction to his recent book on innovation analyses the literature on NSI, and notes that all of the NSI approaches emphasize the role of institutions. He notes:

"Institutions are of crucial importance for the innovative process...It is therefore a great strength of the systems of innovation approach that "institutions' are central in all versions of it "

Thus, in analyzing NSIs, it is necessary to be able to measure the stocks and flows of knowledge among institutions, both public and private, and if necessary to develop indicators appropriate to this task. Innovation does not necessarily occur only in the private sector, but as yet there has been no procedure offered for the assessment and quantification of innovation in the public sector.

The OECD (8) concluded that the study of NSI offers new rationales for government technology policies. Government policies in the past have focused on market failures; studies of NSI make it possible to study systemic failures. The analysis of NSIs enables policymakers to identify successes and failures, chokepoints and areas of over-capacity.

The UN Conference on Technology and Development (UNCTAD) (9) recently stated, in the context of discussing science, technology and innovation policy reviews in developing countries:

II *A useful notion in this context is the national system of innovation which refers to the network of economic agents together with the institutions and policies that influence their innovative behaviour and performance . . .. The NSI perspective refers to a new understanding of innovation as an interactive process in which enterprises alone or in interaction with each other play a key role in bringing new products, new processes and new forms of organization into economic use... In the present ea of internationalization, the critical issue becomes of how to integrate NSIs into the international division of labour. This may be done through exploring how well each NSI is capable of drawing on a rapidly growing of generic knowledge which is not necessarily produced in the country itself.* ".

The Measurement of Innovation

Joseph Shumpeter, in his classic work on innovation (10) defined five types of innovation:

- Introduction of a new product or qualitative change in an existing product
- Process innovation new to an industry
- The opening of a new market
- Development of new sources of supply for raw materials or other inputs
- Changes in industrial organization

In terms of S&T policy the analysis of innovation is usually restricted to the first to categories of innovation. The Oslo Manual (11), prepared by the OECD, which is the internationally recognized standard for measurement of innovation, defines innovation in terms of technological product and process innovations:

"Technological Product and Process (TPP) Innovations comprise implemented technologically new products and processes and significant technological improvements in products and processes. A TP P innovation has been implemented if it has been introduced on the market (product innovation) or used within a production process (process innovation). TPP innovations involve a series of scientific, technological, organizational, financial and commercial activities. The TP P innovating -firm is one that has implemented technologically new or significantly technologically improved products or processes during the period under review"

The management of innovation and its influence on a national economic systems is of great interest to economic planners. Understanding the scope of national systems of innovation and the degree to which innovation pervades the workplace is a goal which many would like to achieve. Unfortunately it is often difficult to measure innovation, not only because the concept, though well defined in the Oslo Manual, is difficult to quantify, but also because most nations simply have no clear idea of how many innovative enterprises there are in their jurisdiction. In a recent survey carried out in British Columbia, Lipsett, et.al. (12) found that there were at least 13,000 enterprises connected in some way to S&T activities, approximately half of which could be said to be innovative, yet far fewer had applied for a tax incentive based on innovation or were being surveyed by Statistics Canada for R&D performance.

