NBER WORKING PAPER SERIES

# INNOVATIONS AND TECHNOLOGICAL SPILLOVERS

M. Ishaq Nadiri

Working Paper No. 4423

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
August 1993

This paper is part of NBER's research program in Productivity. Any opinions expressed are those of the author and not those of the National Bureau of Economic Research.

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## ABSTRACT

In this paper we analyze the evidence from a large number of studies on three specific questions pertaining to R&D investment: (1) Are there diminishing returns to inventive activities? (2) What is the relationship between R&D and productivity and what are the magnitudes of the returns to a firm's or industry's R&D investment? (3) What are the magnitudes of the benefits from R&D undertaken by other firms, industries and countries and the vehicles by which they are transmitted to the recipients?

The evidence on the first issue is still controversial, basically because of the lack of an adequate measure of output and precise measurement of the inputs to the inventive process. Patent counts are often considered as a measure of output while expenditures on R&D are used as a measure of input in this process. If proper adjustments are made and the significant spillover effects of R&D documented in this paper are taken into account, the possibility of diminishing returns to inventive activities seems implausible. On the second question, the results clearly suggest a positive and strong relationship between R&D expenditures and growth of output or total factor productivity. The relation is pervasive, though the magnitudes of the contribution of R&D vary among firms, industries and countries. On the average, net rates of return on own R&D are about 20% to 30%. There is no clear cut evidence of decline in the potency of R&D investment in the late 1970s. However, there is evidence that R&D as a factor of production affects not only productivity growth but also the demand for conventional inputs and is influenced by changes in input prices and the level of demand.

The evidence points to sizable R&D spillover effects both at the firm and industry levels; the social rates of return of R&D often vary from 20% to over 100% in various industry, with an average somewhere close to 50%. The channels of diffusion of the spillovers vary considerably and their effects on productivity growth are sizable. These results suggest a substantial underinvestment in R&D activities.

International technology trade among the OECD countries has increased substantially in recent years. The diffusion of new technologies has been very rapid; the channels of transmissions have been exports, foreign direct investment, and multinational enterprises' research operations, the latter being the most dynamic agents of technology transfer. With the further globalization of business activities, international technology transfers will be a major source of new R&D spillovers.

M. Ishaq Nadiri
NBER/New York University
Department of Economics
269 Mercer Street, 7th Floor
New York, NY 10003

## INTRODUCTION[1]

In this paper we shall focus on the empirical evidence on three important issues related to research and development (R&D) investment. The first issue is whether there is evidence of diminishing returns to innovative activity. The worldwide slowdown in productivity growth in recent years has led to vigorous efforts to identify the responsible economic factors. Slowdowns in capital formation, energy crises, regulation, and demand, or a combination of all these have been identified as possible influences. Some have argued that this slowdown reflects the exhaustion or diminution of technological opportunities and contributions, particularly in the rate of fundamental invention. To ascertain whether there has been technological stagnation many economists have examined patent statistics as an output of the invention process and expenditures on R&D as a measure of input in this process. Comparing the output and input measures of the invention process, some have argued that there are signs of diminishing returns to inventive activities, which may arise because it is more difficult or more costly to exploit new technological discoveries or because the rate of fundamental invention has slowed down or stopped growing.

Our second issue is the evidence on the relation between R&D as an index of technological change and productivity growth. Is there a significant relationship between R&D, output and productivity growth and what is the rate of return on R&D investment at the firm and industry levels? Another relevant question is whether the stock of R&D as an input in the production process affects the demand and productivity of the conventional inputs. Also, there are some questions about whether the potency of R&D investment has declined in the late 1970s, contributing to the slowdown in productivity growth.

Our third issue is whether there are important R&D spillovers and how they affect productivity growth and the structure of production in a firm or an industry. If there are significant spillovers from R&D investment, both in magnitude and pervasiveness, they can lead to increases in the growth rate of productivity and perhaps overcome any diminishing return

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[1]The author wishes to thank Catherine Labio, Theofanis P. Mamuneas, Bhaswar Mukhopadhyay, and Richard Simon for their valuable assistance in research and preparation of this manuscript.

effects. We shall assemble the evidence on the private and social rates of return on R&D investment and comment on its dynamic relationship with R&D investment, physical capital investment, intermediate inputs, employment, output, and output prices. We shall also look at the evidence on technology trade among the major OECD countries to assess the possible technology spillovers across national boundaries. The role of multinational enterprises (MNEs) and foreign direct investment (FDI) in the process of international technology trade is also examined.

The empirical evidence assembled here pertains mainly to studies on U.S. firms and two-digit industries, but we shall include evidence from other countries wherever possible. The paper is organized as follows: in section I we examine the issues related to patent statistics and technological stagnation. Section II is devoted to the evidence assembled on the effect of R&D investment on productivity growth. In section III we examine R&D spillovers, their effect on productivity growth, and their role in changing the demand for different factors of production. International transactions in technology are examined in section IV. The concluding section provides a summary of our analysis.

## I. Patents and Technological Stagnation

Understanding of the process of economic growth, the rate of technical change, and the competitive performance of firms, industries and economies as well as the evolution of the structure of production of these economic units ultimately depends, as Griliches (1990) has pointed out, on understanding of the underlying process of inventiveness in an economy. In principle, one can postulate a "knowledge production function" which describes how new products or new methods of production are discovered using specific resources. It is an extremely difficult task to specify the form of the underlying knowledge production function and to measure with any degree of precision the output and inputs of the invention production process. Patent statistics are often used as a measure or indicator of the output of the invention process while R&D expenditures are considered as an input generating economically valuable knowledge. Since addition to knowledge is not observable, it is approximated by either patent counts, P, as a quantitative indicator of the number of inventions or by the expenditure on R&D, R, as an input in the production of inventive activities.[2]

Unfortunately the "output" of research is not well defined nor easily measurable. Some

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[2]Griliches (1990) has sketched a simple model to clarify the meaning of the empirical evidence on the use of patents and R&D expenditures to measure the effect of knowledge creation on economic activity. Let

$$\dot{K} = R + \mu$$
$$P = a\dot{K} + \nu = aR + a\mu + v$$
$$Z = b\dot{K} + \epsilon$$

where Z is a measure of expected or realized benefit from invention such as productivity growth. The quality of P as indicator of $\dot{K}$ depends on the size of v, the error in the indicator relationship and the quality of the relationship between P and R provide a lower bound on quality of P as an indicator of $\dot{K}$. By looking at the correlation between P and R it can be argued under the assumptions of the model that the correlation between P&$\dot{K}$ would have been higher if it could have been measured. Whether P or R is a better proxy for $\dot{K}$ depends on the relative size of the variance of the error terms $\nu$ and u. If the measurement error in patents relative to stochastic $\dot{K}$ is large then R may be a better means to approximate $\dot{K}$.

important measurement issues affecting patent data as a measure of research output are noted below. A number of recent studies, mainly by Griliches (1984) and Griliches et al. (1987) have reached the conclusion that while there are large stochastic elements and great variance in the value of individual patents, patent applications are reasonably good measures of research output. Similarly, there are a number of problems affecting R&D expenditures as an input of research efforts. Classifications of expenditures on R&D differ greatly among firms and are often motivated by tax legislation; R&D investment expenditures are treated as current expenses; and different countries permit different definitions of R&D expenses. Further, the comparability of R&D expenditures among countries is affected by differences in the R&D deflator and by exchange rate fluctuations.

