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ECONOMIC ASPECTS OF TECHNOLOGICAL INNOVATION

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by

U.K. Ranga Chand

Policy Research Group
Industry Branch
Ministry of State for Science & Technology

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I. INTRODUCTION

There has been a lot of attention and discussion in recent years on the role and impact of research and development and technological innovation on the Canadian economy. Although it is now generally accepted that R&D and technological innovation play an important role in the long-term rate of growth of an economy, there has been relatively less discussion concerning the total process and the overall costs of technological innovation. While it is commonly recognized that technological innovation is much more than simply R&D, because of the paucity of measures of technological innovation, R&D has tended to be emphasized as the proxy for the much more extensive activities in the complete cycle of technological innovation. The use of R&D measures to assess the technological health of a nation is convenient but there are obvious pitfalls to be wary of, the most apparent being that R&D expenditures capture only a portion of the overall costs of technological innovation.

The purpose of this paper is to examine various aspects of technological innovation. It begins by examining technological innovation and the role of research and development activities in this process. The next section discusses the influence of firm size and market structure on technological innovation and is followed by a section on the costs of technological innovation. The final section draws conclusions and implications based on the above findings.

II. THE PROCESS OF TECHNOLOGICAL INNOVATION

Although there are numerous variants regarding the definition of technological innovation, all have in common the concept of newness and of the application of a technology. Thus, Mansfield states that "an invention, when applied for the first time, is called innovation".(1) Similarly, the National Science Foundation defines technological innovation as "the introduction of new or improved products, processes or services into general use".(2) Hence, the term technological innovation implies the transformation of an idea into a new or improved marketable product or operational process.

Technological innovation encompasses research and development activities which is defined as investigative work carried out to acquire new scientific and technological knowledge, to devise and develop new products or processes or to apply newly acquired knowledge in making technically significant improvements to existing products or processes.

(1) Edwin Mansfield, The Economics of Technological Change. W.W. Norton & Company, Inc., New York, 1968. Page 99.

(2) National Science Foundation, Science Indicators 1976. Washington, D.C., 1977. Page 20.

The OECD categorizes R&D into three identifiable activities: basic research, applied research and experimental development.(3) Most basic reseach is conducted by universities and government laboratories and is directed toward increasing the existing stock of knowledge. In industry, however, the focus is more on the applied research and development phase of R&D. Although industry does some basic research, the main thrust is on using the existing stock of scientific knowledge with a view to commercializing the results of research findings.

Although the above characterization captures the main thrust of R&D activities, they do not necessarily fall into such sequential and distinct categories. In reality, the distinction between the three types of R&D activities is blurred at best and, indeed, there may be movement in both directions. For example, when an R&D project is at the applied research/development stage, some funds may have to be spent on additional basic research that is needed before further progress can be made.(4)

(3) OECD, The Measurement of Scientific and Technical Activities, "Frascati Manual". Paris, 1976. Chapter 2.

(4) Ibid., page 19.

The "output" of research and development activities, when successful, results in an invention which is "...a prescription for a new product or process that was not obvious to one skilled in the relevant art at the time the idea was generated".(5) Inventions can occur in either the research phase or the development phase of organized R&D activity with the central ideas generally coming from research and inventions, in patentable form, arising during the course of development.(6)

Research and development ceases and the pre-production phase of the innovation activity begins when the work is no longer experimental. There are several further steps involved in the innovation process before the results of R&D reach the market place on a commercial scale. Once the decision to innovate is made by a firm, the post-R&D phase of innovation consists of production engineering, industrial design engineering, the testing of proto-types and trial-runs, manufacturing start-up, marketing, and financing.

(5) Edwin Mansfield, The Economics of Technological Change. W.W. Norton & Company, Inc., New York, 1968. Page 50.

(6) Ibid.

An innovation project is completed only when the new product or process reaches the market place for the first time. Needless to say, the commercial success or failure of a completed innovation project lies in the market place.