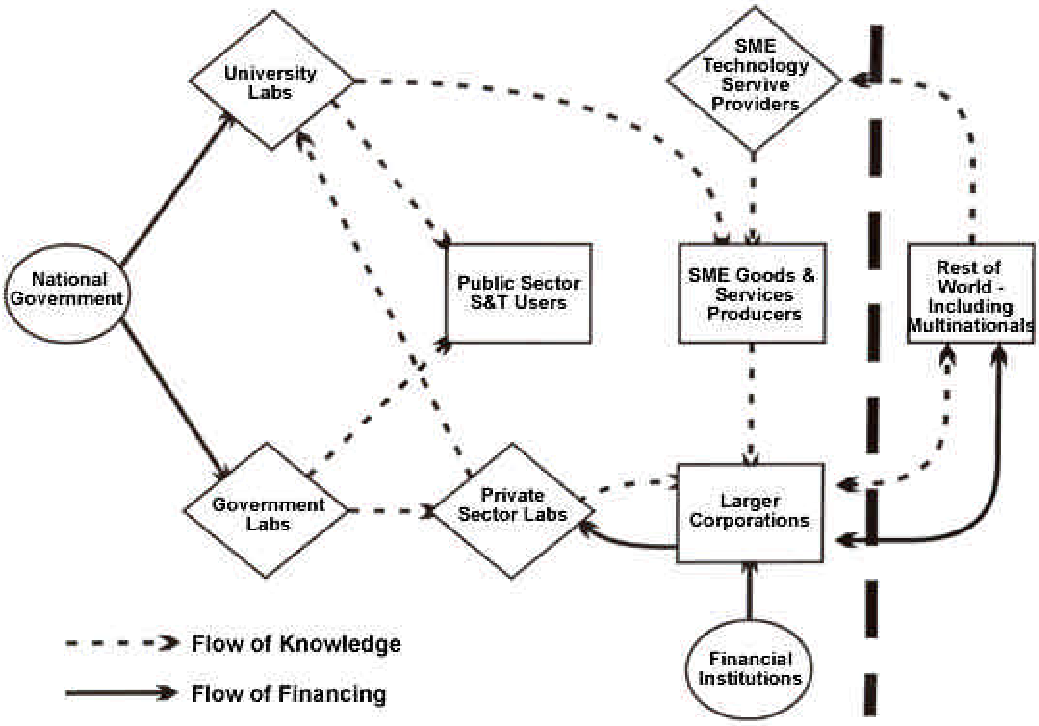
Current systems of S&T indicators have been developed primarily by and for large complex national economies. Although smaller economies may not have extensive systems of innovation they too use S&T directly in support of their specific economic and social objectives. In analyzing national systems of innovation it may be easier to aggregate upwards from a series of regional systems of innovation to the national level than to try to develop an understanding of a complex national system from the top down. It may also be easier to develop systems for smaller economic units (whether a region in a federation or a small national economy). In a recent study of the Canadian system of innovation, the National Research Council of Canada (13) noted that:

"regions within nations are increasingly being recognized as the primary milieu where innovations occur and are spread, and appropriate targets of government action"

There have been many studies of regional industrial clusters (or "poles") and comparisons of regional, or sub-national, innovative performance. These concepts are addressed, in the Canadian context, by de la Mothe (14) and others in "Local and Regional Systems of Innovation". These local systems of innovation are the building blocks of national systems. They are often a great deal easier to conceptualize and measure, particularly if they correspond to some administrative unit such as a province or a small nation-state.

At a recent workshop on S&T indicators held at the Universidad Nacional de Quilmes in Buenos Aires, Argentina, by the Red Iberoamericana de Indicadores en Ciencia y Tecnologia (RICYT), the topic of measuring stocks and flows of knowledge in a national system of innovation was discussed. The participants started with the generic model outlined in figure 1 of this paper, and went on to build a model that more accurately reflected the NSIs in the countries of the Southern Cone of South America.

Figure 2



The resulting network is shown in figure 2. The significant differences between figure I and figure 2 are:

- the public sector, whether state-owned enterprises or government ministries and the military, is a significant consumer of technology .
- the business world is divided into two spheres: the larger corporations, most of which have technology links with multinational enterprises (MNEs), and small and medium-sized enterprises (SMEs) which do-not.
- SMEs get some technologies from the larger corporations (often through

transfers cementing a hierarchical relationship), but they also get technologies through an entirely different window: that of other SMEs which specialize in providing technologies and technologically-based services (such as computer sales and service). These service providers in turn get their technologies directly from abroad, from the MNEs which developed the technologies

- the dotted lines show the links that are tenuous and which need strengthening: the university/SME links and the university/business labs links

The discussion which followed illustrated the utility of NSI analysis as a tool to identify which institutional linkages were weak and which were strong. The consensus was the diagram illustrated graphically those linkages which were in need of significant policy analysis and support by S&T policy planners.