Nonetheless, it is common to use the ratio of patents per unit of R&D expenditure or per unit of R&D personnel to see whether there are any signs of increasing (decreasing) returns in knowledge production.[3] In more recent years all indicators of patenting effort——series on domestic patent applications, patent grants, and external patent applications as a percentage of R&D expenditures——declined in the 1970s and have stabilized only recently in all the major OECD countries. In fact, a striking feature of patent applications in most OECD countries is the end of growth and even a decline in national patent applications from the early seventies until 1978, followed by a recovery mainly due to the stimulating effect of the growth of international patenting.[4] In most countries, Japan being an exception, the trend in national applications was mainly determined by foreign applications. The share of domestic applications decreased and external patent applications showed substantial and dynamic growth. Since 1968, only in Japan has there been extremely rapid growth of domestic patent application, though it has slowed down recently (OECD (1986)). The rapid increase in Japanese patenting is partly due to the fact that

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[3]The number of domestic patent applications in the US peaked in the late 1920s and after a severe decline during the great depression and the war period and a brief postwar recovery, they have remained flat in the post-war period. The company-financed R&D and GNP both were rising since World War II (Griliches (1990)).

[4]The domestic patent applications peaked for the U.S. in 1970, France in 1968, West Germany in 1965, Sweden in 1967, Switzerland in 1972, and the U.K. in 1968. The series on actual patents granted followed with a short lag the same pattern as the application series. See Scherer (1986).

until recently the Japanese filed "single claim" patents whereas in other countries each patent contains several claims.

The slowdown in domestic applications in most OECD countries has led to an apparent productivity slowdown in innovations, i.e., except for Japan, the ratio of the number of researchers to the number of patents has declined in the 1970s. In the late 1970s the ratio of company R&D expenditures to domestic patent applications rose in most major OECD countries, particularly in the U.S.. Since 1981, and particularly after 1985, this ratio has been fairly stable. The ratio of patents to real R&D expenditures also declined dramatically since 1970 and until the early 1980s in thirteen two-digit U.S. manufacturing sectors. Similar patterns have been recorded for industries in other major OECD countries as well. The exceptions were some high-tech industries such as robotics, lasers, drugs, microbiotics, telecommunications, and a few others where the P/R ratio has been rising, particularly in Japan, Germany, and France.

These trends suggest the possibility that because of some imperfectly understood diminishing-returns phenomenon, maintainance of a given rate of improvement in technology and, hence, in productivity may require a substantially more rapid rate of increase in the quantities of inputs devoted to technology-advancing activities. The divergent trends in patenting and real R&D expenditures suggest not only the possibility of diminishing returns to inventive activities in all countries except Japan, but also a deterioration of the U.S. competitive position in innovative activities vis-a-vis Japan and some European countries.

Before accepting the conclusion that there are diminishing returns to inventive activities, it is necessary to ask two questions. One is whether the numerator and denominator of the ratio of patent applications to R&D expenditures are properly measured. The other is, what does it signify if P/R is still declining after proper adjustments?

As noted by Griliches (1990), in the cross-sectional data there is no evidence of diminishing returns to R&D, particularly for large firms. In fact, the average elasticity of patents with respect to R&D expenditures for large firms was about one while this elasticity for small firms (of less than 2 million dollars in assets) was about 0.4. The low propensity to patent in the case of small firms is partly due to sample selectivity and partly because small firms tend to do more informal R&D, which biases the P/R ratio downward. The picture is different when the time-series data are examined. The elasticity of patent with respect to R&D expenditures ranges from about 0.4 to 0.6, which suggests the possibility of diminishing returns.[5] But this may be due to various mismeasurements in either patent counts or R&D expenditures or both.

There are several other possibilities. One is that our measure of patents should include both the domestic and external patent applications; the ratio of national patenting to (the sum of domestic and external patent applications) R&D expenditure has remained fairly flat in the 1970s and rose slightly in the U.S. in the 1980s. Also, patents are not of uniform value. In fact, as Pakes and Schankerman (1984) and Griliches et al. (1987) have shown, most patents are worth very little and only a few patents are responsible for the major part of the social and private returns of the inventive system. When aggregate patent time-series are adjusted for "quality," Pakes and Schankerman report that though the number of patents/scientists fell sharply between 1965 and 1975 in Germany, France and the U.K., the quality adjusted patent rights per scientists and engineers were effectively stable (see also Pakes and Simpson (1989) and Schankerman (1991)).

Finally, another possibility is that there has been overestimation of the growth rate of real R&D; the conventional R&D deflators are likely to underestimate the real cost of doing science and research. If the true R&D deflator grew at slightly higher rates per year than the conventional R&D deflator, most or all of the observed decline in observed P/R ratio is likely to disappear. A large portion of formal R&D expenditures may be devoted to development and to inventions which are not patentable. Also, industries with substantial government support (aircraft and motor vehicles) tend to have a low propensity to patent. Both of these reasons introduce a downward bias in the elasticity of patents with respect to R&D expenditures.

Not many econometric studies identify or explain the determinants of the aggregate ratio of patents to R&D. Griliches (1990) attempted to provide an answer for the U.S.. On the basis of aggregate time-series patent data for the U.S. for the period 1953-1987, his results show a negative trend of about one percent per year in patents and an elasticity of patents with respect

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[5] The evidence from the micro time-series data sets analyzed by Pakes (1985) and Hall et al (1986) also suggest an elasticity of patent with respect to R&D of 0.2 to 0.4. A similar estimate was obtained by using industry data for the period 1970-79 (see Griliches (1990)). The estimated trend was negative for all the years (except for 1975) and for all industries except for drugs and agricultural chemicals.

to company R&D of about 0.2 to 0.4. His results also show that increases in defense expenditures pull resources away from inventive activities and channel them into areas where patenting is either more difficult or less important. Basic research at universities contributes positively to increased patent applications. Finally, there is some evidence that the rising relative cost of real R&D may have a negative effect on patenting either because of the rising cost of patenting or the fact that the cost of research is rising.[6] Another possibility is that the decline of the conventionally calculated ratio of patent applications to R&D expenditures may be due to a change in the industrial mix away from the traditional high patenting areas such as chemicals and toward the faster growing, lower patenting industries such as computers. Using patents per R&D dollar intensities for 1979 and reweighting them with the industrial distribution of R&D expenditures in 1957 and 1985, and also by using Scherer's data on 1974 patents by line of business/R&D, Griliches (1989) also reports that the effects of industry mix are very small——about 3%.

Patent applications may not be a good proxy for the underlying inventive activity. Not all technical progress is of a patentable nature; there is a large body of evidence that shows that great strides in productivity growth are often achieved through learning by doing and advances in human capital. Also, as shown by Schankerman (1991), while patent protection is a source of return to inventive effort, it does not appear to be significant. Firms resort to other types of barriers such as secrecy or trade restrictions, etc., to capture some of the benefits of their inventions. Therefore, patent counts may decline but the underlying invention activities may be increasing.

Even if there is a reduction in inventive output associated with the observed decline in patent applications, its effects, at least over a short period of time, on productivity growth may not be very large. Several studies have shown that total factor productivity growth (ΔTFP) is affected by economies of scale, input quality improvements, reallocation of resources among industries, and advances in knowledge due to factors other than the patented inventions. Also, the effect of invention on productivity appears to have a long and variable lag. If the

[6]These results are tenuous because of multicolinearity, particularly between company R&D and the relative price of R&D.

fundamental inventions are introduced slowly in the economy so a small portion of their effect on productivity is realized in the first decade, technological change in such an economy will be highly variable because of the extreme variability of the values of the inventions. The economy may go along for many years with a stagnant technology and then suddenly take off because of a few fundamental inventions.