It might be noted that the process of technological innovation is surrounded by uncertainty. Conceptually, at least, there are two different types of uncertainty that one can identify which are encountered in the process of innovation. The R&D phase of innovation is essentially characterized by technical uncertainty, i.e., can a problem or an idea be solved in the technical sense, whereas the post-R&D phase of innovation is concerned more with market uncertainty and it is at this stage that the role of the "entrepreneur" comes to the forefront.

Although the above discussion has presented a schematic framework in sequential form for technological innovation, beginning with R&D activities and proceeding through to the post-R&D phase of the innovation process, it does not necessarily follow that, in order for a firm to be innovative, it has to engage in all aspects of innovative activity. Indeed, as indicated earlier, most industrial firms enter the innovation process at the applied research/developmental phase by utilizing ideas and/or inventions which may have originated elsewhere.

III. THE INFLUENCE OF FIRM SIZE AND MARKET STRUCTURE ON TECHNOLOGICAL INNOVATION

Because of the nature of technological innovation and the uncertainties surrounding it both during the R&D and post-R&D phase, one area of innovation which has generated considerable interest and controversy is related to the size of firm and market structure in general. The debate has essentially focussed around the following questions -- are large firms more adept at producing innovations than their smaller counterparts and, secondly, does a monopolistic situation provide a more favourable environment for technological innovation as opposed to perfect competition?

The main proponents of the monopolistic school of thought have been Joseph Schumpeter and John Kenneth Galbraith. Schumpeter argued that firms possessing monopolistic powers were in a far better position and had a much higher incentive to innovate. In essence, Schumpeter's argument in support of monopolies as being the ideal market structure for promoting innovations was that the profits accruing under monopolistic conditions provided firms with the incentive for undertaking innovative activities in order to further increase profits. Obviously, a monopolist, like the firm in a perfectly competitive situation, can increase profits in the short-run by reducing costs. However, because a monopolist can prevent new firms from entering the industry and hence eliminate or restrict competition, the additional profits will be sustained in the long-run. Thus, Schumpeter concluded, on a priori grounds, that the large-scale establishment or unit of control has become the most powerful engine of economic progress and "In this respect, perfect competition is not only impossible but inferior, and has no title to being set up as a model of ideal efficiency".(7)

Galbraith, in a similar vein, has asserted that in modern industrial economies the existence of a few large firms is "admirably equipped for financing technical development. Its organization provides strong incentives for undertaking development and putting it into use. The competition of the competitive model, by contrast, almost completely precludes technical development".(8)

Furthermore, Galbraith has argued that "because development is costly, it follows that it can be carried on only by a firm that has the resources which are associated

(7) Joseph A. Schumpeter, Capitalism, Socialism and Democracy. Third Edition. Harper Colophon Books (Harper & Row, Publishers, Inc., New York), 1975. Page 106.

(8) John Kenneth Galbraith, American Capitalism. Houghton Mifflin Company Boston (The Riverside Press Cambridge), 1962. Page 86.

with considerable size. Moreover, unless a firm has a substantial share of the market, it has no strong incentive to undertake large expenditures on development".(9)

Although the Schumpeter/Galbraithian thesis was based on a priori reasoning, there have been some empirical studies over the past several years which have shown that small firms and independent inventors have contributed substantially towards the creation of new products and processes. One of the most influential studies detailing the contribution by small entities and independent inventors is by Jewkes, Sawers and Stillerman. In their study on the sources of invention, Jewkes et al compiled case histories of seventy of the most important inventions of this century and, based on their findings, concluded that more than one-half of these inventions emanated from individual inventors.(10)

Whilst the Jewkes et al study focussed on the sources of inventions, there have also been attempts to determine

(9) Ibid., page 87.