A Pilot Study on Innovation in Smaller Economies

In an ideal world one could measure both the stocks of knowledge in each element of the regional system of innovation and the flows of knowledge among them. This is hampered by the lack of a unit of measurement for knowledge (money and people are taken as indicators of this flow), and the large number of inter-relationships inherent in even a simple model of innovation. In the practical world only some of this information is usually available. With special efforts a model of an NSI for a smaller economy or a region could be developed, through additional survey work, built on a number of assumptions, not the least of which would be to ignore many of the small (low-volume) inter-relationships among the elements of the system. Such an economy usually has only one large urban area where most innovative activities take place, and its GDP is usually small compared to the levels of the larger developed nations (e.g. less than $100 billion). This approach does not differentiate between national and regional economies: the economies of New Zealand and the province of British Columbia in Canada (BC) are similar in size and to certain extent in structure, yet one is separate nation and the other a province in a federation.

BC is an ideal laboratory for experiments in the measurement of innovation. The economy is simple, with one large metropolitan area, where most of the innovative firms are located, supported by a hinterland whose primary outputs are in the natural resources sector. BC is a distinct geographic region so that external influences in the acquisition and adoption of technology are readily noticeable. Thus (in theory) economic measurements in BC should be relatively well-behaved and predictable.

Discussions with BC government officials have established that the following indicators represent their priorities for information on the BC system of innovation:

- investment in knowledge through R&D expenditures in each of the governmental, business and higher education sectors *(Benchmark:* R&D expenditures as a percentage of GDP)

- production and trade of high-technology products *(Benchmark:* revealed competitive advantage by sector)

- output and trade in high-technology services *(Benchmark:* balance of trade in services)

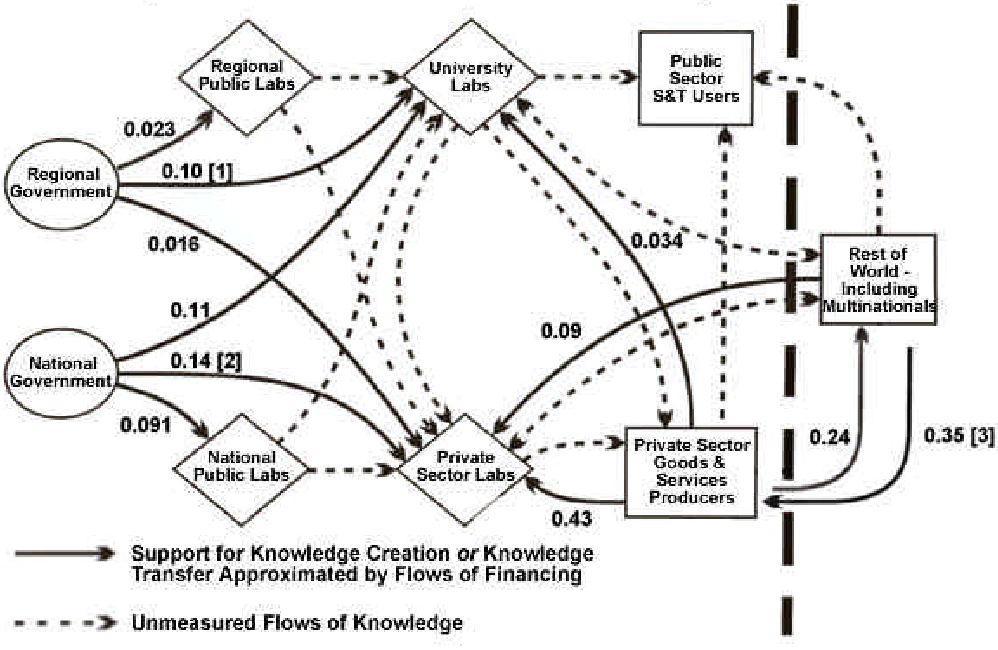
- investment in knowledge through the training of scientists and engineers, including social scientists and health care professionals *(Benchmark:* ratio of students (who are citizens) to labour force or population)