The bulk of the evidence seems to point to two basic conclusions: first, the series on domestic patent applications as well as other measures of patenting effort contain some interesting information but cannot be considered a correct measure of accretion of knowledge. The values of the patents are so variable and there is so much knowledge that is likely to be unpatentable and have a different variation than the patent series, that patent application may not be a good proxy for the underlying invention activity. Also, R&D expenditures may be largely geared towards maintaining the research capacity of a firm or they may be directed to the development and application phases of inventive activity which are not patentable. There is some worry, particularly in the U.S., that the cost of research might have increased somewhat in recent years. If, on the basis of more detailed research, it turns out that inventive activity is facing rising costs, the long-run implications will be quite worrisome. Financing of R&D by the private sector is likely to decline (Baumol and Wolff (1983)). The solution may be to finance research activities with public funds or to find new sources of productivity enhancement in the inventive process. On the other hand, as we shall argue in sections II and III, there may be a fairly sizable spillover to R&D activity which is not reflected in the P/R ratio. If the externalities are large, then there is less reason to worry about the diminishing returns to inventive activities suggested by a decline in the P/R ratio as conventionally measured.

## II. R&D Investment and Productivity Growth

The relationship of productivity growth and R&D investment has been a subject of considerable interest and analysis in the economic literature as well as in policy analysis. Even in the narrower field of the econometric literature on the subject, the volume of studies is quite extensive and the subject of several surveys (see for instance the recent surveys by Mohnen (1990a), Mairesse and Sassenou (1991), Griliches (1991) and Mairesse and Mohnen (1990)). We shall review only some of the major but selective findings suggested in the literature and will not address the technical measurement and estimation problems involved.[7]

An ubiquitous finding of all the empirical studies summarized two decades ago by Mansfield (1972) was that R&D expenditures contribute substantially to the growth of output in a variety of industries. Subsequent surveys by Nadiri (1980b), Griliches (1991) and others have confirmed these findings. The analytical tool often used to link productivity growth with R&D is a simple Cobb-Douglas production function where output is a function of conventional inputs and the stock of R&D. The governing assumptions are constant returns to scale with respect to the conventional inputs, equilibrium in product and input markets, and a zero or a very small depreciation rate for the stock of R&D. Based on these assumptions, total factor productivity growth, ΔTFP, is related to R&D expenditure by

$$\Delta TFP_i = \lambda + \rho \, (RD/Q) + \eta_{it}$$

where $\rho$ is the net rate of return of R&D and Q is output or sales. An alternative and nearly equivalent approach is to estimate the underlying Cobb-Douglas production function directly, using the stock of R&D in addition to the conventional inputs as a determinant of output; the stock of R&D is often generated by the familiar "perpetual inventory" method with an arbitrary assumption about the depreciation rate for the stock of R&D. In table 1 we have listed the output elasticities of the stock of R&D and the rates of return to R&D investment reported in different studies. There are a number of econometric and estimation issues concerning these

[7]Interested readers are referred to the survey papers mentioned above and the references included therein.

estimates. However, here we shall comment briefly only on the overall results that have emerged from this line of research. In table 1a the estimates of the output elasticities and the rate of return to R&D at the firm level are presented while those pertaining to the industry level are reported in table 1b.

1. The estimated magnitudes of the elasticities and rate of return to R&D investment vary considerably depending on the type of data used (cross-section or time-series), the method of estimation, and whether the unit of analysis is the firm, the industry, or a country. Also, the elasticities and rates of return derived from time-series data are often smaller than those obtained from the cross-section data. The results, however, suggest a strong relationship between R&D and growth of output and productivity. The elasticities of R&D at the firm level tend to be around 10% to 30% and the rates of return around 20% to 30%. There are of course significant outliers in both sets of estimates. For the industry data, the elasticities range between 8% and 30%, while the rates of return range between 20% to 40%. Again, there are a number of outliers in both sets of estimates.
2. Almost all the available studies suggest that rates of return on privately financed R&D are much higher than those on publicly financed R&D. For privately financed R&D, the rates of return range between 27% to 60% while the rate of return for publicly financed R&D are often insignificant or negative. Federally financed R&D induces private sector R&D by facilitating and expanding privately funded R&D (Scott (1984)), but may not have a direct relation with $\Delta$TFP. However, Lichtenberg (1984, 1988) has argued that federal R&D funding for particular industries may actually crowd private R&D spending out. Also, the rate of return

## TABLE 1

**TABLE 1a:** Direct Rates of Return and Elasticities of R&D at the Firm Level

| Study | Rates of Return | Study | Rates of Return |
|---|---|---|---|
| **U.S.** | | **Japan** | |
| Minasian (1969) | 54% | Odagiri (1983) | 26% |
| Griliches (1980) | 27% | Odagiri-Iwata (1985) | 17%-20% |
| Mansfield (1980) | 28% | Griliches-Mairesse (1986) | 20%-56% |
| Nadiri-Bitros (1980) | 26%[e] | Sassenou (1988) | 14%-16%[e] |
| Schankerman (1981) | 24%-73% | Griliches-Mairesse (1990) | 30%-56%[e] |
| Griliches-Mairesse (1983) | 19% | **France** | |
| Link (1983) | n.s.-5% | Griliches-Mairesse (1983) | 31% |
| Clark-Griliches (1984) | 18%-20% | Cuneo-Mairesse (1984) | 55% |
| Griliches-Mairesse (1984) | 30% | Mairesse-Cuneo (1985) | 9%-26%[e] |
| Griliches (1986) | 33%-39% | **West-Germany** | |
| Griliches-Mairesse (1986) | 25%-41% | Bardy (1974) | 92%-97% |
| Jaffe (1986) | 25% | **Belgium** | |
| Schankerman-Nadiri (1986) | 10%-15% | Fecher (1989) | n.s. |
| Bernstein-Nadiri (1989a) | 9%-20% | | |
| Bernstein-Nadiri (1989b) | 7% | | |
| Griliches-Mairesse (1990) | 27%-41%[e] | | |
| Lichtenberg-Siegel (1991) | 13% | | |
| **Canada** | | | |
| Longo (1984) | 24% | | |
| Bernstein (1988) | 12% | | |

<u>TABLE 1 (cont'd)</u>

**TABLE 1b:** Direct Rates of Return and Elasticities of R&D at the Industry Level

| Study | Rates of Return | Study | Rates of Return |
|---|---|---|---|
| **U.S.** | | **Japan** | |
| Terleckyj (1974) | n.s.-29% | Odagiri (1985) | (66%)-24% |
| Link (1978) | 19% | Mansfield (1988) | 42%[e] |
| Griliches (1980) | n.s.-42% | Patel-Soete (1988)[t] | 37%[e] |
| Nadiri (1980a)[t] | 06%-10%[e] | Goto-Suzuki (1989) | 26% |
| Nadiri (1980b) | 08%-19%[e] | Mohnen-Nadiri-Prucha (1986) | 15% |
| Terleckyj (1980) | n.s. | Nadiri-Prucha (1990a) | 27%[e] |
| Sveikauskas (1981) | 7%-25% | **France** | |
| Scherer (1982, 1984) | 29%-43% | Patel-Soete (1988)[t] | 13%[e] |
| Griliches-Lichtenberg (1984a) | 3%-5% | **West-Germany** | |
| Griliches-Lichtenberg (1984b) | 21%-76% | Mohnen-Nadiri-Prucha (1986) | 13% |
| Mohnen-Nadiri-Prucha (1986) | 11% | Patel-Soete (1988)[t] | 21%[e] |
| Wolff-Nadiri (1987) | 11%-19% | **U.K.** | |
| Bernstein-Nadiri (1988) | 10%-27% | Mohnen-Nadiri-Prucha (1986) | 11% |
| Patel-Soete (1988)[t] | 6% | Patel-Soete (1988)[t] | 7%[e] |
| Nadiri-Prucha (1990a) | 24%[e] | Sterlacchini (1988) | 12%-20% |
| Bernstein-Nadiri (1991) | 15%-28% | | |
| **Canada** | | | |
| Globerman (1972) | n.s. | | |
| Postner-Wesa (1983) | n.s. | | |
| Hanel (1988) | 50% | | |
| Mohnen-Lepine (1988) | 5%-143% | | |
| Bernstein (1989) | 24%-47% | | |