(10) John Jewkes, David Sawers and Richard Stillerman, The Sources of Invention. Second Edition. W.W. Norton & Company, Inc., New York, 1969. Pages 65-78.

the contribution of large and small firms to technological innovation. For example, Mansfield found that, between 1939 and 1958, the largest four firms in the coal and petroleum industry in the United States contributed more technological innovations than their share of the market whereas the four largest firms in the steel industry contributed fewer innovations relative to their market share.(11)

The National Science Foundation, on the basis of a study of 310 major technological innovations introduced into the U.S. commercial market during 1953-73, found that large companies (those with 10,000 or more employees) produced over one-third of the innovations. At the other end of the company size spectrum, companies with less than 100 employees accounted for twenty-three percent of the innovations and companies with between 100 and 1,000 employees accounted for twenty-four percent. Thus, although large firms produced the greatest proportion of major innovations during the period 1953-73, if firms with up to 1,000 employes are classified as "small", then small firms produced more major innovations than large firms.(12)

(11) Edwin Mansfield, The Economics of Technological Change. W.W. Norton & Company, Inc., New York, 1968. Pages 108-110.

(12) National Science Foundation, Science Indicators 1976. Washington, D.C., 1977. Page 116.

The existing evidence thus clearly indicates that the position postulated by Schumpeter and Galbraith is unnecessarily extreme. Small firms and, indeed, individuals have contributed substantially towards both inventions and technological innovations. Obviously, the costs for the majority of technological innovations are not so exorbitantly high as to preclude small firms from being innovative.

The supporting evidence for this latter contention is contained in the results of a Statistics Canada survey on tehnological innovation in Canadian industry. This survey of innovation projects, carried out in 1973, resulted in fifty-seven firms providing cost estimates for a total of eighty-three innovations which were completed. The total cost for these projects was $277 million and the projects included both product and process innovations (fifty-nine and twenty-four respectively).

Table 1 shows the average cost of the eighty-three innovation projects by industry group. Although the overall average cost for these projects was about $3.3 million, the average cost varied widely by different industry groups. For example, the fourteen innovations in the machinery and transportation equipment industry accounted for over half of the total costs of the eighty-three projects and incurred

TABLE 1

AVERAGE COST OF INNOVATION PROJECTS
BY INDUSTRY GROUP

INDUSTRY GROUP	NO. OF PROJECTS	TOTAL INNOVATION COSTS ($'000)	AVERAGE COST OF PROJECT ($'000)
Chemical-Based	17	26,662	1,568
Wood-Based	16	23,651	1,478
Machinery & Transp. Eq.	14	141,444	10,103
Electrical	18	55,008	3,056
Other	18	30,785	1,710
Total	83	277,550	3,345

Source: Based on data from Statistics Canada, "Selected Statistics on Technological Innovation in Industry", Catalogue No. 13-555, January 1975.

average costs of over $10 million. The eighteen projects in the electrical industry had an average cost of approximately $3 million whereas in the chemical-based and wood-based industries the average cost of an innovation was about $1.5 million.

Inevitably, the average cost of innovations expressed in dollars will be biased by the few innovations which are very costly. Table 2 shows the total innovation costs for the eighty-three projects broken down into four different project expenditure sizes. For the fifty projects which cost less than $1 million, the total innovations costs amounted to approximately $22 million and represented eight percent of the innovation costs for the eighty-three projects. Although there were only twelve projects which incurred costs of over $4 million, they accounted for over three-quarters of the overall costs.

Thus, based on these findings, it is apparent that most innovations are relatively inexpensive and, hence, are well within the bounds of most firms, be they either large or small. Although one cannot generalize about the precise role of large and small firms in the process of technological innovation, nevertheless, from a policy perspective it is clear that, as F.M. Scherer has correctly observed, there is no single firm size which is uniquely

TABLE 2

TOTAL INNOVATION COSTS
BY SIZE OF PROJECT EXPENDITURE

SIZE OF PROJECT	NUMBER OF PROJECTS		TOTAL INNOVATION COSTS	
	NO.	%	$'000	%
$0-1 million	50	61	21,825	8
$1-2 million	12	14	17,390	6
$2-4 million	9	11	27,112	10
$4 million +	12	14	211,223	76
Total	83	100	277,550	100

Source: Based on data from Statistics Canada, "Selected Statistics on Technological Innovation in Industry", Catalogue No. 13-555, January 1975.

conducive to technological progress.(13) Similarily, the OECD by weighing the existing evidence arrives at the perhaps somewhat obvious conclusion that large firms tend to make a strong contribution to innovation in areas requiring large-scale technological production or market resources, and small firms in areas requiring sophisticated and specialized technological capabilities, but relatively small production and marketing resources.(14)

(13) F.M. Scherer, Industrial Market Structure and Economic Performance. Rand McNally College Publishing Company, Chicago, 1970. Page 357.