- productive use of knowledge (human capital) through the employment of trained engineers and scientists (including social scientists and health care professionals) *(Benchmarks-:* trends in real economic growth, mortality and morbidity)

- census of innovating firms by sector *(Benchmark:* Rate of increase of the number of innovating firms)

This led to an attempt to identify the more important linkages in the BC system of innovation for policy analyses using the admittedly imperfect measure of R&D funding. Using data available from Statistics Canada for 1993, the R&D funding linkages (taken from figure 1) are shown in figure 3. The figures are shown as a percentage of gross provincial domestic product (GDP) to facilitate comparisons with other NSIs. In addition to R&D funding flows estimates of the value of the flows of the knowledge embedded in private sector transactions in intellectual property and high-technology products are shown.

***Figure 3:* British Columbia System of Innovation, 1995**
(flows measured a % of GDP; GDP = $94Bil. Cdn)



Notes: [1] Includes general university funding
[2] Includes R&D tax credits
[3] Knowledge transfer based on estimated high-tech trade flows

Direct surveys provide, of course, a more sophisticated source of information on the NSI. The Centre for Policy Studies on Science and Technology (CPROST) at Simon Fraser

University in collaboration with the Centre for Policy Studies in Education at the University of British Columbia has established a major multi-year project to study innovation in smaller economies. The first element in this study was to carry out a survey of technological innovation in BC. A short questionnaire for use with BC enterprises was prepared for the project. This questionnaire was not intended to cover all aspects of technological innovation identified in the OECD "Oslo Manual" but it had to conform to the main points in the OECD standard. To ensure a reasonable response rate, the questionnaire had to be short (no more than one page, printed on both sides) so that it would be user friendly, take little managerial time to complete, be comprehensible to a technology-based entrepreneur based in BC, and be faxable to expedite its return. A complete report on the results appears in Holbrook and Hughes (15).

The results of this survey can be used to give some indication of the strength (or weakness) of -some of the linkages in the BC system of innovation. 78% of respondents reported having introduced a new product or process in the last five years. However there is more to innovation than product or process development. Inherent in Schumpeter's definition of innovation is the idea of uniqueness. For a development to be innovative it must be unique in that firm's competitive market. Thus the questionnaire also asked if the new product or process was unique to the industry. A product or process unique in the industry (to the knowledge of the respondent) would likely be unique in the firm's market and thus innovative. By this measure only 47% of respondents were considered to be innovative.

Firms were asked to rate the value of different sources of technology in the BC system of innovation in terms of contributing to their innovative activities. Figure 4 shows the results, and compares innovative and non-innovative firms. The respondents were also asked to rate factors affecting innovation; these are shown in figure 5.