[e]: elasticity; [t]: total economy; <u>n.s.</u>: insignificant

<u>Sources</u>:
Griliches (1990), Mairesse and Mohnen (1990), Mohnen (1990a), Lichtenberg and Siegel (1991).

on R&D investment varies significantly, whether it is for process technology or for product improvement and new products. The rate of return to process R&D is estimated in one study (Griliches and Lichtenberg (1984b)) to be in the range of 58% to 76% while for product R&D the range is between 20% to 30%. These differential rates of return confirm the proposition suggested by Mansfield (1984) that firms are more reluctant to transfer knowledge of their process R&D to firms abroad than they are for product R&D. Also, whether an industry is R&D intensive or not affects the rate of return on R&D. The interindustry rates of return between the R&D intensive and those which are less R&D intensive are pronounced (Englander et al. (1988) and Griliches and Mairesse (1984)).

3. The issue of whether the productivity of R&D has declined, particularly during the 1970s, has been the subject of several studies. In a number of earlier studies, Scherer (1982), Griliches and Lichtenberg (1984a) and Griliches (1986) reported a drop in the significance of R&D. Recently Englander et al. (1988) have also argued that the potency of R&D may have declined in this period. Nadiri and Prucha (1990a) also found that the effect of R&D on labor productivity in the U.S. electrical machinery declined substantially between 1968-73 and 1973-79, while the opposite took place over the same period in the same industry in Japan. However, several studies, including those by Griliches and his associates, Lichtenberg and Siegel (1991), and Scherer (1984) have found no such evidence. In fact, Lichtenberg and Siegel, using a very large body of firm data, obtained significantly higher estimates for R&D productivity in the early 1980s than for the 1970s.

4. In the interrelated factor demand models, the stock of R&D is treated as a factor of production. Empirical results indicate that changes in R&D affect the demand for inputs such as labor, materials, energy, and physical capital. The pattern of substitutions and complementarities of R&D with these inputs differ across industries (Nadiri and Bitros (1980), Bernstein and Nadiri (1989b), Nadiri and Prucha (1990b), Prucha and Nadiri (1991), and Mohnen et al. (1986)). In

general, R&D investment seems to increase demand for capital but decreases demand for labor and materials. Also, the stock of R&D, like the stock of physical capital, is subject to adjustment costs, which affects the level of R&D investment and its rates of return. The adjustment costs of stock of R&D is often much greater than that for physical capital. Investment in R&D in turn is affected by changes in relative prices of other inputs and in physical capital stock and also by changes in the level of demand. That is, R&D investment affects the structure of production and its own demand is affected by changes in prices and quantities of conventional inputs as well as changes in demand.

The general impression from the data is that there was some slackening of R&D growth in the early 1970s and then an acceleration in the late 1970s and the 1980s. The question is what explains this phenomenon. Griliches (1989) argued that decline in the mid 1970s and the subsequent rise of R&D productivity may reflect the variation of the rates of return over the business cycle. The cause of the slowing down of productivity growth was probably a slowing down of the aggregate demand after the oil shocks and the policy responses that followed. Ravenscraft and Scherer (1982) reported that the profitability of industrial R&D was severely depressed during the mid-1970s and firms responded by pruning their R&D portfolios; the changed demand conditions in the late 1970s and the 1980s led to a resurgence in R&D spending. Also, the slowdown of R&D productivity in the early 1970s might have been, partly, a response to the rapid exploitation of technological opportunities during the 1960s in the U.S. while its subsequent acceleration may have been due to competitive pressure, coming particularly from the Japanese surge in R&D activity and its success in the export markets.

There is some confirmation that the condition of demand may have been a major culprit in the slowing down of R&D expenditure and productivity in the U.S. late 1970s. The evidence from a structural model that incorporates specifically the estimation of demand and costs (Nadiri and Schankerman (1981)) suggests that it was the deceleration of demand and to a lesser extent the relative factor prices and R&D effects that dominated the productivity slowdown in the U.S. manufacturing industries in the period 1958 to 1978.

Changes in real factor prices contributed only modestly to the deceleration of $\Delta$ $T\dot{F}P$ in the periods 1958-65 and 1965-73 except in nondurable manufacturing but they contributed much more significantly to the $\Delta$ $T\dot{F}P$ slowdown in the periods between 1965-73 and 1973-78 . The demand deceleration, especially between 1965-73 and 1973-78, dominated the picture, accounting for 70 to 100 percent of the slowdown in TFP growth. The decline in the growth of R&D stock contributed modestly to the slowdown of TFP growth——about 4% and 17% respectively in the first and second slowdowns of TFP. Thus, the state of demand facing the firm or industry plays a considerable role in explaining the rate of productivity growth and also the rate and magnitude of the contribution of the stock of R&D.

## III. Externalities of R&D Investment

Two important features of knowledge capital are the lumpiness of inventive inputs necessary to produce it and the high degree of spillover or externality that accompanies the inventive process. These two features lead to a higher degree of imperfection in the knowledge market (Nordhaus (1962)). The first feature arises because knowledge is expensive to produce but cheap to reproduce. There are some costs to the diffusion of knowledge; the absorptive capacity of the recipients plays an important role in the transfer of technical knowledge. That is, a firm must do R&D to be able to borrow knowledge from other firms. But on the whole, particularly in the case of "general knowledge," the unimportance of marginal cost compared to average cost of producing new knowledge leads to a nonfunctioning of competitive market mechanisms, i.e., either there will be no production of knowledge or it will be concentrated in a small number of firms. Externalities arise on the other hand because of the inability of firms to capture all the benefits of their invention, i.e., the problem of appropriability arises unless patent legislation, trade secrecy and other impediments allow the firm to appropriate a sizable proportion of the benefits of their inventions.

An important feature of the linkage between innovation and productivity growth is the imitation process. Some firms devote resources to the improvement of the quality of their existing products and production processes or to the discovery of new products and processes. When they are successful, other firms devote resources to copying the success of the innovating firm and thereby accelerate the development and production of the new products or processes. The process of innovation and imitation may not take place at the same time and in the same industry. Firms may target some industries for innovations while other industries are targeted for potential imitations (Segerstorm (1991)). There is empirical evidence that patents are not perfectly enforced and many technologies are imitated very rapidly. Mansfield's (1984) reported that about 60% of patented innovations were imitated within four years; the rate of imitation will be high in industries where the ratio of imitation costs to innovation costs is low and where the degree of concentration is low. He found no evidence that the pace of innovations slowed down even though other firms could imitate these products at about 2/3 of the cost and time expended by the innovator. Imitations are fairly rapid across countries as well. Tilten (1971) has estimated that innovations by American semi-conductor industries were commercialized within one year by Japanese firms. As will be noted in section IV, the emergence of the multinational firms has also been a powerful vehicle for the diffusion of technology across countries as well as various industries.