(14) OECD, The Conditions for Success in Technological Innovation. Paris, 1971. Page 36.

IV. THE COSTS OF TECHNOLOGICAL INNOVATION

Aside from ascertaining the contribution to technological innovation by different sizes of firms, there have been some studies which have attempted to break down the costs of technological innovation into its various components, including R&D. One such study which has received widespread attention concerning the costs of technological innovation is the report of the panel on invention and innovation chaired by Robert A. Charpie and published by the U.S. Department of Commerce in 1967.(15) The Charpie panel estimated that R&D typically accounts for less than ten percent of the total innovative effort with the post-R&D efforts being the most costly component of successful innovations.

Similarily, in Canada the Hatch report, although it does not provide cost estimates for technological innovation, states that "R&D is not the really expensive part of innovation...The downstream costs of innovation, e.g., product design and engineering, production engineering, tooling, prototype production and market

(15) U.S. Department of Commerce, Technological Innovation: In Environment and Management. Washington, D.C., January 1967.

launch, are much more costly."(16)

However, the results of Statistics Canada's survey on the costs of technological innovation in Canadian industry differ substantially from the estimates of the Charpie panel and the views expressed in the Hatch report. The Statistics Canada survey revealed that the costs of R&D are a higher proportion (approximately fifty percent) of the total costs of technological innovation.(17)

Seven component activities of technological innovation were identified in Statistics Canada's survey. These were R&D, new product marketing, patent work, financial and organizational changes, final product or design engineering, tooling and industrial engineering, and manufacturing start-up. In addition, the Statistics Canada survey included capital expenditures as a separate item whereas in most other studies capital expenditures have been included in the post-R&D or pre-production activity phase of the innovation.

(16) Department of Industry, Trade and Commerce, Strengthening Canada Abroad. Export Promotion Review Committee, Chairman, Roger Hatch. Ottawa. 1979. Page 14.

(17) Statistics Canada, Selected Statistics on Technological Innovation in Industry, Catalogue No. 13-555, January 1975.

Table 3 shows the relative distribution of the costs of innovations in terms of R&D activities, pre-production activities and capital expenditures for five different industry groupings. In the table, the term "capital expenditures" refers to new production equipment required to bring the innovation to commercial production. Capital expenditures for pilot plants and specialized R&D equipment have been included in the R&D phase of the innovation.

As shown in the table, R&D clearly accounts for a significant portion of the total costs of technological innovation in Canadian manufacturing industries. Nevertheless, the distribution of R&D costs varies substantially within the different industry groups. Thus, for example, in the chemical-based and wood-based industries, the R&D component accounted for over one-fifth of the total innovation costs, whereas, in the electrical products industry, R&D accounted for over three-quarters of the total costs.

Although one has to entertain a certain amount of caution in drawing generalizations based on the findings of a limited sample of completed innovation projects, it is clear that the different distributions of the costs of technological innovation is related to the type of industry. Thus, depending on the nature and characteristics of an

TABLE 3

RELATIVE EXPENDITURES ON EACH INNOVATION ACTIVITY
BY INDUSTRY GROUP

	PERCENTAGE DISTRIBUTION					
	CHEMICAL BASED	WOOD BASED	MACHINERY & TRANSP. EQ.	ELECTRICAL	OTHER	TOTAL
R&D Activities	22	21	43	77	44	46
Pre-Production Activities[1]	17	9	51	10	28	34
Capital Expenditures[2]	61	70	6	13	28	20
Total	100	100	100	100	100	100

[1] Commercialization of the results of R&D.

[2] New production equipment, etc.

Source: Based on data from Statistics Canada, "Selected Statistics on Technological Innovation in Industry", Catalogue No. 13-555, January 1975.

industry, R&D may be the most or least costly component of an innovation. Indeed, what is certain is that the notion that R&D typically accounts for only five to ten percent of the total costs of innovation is in itself a misleading generalization.