Figure 4: Sources of Innovation

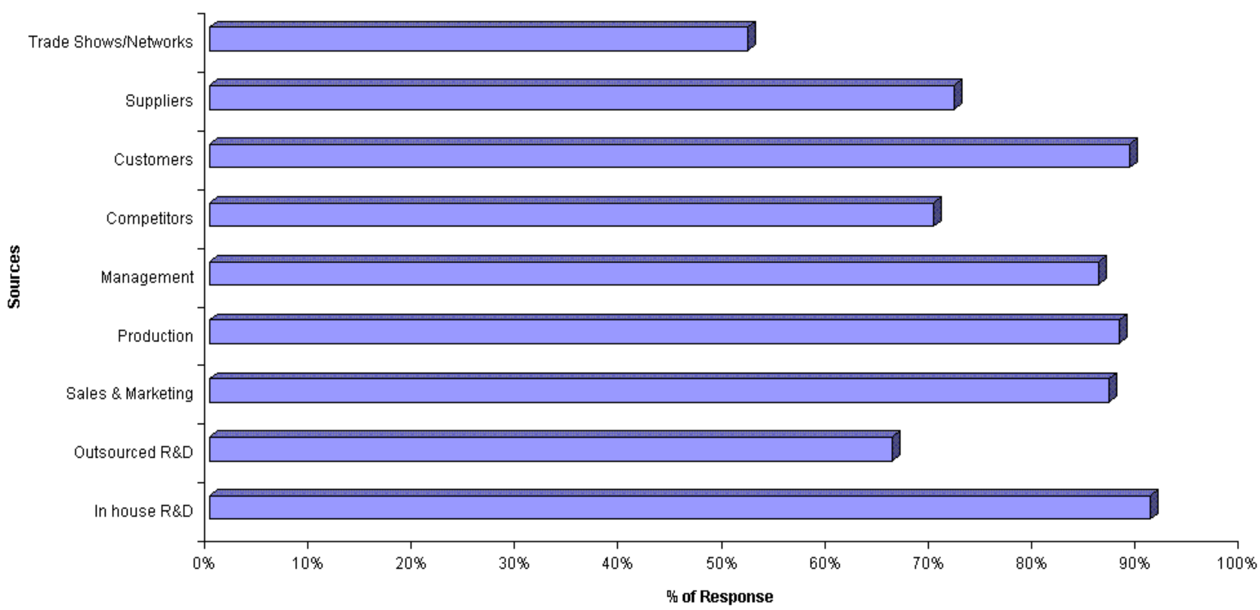
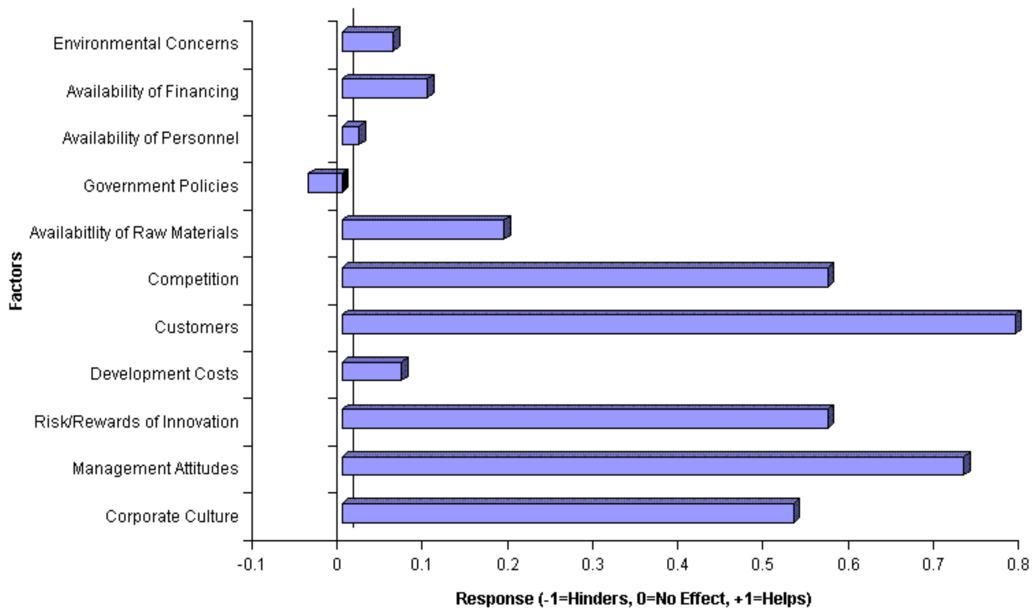


Figure 5: Factors Affecting Innovation



From a policymaker's point of view the data, although crude, identify specific policy issues: external factors are less important than internal ones in influencing innovation, and innovative firms do not regard access to financing as a hindrance to innovation. For government policy analysts the results might suggest the need to move away from direct support programs to less visible programs designed to support the competitive environment. In particular the role of governments (both directly in financing innovation and indirectly through the trade shows and networks that they sponsor) may be relatively unimportant. What is important is the internal environment within the firm and feedback from their customers. For a corporate manager, the results clearly indicate the need to ensure that the firm is sensitive to signals from the marketplace. These results are preliminary and will require extensive additional analysis.