The notion that externalities of inventions are of great importance has been known for a long time and empirical evidence on the spillover effects of specific inventions in industry and agriculture has been discussed widely in the literature.[8] In recent years new methodologies and extensive bodies of new data have been employed by different researchers in their quest to estimate the magnitudes of R&D spillovers and their effects on productivity growth. Two basic methodological approaches seem to have emerged. One class of studies uses an input-output (I-O) or a technology matrix based on patent data to position the firms or industries in a matrix of technological linkages and examine the spillover effects of R&D undertaken by one firm or industry on the remaining firms or industries. We refer to this approach as the "technology flow" approach. The second line of research is an econometric approach which estimates the effects of spillover on the costs and structure of production of the receiving firms or industries. We refer to this approach as the "cost function" approach.

A sample of the magnitudes of the rate of return on borrowed R&D and the social rates of return reported in the literature using these two analytical approaches are provided in tables 2a and 2b. The figures in table 2a are based on firm level data while those in table 2b are based on industry data. The technical features and references to the specifics of the data used in various studies are not discussed. Only the substantive results of the collection of the studies as they pertain to the measurement of R&D spillover are discussed briefly.

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[8]See Mansfield (1984) and Griliches (1990).

## TABLE 2

### TABLE 2a: Indirect Rates of Return on R&D at the Firm Level

| Study | Rates of Return | Study | Rates of Return |
|---|---|---|---|
| **U.S.** | | **Japan** | |
| Jaffe (1986) | 10%[e] | Sassenou (1988) | 10%[e] of own |
| Bernstein-Nadiri (1989b) | 9%-14%[s] | **Belgium** | |
| **Canada** | | Fecher (1989) | 0.5% |
| Bernstein (1988) | 20%-26%[s] | | |

### TABLE 2b: Indirect Rates of Return and Elasticities of R&D at the Industry Level

| Study | Rates of Return | Study | Rates of Return |
|---|---|---|---|
| U.S. | | Japan | |
| Terleckyj (1974) | 48%-78% | Odagiri (1985) | n.s. |
| Terleckyj (1980) | 183% | Goto-Suzuki (1989) | 80% |
| Sveikauskas (1981) | 50% | | |
| Scherer (1982,1984) | 64%-147% | | |
| Griliches- Lichtenberg (1984b) | 11%-62% | | |
| Wolff-Nadiri (1987) | 10%-90% | | |
| Bernstein-Nadiri (1988) | 11%-111%[s] | | |
| Bernstein-Nadiri (1991) | 20%-110%[s] | | |
| Canada | | | |
| Postner-Wesa (1983) | (26%)-18%[e] | | |
| Hanel (1988) | 100% | | |
| Sterlacchini (1988) | 15%-35% | | |
| Mohnen-Lepine (1988) | 11%-314%[s] | | |
| Bernstein (1989) | 29%-94%[s] | | |

[e]: elasticity; [s]: social rate of return (direct + indirect rates of return);
n.s.: insignificant

Sources:
Griliches (1990), Mairesse and Mohnen (1990), Mohnen (1990), and Lichtenberg and Siegel (1991).

### III.A. Technology Flow Approach

Griliches (1979) identifies two types of spillover effects. One is knowledge spillovers, which refer to the effect of research performed in one industry in improving technology in a second industry. The other is that inputs purchased by one industry from another industry embody quality improvements that are not fully appropriated by the selling industry. While in principle these two notions are quite distinct, in practice it is very hard to distinguish between them either analytically or statistically, and we shall refer to the two effects jointly as spillovers.

A number of studies have used either I-O coefficients or technology flow matrices based on patent data to measure spillovers among industries. The rates of return on borrowed R&D and the social rates of return estimated in a number of studies using firm and industry data are shown in tables 2a and 2b. Terleckyj (1974, 1980) was one of the first researchers to estimate the stock of borrowed R&D of an industry using its purchases of materials and capital from other industries given by the I-O tables. Regressing total factor productivity of the industry on its own R&D and borrowed R&D (both expressed as ratios of industry output) he reported a 45% rate of return for borrowed R&D and about 28% for own R&D in the manufacturing sector. When R&D was decomposed into private and public R&D, the return to borrowed R&D was even higher while the returns on government financed R&D were weak and insignificant (Nadiri (1980b)). Other studies such as Postner and Wesa (1983) confirmed similar patterns, i.e., the rate of return on borrowed R&D was more than twice that of own R&D (see Mohnen (1990b) for details). Griliches and Lichtenberg (1984b) argued that TFP growth is affected by borrowed R&D because the deflator for materials is mismeasured.[9] Regression of TFP growth on own product and

[9]It is arguable, however, that if the deflator for the purchased inputs were correctly measured there would still be a possibility of technology spillover. The seller of technology cannot anticipate all its potential uses by the purchaser to capture all the benefits. The circumstances facing the purchasers are different and largely unknown and also the potential of learning by the purchasing firm from the adaptation of a new technology is likely to be fairly high and not known to the sellers of technology.

borrowed R&D intensities and own process R&D grouped together suggest a rate of return of 75% in the 1960s and 50% in the 1970s, indicating a decline in potency of outside R&D on productivity growth. Scherer (1982, 1984) constructed a technology matrix based on patent data distinguishing between industries of origin and user of innovation using the Federal Trade Commission Line of Business Survey data for 1974. He distinguished between process R&D geared toward improving efficiency in production and product R&D aimed at improving output quality which can be considered as a spillover effect from the point of view of the purchasing industry. The "user" R&D, defined as the sum of own process R&D and embodied R&D borrowed from outside, indicated a 70% to 100% rate of return while the rate of return on own product R&D was relatively small.

Wolff and Nadiri (1987) used an I-O framework to analyze the relation between R&D, technological spillovers and I-O linkage structure. They considered three potential avenues for transmission of R&D spillovers. First, R&D performed in an industry may affect the technology of both customers (i.e., forward linkages) and suppliers (i.e., backward linkages).[10] Second, technological changes in one sector may affect the production structure of both its customers and suppliers.[11] Third, R&D engaged in by a sector and its degree of technical change may affect its linkage structure with other sectors in the economy.[12]

They found no significant forward or backward spillover effects from R&D embodied in intermediate inputs but did find significant forward spillovers from R&D embodied in capital stock. There were significant forward spillover effects emanating directly from a sector's technological progress. Also, both sectoral R&D intensity and

[10]For example, the computer industry earmarks R&D expenditures to develop new software designed specifically for customers, such as the banking sector. The airline industry has often worked closely with its supplying sectors to develop new aircraft.

[11]The improvement of motor vehicles in the automobile sector has radically altered the input structure in sectors like farming (tractors and other farm machinery), construction (cement mixers, dump trucks, and the like), transportation (trucks), and health (ambulances). Moreover, the development of the automobile sector brought forth tremendous changes in supplying in industries, such as steel, glass, machine tools, radios, and electrical equipment.

[12]The automobile and computer industries are good examples of sectors whose product development has fostered tremendous growth in both forward and backward linkages over time.

technological progress were found to affect positively its degree of forward and backward linkage with other sectors. Finally, the direct return to private R&D was substantially greater than that to total R&D, which also includes government R&D, and that private R&D embodied in capital stock has a stronger spillover effect on sectoral TFP growth than the total R&D embodied in capital stock.

For the German economy, Oppenlander and Scholz (1981) calculated that only about a third of new products are derived from new technology (i.e., process innovation). The remainder are "market innovations," which are used to open up new markets for the products. Pavitt (1984) has estimated that out of 2,000 innovations introduced in the United Kingdom, only about 40% were developed in the sector using the innovation. The remaining innovations were borrowed from new technologies developed in other sectors.

The work of Nelson and Winters (1982) illustrates another approach. In their "evolutionary model," spillovers in technology among firms may occur as firms search or sample from their environment to develop new production techniques. Finally, Rosenberg (1982) and Rosenberg and Frischtak (1984) suggest the existence of clusters of innovations in industries that occupy a strategic position in the economy in terms of both forward and backward linkages. They speculate that there are certain intraindustry flows of new equipment and materials that have generated a vastly disproportionate level of technological change and productivity growth in the economy.