One plausible explanation of the observed difference of the cost structure of technological innovation between the Statistics Canada results and the Charpie panel is to do with the differences in the size of the respective markets of Canada and the United States. For example, H. Stead presents a reasonable hypothesis by stating that "if the product of the U.S. firm is destined for a larger market than is the innovation of the Canadian firm, then its 'commercialization' costs may well be larger. If two firms were to develop exactly the same innovation, the R&D costs might be similar. However, if one firm's innovation is intended for a much larger market, then its tooling, its capital expenditures, its manufacturing and marketing start-up costs would be absolutely and relatively larger".(18)

On the other hand, if innovating Canadian firms market

(18) H. Stead, "The Costs of Technological Innovation", <u>Research Policy</u> (5), 1976. Page 9.

their new products on a worldwide basis, the relative distribution of R&D costs to total innovation costs would probably be more in line with those industrial countries which possess large internal markets for their products. Nevertheless, it is likely that for small- or medium-sized countries such as Canada, the R&D component of technological innovation will be significantly higher than that of large industrial nations such as the United States.

V. CONCLUSIONS

Technological innovation clearly involves much more than research and development activities. After the R&D phase of innovation is completed, several more steps such as production engineering, testing of proto-types, manufacturing start-up, marketing, etc., are required before commercialization of the "output" of R&D can be realized in the market place. Of course, for a firm to be innovative does not necessarily mean that it has to engage in all aspects of the innovation process. As indicated in the first section of the paper, most industrial firms enter the innovation process at the applied research/development phase by utilizing ideas and/or inventions which may have originated elsewhere.

As far as the influence of firm size and market structure on technological innovation is concerned, it is clear that, contrary to the thesis postulated by Schumpeter and Galbraith, innovation is not simply the preserve of large firms. The existing evidence has amply demonstrated the contribution to technological innovation by firms of all sizes. Although there may be a tendency for firms which control a large share of the market to be complacent about innovation, in reality this is doubtful. What large firms may be adverse to is undertaking research and development projects for which the expected payoff is extremely tenuous and doubtful. They may feel that the risks associated with such projects are not worth their effort and may leave the door open for small firms to pursue these activities. On the other hand, large firms may enter the innovation process at a later stage by marketing and developing the inventions which are the product of small firms. Thus, in this case, the role of small and large firms in the innovation process, although distinct, is essentially a complementary one with each firm taking advantage of its own specialities and thereby contributing to overall technological innovation.

With respect to the costs of technological innovation, the findings of the Charpie panel, indicating that R&D accounts for five to ten percent of total innovation costs in the United States, cannot be applied across the board to small- and medium-sized countries such as Canada. The Statistics Canada survey on technological innovation in Canadian industry revealed that, on "average", R&D accounts for approximately fifty percent of the total costs of innovation.

There are relatively few technological innovations which have a major and far-reaching impact on the economy and society in general. Obvious examples are the advent of jet engines, computers, television, micro-processors, etc.

These innovations not only profoundly affect their own industries but cut across all sectors of the economy and, indeed, spawn whole new growth industries. However, the vast majority of innovations are relatively minor ones which have a minimal impact on the economy in general. Nevertheless, they play an important role in increasing the productivity of the firm or industry, thereby enhancing its competitiveness both domestically and internationally.

One aspect of technological innovation which has generally caused concern has been its impact, either imagined or real, on the level of employment. The impact of technological innovation, by permitting increases in productivity, will vary from industry to industry. In more mature industries where further opportunities for growth are inherently limited and technological advances are directed at reducing costs or maintaining a firm's existing market share, there will almost certainly be declines in employment. In other industries, however, especially where advances in productivity are associated with the development of either new or better quality products, the potential for further growth in sales may be sufficient to generate absolute increases in employment.(19)

(19) U.K. Ranga Chand, "Can Growth in Output Create More Jobs?", Canadian Business Review. Winter 1979/80. Pages 19-22.