Measuring the Contribution of S&T to the Quality of Life

S&T indicators must also measure the social and environmental gains being made as a result of investment in S&T. While attempts have been made to measure the economic benefits resulting from S&T activities, the field of S&T for the public good has been virtually unexplored.
However, S&T is a means to an end when it is applied to the improvement of the quality of life. Generally this is a characteristic of S&T in the public sector. S&T then becomes a tool which can help to deliver programs more efficiently and effectively.

Innovation does not necessarily occur only in the private sector, but as yet there has been no procedure offered for the assessment and quantification of innovation in the public sector. The government of New Zealand, in its act establishing its S&T budget, the Public Good Science Fund, has defined S&T for the public good to be:

- increases knowledge and understanding of the physical, biological or social environment
- develops or increases the skill base and expertise important to New Zealand
- generates outputs of future benefit to a broad cross-section of the New Zealand public, and,
- is unlikely to funded from other sources.

This definition can, of course, include economic development, if economic development is thought to be in the public good. However it is a definition that can be applied to S&T carried out in support of health, social, environmental, justice, defence and administrative efficiency. Investment in health care is clearly a public good, but is generally excluded from discussions on S&T policy. While the line is fuzzy, it is usually accepted that any health care activity that is intended to improve existing levels of quality of life by the application of technology (e.g. research into new drugs) is included as investment in S&T while investments in the capacity to provide health care (e.g. more hospital beds to shorten waiting lists) are not, as these are applications of existing technology. The same arguments apply to the environment, defence, justice and other public goods.

Conclusions

The problem is simple: policy makers want information of the state of investment in knowledge, and this information is simply not available. Knowledge is intangible, and is measured only indirectly through money, people and trade in goods and services. It is possible to measure capital stocks of internally generated new knowledge, using levels of R&D funding as the unit of measurement, but heroic assumptions have to be made as to the depreciation rate for this knowledge. However, with these assumptions, it would be possible to carry out this type of comparative study to establish a nation's (or a region's) place among a group of similar economies.

In order to broaden the scope of this investment in knowledge, data on investments in intellectual property and technologies embedded in high-technology goods have to be added. Both would require substantial work, the first to capture all flows of intellectual property into and out of the region, and the second to assign a value to the knowledge embedded in each good or service traded. Nevertheless, standard assumptions, such as using R&D/sales ratios to calculate the knowledge component of high-tech goods and services could be brought to bear on the problem.

The third area that would amenable to improvement for a modest investment would be to improve knowledge of the transfers from field of study to employment. Given the high cost of educating post-graduate students in S&T, we need to know more about how these talents are used, and how over time technical knowledge is either augmented or depreciated.

Studies of the stocks and flows of human capital lead directly to the study of the actors and networks that make up an NSI. This is a field which is only just beginning to be being examined, but which is probably important in smaller economies than in larger ones, where the sheer number of networks and individual actors, means that individual actor-network complexes have less individual influence on the system. Dagnino and Thomas (16), in a paper presented at the 2nd RICYT workshop discuss this from a perspective which is probably more relevant to Latin American NSIs. It is likely that Latin American researchers can add significantly to the world' s literature on NSIs in this area in analysing their own NSIs, as these NSIs, like the sub-national and regional NSIs of the developed countries are better candidates for systematic study because of their simplicity.

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