Mohnen and Lepine (1988) use the Canadian technology flow matrix for Canada to estimate the cost function for twelve Canadian manufacturing industries for the period 1975-83. They report that borrowed R&D is cost-reducing and estimate a social rate of return of 84% for R&D. The rates of return vary, however, across industries. A similar approach is followed by Englander et al. (1988) to analyze potential spillover effects using data on sixteen industries in six large OECD countries. They find that TFP growth is affected significantly by "used" R&D in the manufacturing sector and particularly in the R&D intensive industries within this sector. They also report some evidence of a loss of potency of R&D on productivity growth after 1973.

Finally, in a number of studies, Jaffe (1986, 1989) has used patent classification to position a firm in a technological space. He clusters firms in similar patent spaces using two cross-sections of 432 U.S. firms in 1973 and 1979 and examines the effects of technological opportunity and R&D spillover on patents, profits, and market value. His results indicate an elasticity of about one for patents, a positive relationship between a firm's own R&D and the size of the R&D pool in its technological space; a firm's productivity growth varies positively with its own R&D as well as the R&D of its neighboring firms in the technological space. There is evidence of spillover effects based on geographic proximity. Jaffe's (1989) results suggest positive and strong spillover effects from university research on industry data (but not vice versa). The implied elasticity of corporate patents induced by university research is about 0.6.

There are many drawbacks in the specific procedures followed in these studies. The patent data used in the design of the technology matrix flow is a major problem because of the variability of patent values noted earlier. The restrictive nature of the I-O matrices is an issue of concern. Also, since most studies of this type examine the interindustry relationship at a given point in time the temporal aspect of the R&D spillovers is not captured. Nonetheless, the overall conclusion that can be drawn from the "technology flow" approach is that there are substantial spillover effects among different industries. The effects vary across industries and firms; the spillover effects are particularly strong in industries which are active in R&D. The spillover effects come from a variety of sources and the exact mechanism of the flow of these effects is often complex. Also, not only does borrowed technology have an impact on the productivity of the firm or industry, it may also modify the I-O linkages among industries.

## III.B. The "Cost Function" Approach

In many industries firms undertake R&D investment in order to develop new products or new processes. As we noted earlier, a feature of R&D investment that distinguishes it from other forms of investment is that firms which do the investing are often not able to exclude others from easily obtaining the benefits of the R&D projects. The benefits from R&D investment spill over to other firms in the economy, although the recipient firms have not paid for the use of the knowledge generated by the R&D activity.

Recent theoretical papers (see Reinganum (1981) and Spence (1984)) have analyzed the implications of R&D spillovers in terms of a dynamic model of industry conduct and performance. In particular, Spence assumes that through spillovers a firm's R&D investment reduces production costs of rival firms. Thus the industry-wide cost-reduction effect of R&D investment is enhanced. Simultaneously, however, because spillovers generate free-rider problems, a firm's incentive to undertake R&D activity is diminished.

The trade-off between the cost-reducing (or productivity) effect and the incentive effect of R&D investment may be exaggerated. Rosenberg (1974) and Nelson (1982) have argued that in order for firms to be able to use the freely available knowledge they may have to invest in R&D. In other words, firms must have their own laboratories and staffs of scientists and engineers in order to incorporate the knowledge obtained through spillovers into their own production process. This has been shown by Cohen and Levinthal (1986) to imply that spillovers also provide an incentive for a firm to undertake its own R&D investment and can lead to an increase in industry R&D capital.

The basic econometric framework for this line of research is to formulate a cost function (and sometimes an inverse output demand function as well) which depends on output, relative factor prices for the variable inputs and quasi-fixed inputs such as stock of own physical capital and R&D capital but also the stock of R&D of other firms or industries. In principle, the latter variable captures the spillover or degree of externality of the research input of other firms or industries. Using a flexible cost function, the spillover variables are allowed to interact with other variables and thus permit the estimation of the effect of spillover not only on the cost of production through the productivity effect, but also on the structure of production through the incentive or R&D bias effect. Also, R&D spillovers create a dichotomy between the private and social rates of return to R&D investment. The difference between the social and private rates of return arise because of intraindustry, interindustry, and possibly international spillovers. An important aim in these studies is to estimate the private and social rates of return. Another result of this approach is to identify the sources of the spillovers and thereby, in principle, create a matrix of recipients and sources of spillovers.

We shall present here the results of three studies as illustrative examples. One illustrates the effect of intra- and interindustry R&D spillovers in the Canadian economy. The second examines the effect of R&D spillovers on price and cost in a number of the U.S. industries. The third study explores the potential spillover effect of public R&D on industry cost and factor demands. Bernstein (1988) estimated intra- and interindustry spillovers among the Canadian industries. His results indicate that interindustry spillovers exert greater downward pressure on average costs of production relative to intraindustry spillovers. The decrease in unit costs in response to an increase in the intraindustry spillover is greatest in industries with relatively larger R&D cost shares, such as aircraft and parts, electrical products, and chemical products. An increase in R&D or knowledge spillovers generates greater benefits on rival firms in industries with relatively larger propensities to spend on R&D.

There is evidence that interindustry spillover acts as a substitute for the R&D capital input of the firm itself. Thus, not only does the interindustry spillover decrease unit production costs, but it also creates an incentive for free riding by firms on the efforts of other industries by substitution for their own R&D capital demand. The intraindustry spillover effect on the demand for R&D capital is smaller in absolute value than the interindustry elasticity. Those firms operating in industries with relatively smaller propensities to spend on R&D tend to substitute the intraindustry spillover for their own demand for R&D capital. However, in industries with relatively larger R&D propensities there is a complementary relationship between their own demand for R&D capital and the intraindustry spillover.

The demands for labor, materials, and physical capital also respond to R&D

investment spillovers. In most industries, the demand for labor decreases as a result of an increase in interindustry spillovers. The same is generally true for materials. The effect on the demand for physical capital depends on the relative propensity to spend on R&D capital. In industries with relatively larger propensities there is a complementary relationship between the demand for physical capital and interindustry spillover; for the other industries the interindustry spillover is a substitute for physical capital. Intraindustry spillover effect on labor, materials, and physical capital are generally not as strong as those obtained for interindustry spillovers. Moreover, the demand for materials in industries with a relatively larger R&D propensity decreases as a result of an increase in the intraindustry spillover.

The magnitudes of the social rates of return on R&D capital (net of depreciation) in industries which have relatively larger R&D spending propensities are about 25% to 115% greater than the net private rate of return (which is approximately 11.5%). The net social rates of return in the remaining industries are on the average around 20% or 72% greater than the net private rates. The marginal interindustry spillovers are quite similar across industries, which implies that the extent to which the social rates of return differ across industries depends on the magnitude of the spillover that occurs between rival firms within an industry.

Bernstein and Nadiri (1991) have estimated a structural model of cost and demand using data for several two-digit high technology industries in the U.S.. In this study a vector of spillovers representing the R&D stocks of different industries is introduced explicitly in the cost function. The major findings of this study are that: (1) R&D spillovers decrease variable costs in all industries——the cost elasticities for the six industries examined range from -0.07 to -0.24;

(2) spillovers increase output in each industry and thereby lead product price to fall; (3) once output expands, then variable production cost increases and the output growth outweighs the initial cost reduction due to spillovers; (4) in each industry demand for labor and materials inputs increase as a result of R&D spillovers; (5) the spillover network showed that some industries are the source of R&D spillover to several industries while others are the spillover source to very few industries;

(6) the private rates of return to capital and R&D capital are similar but the social rate of

return was significantly greater than the private returns to R&D capital. Similar results are reported by Bernstein and Nadiri (1988, 1989b) for the U.S. two-digit industries as well as by Goto and Suzuki (1989) for the Japanese industries where the supplying industries' R&D contributed positively to the productivity of the purchasing industries.

R&D spillovers may also come from the R&D outside the industrial structure. We have already noted the effect of basic research in universities on industry R&D and patents (Jaffe (1988)). A recent study (Nadiri and Mamuneas (1991)) shows that the stock of government-financed R&D as well as public infrastructure capital may affect the cost and factor demand in the twelve high R&D intensive two-digit U.S. manufacturing industries while the magnitudes of the spillover effects differs among industries. Both types of public sector investments reduce average cost in all industries and their effect on factor demand functions is nonneutral. Publicly financed R&D increases demand for labor and capital but decreases demand for materials. The social rates of return for infrastructure investment and public R&D investment are about 7% and 10% respectively. There is also evidence that deceleration in publicly financed R&D contributed to the slowdown of labor productivity in these industries in the early 1970s.

Thus, the results of the econometric cost studies suggest that there are substantial intra- and interindustry spillovers. A network of technology flow exists among the industries where some industries are multiple sources of spillovers to other industries and others are not. Also, the spillovers from other industries affected not only the productivity growth in the recipient industries but also changed the pattern of demand for their inputs such as labor, materials, energy, and capital as well as each industry's own R&D investment. These effects vary considerably among the industries depending on industrial characteristics of the industries, particularly their R&D intensities. There is also evidence of spillovers from aggregate R&D investment financed by the public sector. The spillovers lead to productivity gains and changes in demand for factors of production in a number of industries.

## IV. International Technology Transfer

In the past few years the pace of technology transfers has been increasing rapidly, particularly among the OECD countries. Statistics on international payments for patents, licences and technical know-how among the OECD countries have been growing substantially. The statistics on technology balance payment (TBP) among the OECD countries indicate a rapid increase in technology trade. Both receipts and payments for technology imports have been rising rapidly for most countries, especially for Japan. The U.S. and, to some extent, the U.K., still remain net exporters while France, Germany, and Japan remain net importers of technology in the international technology market.

A more interesting statistic is the total volume of transactions in international technology markets activity obtained by summing the receipts from technological sales and import payments for technology purchases together. The figures on the gross transaction in technology for the five target OECD countries are shown in table 3. They indicate substantial activity by each country. For Japan and the U.K. the total transaction between 1970 to 1988 increased by about 400%, France and the U.S. experienced an increase of about 550% while West Germany had a spectacular increase of over 1000% between 1979 and 1988. The relatively low growth of total transactions for Japan is understandable because the main growth of technology transactions has been in the domestic economy. Another measure of interest is the international diffusion rate calculated by the OECD (1990). This measure is defined as a ratio of the number of external patent applications to the previous year's domestic patent applications. This is a simplistic measure of technological diffusion among countries and suffers from all the shortcomings of patent accounts noted earlier. Nonetheless it can serve as a general indicator of the technology diffusion in international technology transfer for the five OECD countries. As shown in table 4, the diffusion rate has increased for most countries since 1981, particularly for

**TABLE 3**

Technological Balance of Payments: total transactions
(million of $)

| Year | France | Germany | Japan | U.K. | U.S. | Total |
|---|---|---|---|---|---|---|
| 1970 | 455 | 565 | 661 | 787 | 2359 | 4826 |
| 1975 | 865 | 943 | 825 | 1167 | 4481 | 8280 |
| 1980 | 1510 | 1456 | 1609 | 1451 | 7379 | 13405 |
| 1985 | 2419 | 2161 | 2377 | 2681 | 6886 | 16524 |
| 1988 | 2666 | 6017 | 2679 | 3652 | 12912 | 27926 |

Sources: based on OECD (1986), pp. 96-97 and OECD (1990), pp. 48-49, & 60.

## TABLE 4

Rate of Diffusion

| Year | France | Germany | Japan | U.K. | U.S. |
|---|---|---|---|---|---|
| 1981 | 2.83 | 2.70 | 0.30 | 1.58 | 2.04 |
| 1982 | 3.14 | 2.63 | 0.29 | 1.59 | 1.97 |
| 1983 | 3.17 | 2.47 | 0.26 | 1.63 | 2.14 |
| 1984 | 3.24 | 2.83 | 0.28 | 1.78 | 2.49 |
| 1985 | 3.21 | 2.90 | 0.29 | 1.95 | 2.42 |
| 1986 | 3.24 | 3.10 | 0.27 | 2.16 | 2.55 |
| 1987 | 3.67 | 3.45 | 0.31 | 2.43 | 2.71 |
| 1988 | 4.12 | 3.94 | 0.32 | 2.68 | 2.93 |

Sources: based on OECD (1990), pp. 45-57.

France, Germany, and the U.K. Japan's diffusion rate increased markedly only after 1987, reflecting the enormous growth of domestic patenting in Japan. The diffusion rate for the U.S. has been rising but at a very slow pace.

Several features of the international technology trade in patents are of interest. The major sources of technology are the U.S., Japan, the U.K., France, and Germany and, except for the U.S., U.K., and Switzerland, all other OECD countries are net importers. Research-intensive industries such as electronics, communications, aerospace, and pharmaceuticals, which are expanding rapidly internationally, command the major share in technology trade. The main form of technology transfer is usually not licensing but other forms like joint ventures, sales of technology, supply of turn-key plants, etc.

Technology transactions are largely between firms linked by equity holdings (Vickery (1986)). Payments of fees and royalties to the U.S. and several other countries are predominantly from affiliates of their respective parent companies. Technology transfers through the multinational firms——except in recessions——have been increasing rapidly. Foreign direct investment (FDI) is also concentrated in research intensive manufacturing industries.

Multinational firms play an important role in technology trade and direct investment of technology intensive and relatively new industries as well as in traditional industries like the food, drink, tobacco, and rubber industries. It is often the case that R&D activities and transfers of technology follow FDI. Countries with large stocks of FDI have a relatively large share of business R&D performed by foreign affiliate firms. In most OECD countries, about 10% to 20% of R&D performed in the domestic economy are by foreign firms. U.S. multinational firms are the major players in R&D carried out by foreign affiliates, especially in the U.K., Germany, and France. A new and important form of technology transfer that has recently emerged is the international cooperative agreements——often between U.S., European, and Japanese firms——to undertake joint ventures in technology development. These practices are again centered in high research intensive and often science-based industries such as biotechnology, communications, electronics, etc. and are dominated by the multinational firms.

Mansfield (1984) has presented results that show that U.S. multinationals introduce new technologies in foreign markets within the first five years of their commercialization. In some industries like pharmaceuticals, new products are often introduced more quickly in foreign markets than in the U.S. because of regulatory considerations. Also, multinational firms are likely to introduce their product innovations but not the process innovations overseas because of the fear of loss of control over the technology. There is evidence of internationalization of research activity facilitated by collaboration among the laboratories and researchers of the multinational firms located in different countries. Technologies tend to be transferred to the U.S. more quickly in recent years and the speed of their introduction is governed mainly by potential profitability in the U.S. markets.

There are very few econometric studies that assess the effect of foreign technology transfer on the productivity growth of the U.S. firm and industries. Results reported by Mansfield (1984) for fifteen U.S. chemical and petroleum firms for the period 1960-76 suggest a substantial contribution of overseas R&D. In fact the influence of overseas R&D on productivity was several times larger than that of domestic R&D. The exclusion of overseas R&D in explaining productivity growth contributes to an upward bias in estimating the rate of return to domestic R&D.

Another possibility is to look at the potential effects of the R&D expenditures of an industry or economy on its counterpart in another country. Levy and Terleckyj (1985) have reported that the aggregate private R&D expenditures in the U.S., Japan, and seven European countries are interrelated. Both European and Japanese private R&D expenditures seem to have influenced U.S. private R&D outlays. U.S. R&D outlays appear to have influenced R&D outlays in Europe and Japan and there was no evidence of positive cross-effects between the European and Japanese R&D investments. These results raise the possibility of a triangular relationship in investment for new technologies and trading in technology among the three regions of the advanced industrialized world in which the U.S. plays a pivotal role.

Mohnen and Lepine (1988) have analyzed cost structure and productivity growth in twelve technology-intensive Canadian manufacturing sectors using technology import as an input.[13] Their results indicate that import of technology in a given industry does respond to the growth of output and relative input prices in that industry. An industry's demand for imported technology increases with an increase in its own R&D investment. The strength of the effects varies among the industries, depending on the degree of their own R&D industry. They also report that accumulation of technical know-how by other industries lowers the cost of production in a given industry but their import of technology has the inimical effect of raising the cost of the industry. The latter may reflect the loss of relative competitive position if other industries improve their productivity (reduce costs) by importing technology from abroad.

A study by Mohnen (1990c), which uses a cost function approach to analyze productivity growth in the Canadian manufacturing sector for the 1963-83 period, reports a 30% rate of return for foreign R&D and a 20% rate of return for domestic R&D, which is consistent with the results reported by Mansfield. The contribution of foreign R&D explains about 15% of growth of output and about half of TFP growth in the Canadian manufacturing sector. These estimates are somewhat on the high side. According to some preliminary results (Nadiri (1991)) the technological gap influenced the "catching up" process in the manufacturing sectors of Japan, Germany, France, and the U.K. in the postwar period.

What emerges from the evidence is that the volume of technology transfer among the advanced industrialized countries has increased substantially in the past several years. The transfer of technology is taking place much faster than before and the multinational firms are the main propagators of technology diffusion. The method of the technology transfer and the dynamics of the interplay between the domestic and overseas technology vary across industries and among different countries. However, in most cases, it is the R&D intensive multinational corporations that are the main actors in the technology transfer market. Finally, the fragmentary econometric results that are available suggest a major effect of foreign R&D on domestic industries' total factor productivity, the rate of return on borrowed

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[13]They incorporate payment for imported technology as a variable factor of production and estimate the spillover effect of technology imports by other sectors on a given sector's costs.

technology from abraod often exceeding that of the domestic R&D. The mushrooming of cross-border trade in technology and the dynamic role played by multinational enterprises (MNEs) and the research-intensive industries in technology trade and FDI are likely to be increasing sources of new spillovers. The distribution of these benefits will differ across firms, industries, and countries and will have differential effects on the welfare and competitive position of the industries and countries in years to come.

## V. Summary and Conclusions

In this paper we have analyzed the evidence from a large number of studies on three specific questions pertaining to R&D investment: (1) Are there diminishing returns to inventive activities? (2) What is the relationship between R&D and productivity and what are the magnitudes of the returns to a firm's or industry's R&D investment? (3) What are the magnitudes of the benefits from R&D undertaken by other firms, industries and countries and the vehicles by which they are transmitted to the recipients? The evidence on the first issue is still controversial, basically because of the lack of an adequate measure of output and precise measurement of the inputs to the inventive process. Patent counts are often considered as a measure of output while expenditures on R&D are used as a measure of input in this process. Both these measures have serious drawbacks. Taking into account all the measurement and interpretation difficulties noted in this paper, there seems to be no credible evidence for or against the existence of any sizable degree of diminishing returns to inventive activity. However, if the high rates of return to own R&D and the significant spillover effects of R&D documented in this paper are taken into account, diminishing returns to inventive activities become less plausible.

On the second question, the results clearly suggest a positive and strong relationship between R&D expenditure and growth of output or total factor productivity. The relation is pervasive, though the magnitudes of the contribution of R&D vary among firms, industries, and countries. The rates of return to R&D vary considerably from one study to another. On the average, net rates of return on own R&D of 20% to 30% at the firm level and 10% to 30% at the industry level are reasonable sets of estimates suggested by the studies surveyed here. There was no clear cut evidence of decline in the potency of R&D investment in the late 1970s. A substantial number of studies have provided evidence that R&D as a factor of production affects not only productivity growth but also the demand for other inputs such as labor, materials, and physical capital. R&D investment is in turn affected by changes in conventional inputs and the utilization rate. The results also show that the deceleration of growth of demand in the U.S. during the 1970s has had a major impact on the slowdown of total factor productivity and the demand for R&D investment.

As to the question of the existence and magnitudes of R&D spillovers, the evidence points to sizable spillover effects both at the firm and industry levels. These effects are also present and likely to grow rapidly among firms in different countries. The spillover effects of R&D are often much larger than the effects of own R&D at the industry level. The indirect and social rates of return often vary from 20% to over 100% with an average somewhere close to 50%. The channels of diffusion of the spillovers vary considerably. They may take the form of intra- and interindustry relationships, interdependence between public and private sector investment, supplier and purchaser connections, and geographical location, as well as between domestic firms and firms in other countries through international technology market trade and multinational enterprises. The impact of the spillovers seems to be strong, not only on productivity growth, but also on the structure of the production process. They induce changes in the demand for other inputs as well as the scale of operation in the industry. Besides affecting the cost and structure and production, spillovers also affect the demand for output and, thus, the rate of profitability.

We have also documented a substantial rise in international technology trade among the OECD countries with a noticeable increase in the relative positions of Japan and Germany and a relative decline for the U.S. We have also noted that among OECD countries the diffusion of new technology is very rapid and is transmitted not only through exports but also through FDI and MNEs research operations. MNEs are the most dynamic agents of technology transfer. The major challenge is how the technology transfers that occur via MNEs can be capitalized upon to enhance the performance of domestic industries, and particularly small firms which are not participating in international trade.

However, two basic questions that arise are (1) if the rates of return to R&D are so high why is investment in R&D not higher than it has been, and (2) what portion of TFP is explained by the available estimates of R&D spillovers. The answer to the first question may lie in the fact that the results of R&D projects are highly uncertain and the degree of risk is very high for the private sector. Also, uncertainty about ability to appropriate a large amount of the benefits of the innovations is of considerable importance to firms engaged in innovative activities. Adjustment costs are usually much larger for R&D investment than for physical capital, thus requiring a higher rate of return. Also, the rate of depreciation of the stock of R&D may be much higher because of economic obsolescence than the conventionally assumed rates of 0.10 to 0.15. Nonetheless, based on the present evidence, when the spillover effects of R&D is added to the rate of return on own R&D, there is a clear possibility that there may be underinvestment in R&D.

If the estimates of the spillovers presented in this paper are approximately accurate, a significant part, perhaps more than half, of TFP growth can be explained by R&D spillover effects. These estimates are probably somewhat biased upward by measurement errors and estimation techniques. Even in the face of all such potential problems, a case can still be made that R&D spillovers are important and pervasive and are likely to increase further with the globalization of technology. The productivity slowdown in the late 1970s in the U.S. and the accompanying declines in R&D and patent applications were partly due to the deceleration of demand. This was probably the case in other OECD countries as well. Therefore, maintenance of aggregate demand is crucial for increasing productivity growth and investment in R&D, which in turn leads to further increases in R&D spillovers.

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