OXFORD REVIEW OF ECONOMIC POLICY, VOL. 18, NO. 1

THE ASSESSMENT: TECHNOLOGY POLICY

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Current research and problems in science and technology policy are reviewed. Trends in innovative activity in the G-7 economies during the past two decades are summarized and the economic rationale for policy in this area given. Policy tools currently in use in many countries include tax credits and subsidies, the intellectual property system, and competition policy. Ongoing areas of current controversy are the interaction of intellectual property and competition policies, environmental and innovation policy, standard-setting in industries characterized by network externalities, and the privatization of scientific research and its consequences.

I. INTRODUCTION

This issue of the *Oxford Review of Economic Policy* contains a set of articles on various aspects of economic policy toward innovation and technical change. During the past decade and a half, since the publication of a similar issue of the *Review*, the arguments in favour of such economic policies and for study of their design and effectiveness have only increased. In addition, it has become apparent that policies in related areas, such as antitrust and the environment, have considerable impact on innovation and the performance of innovation policy.

Much of the expansion and strengthening of interest in technology policy in the broad sense results from the diffusion of two major innovations around the world: products based on semiconductor (microprocessor) chips, such as personal computers and mobile telephones, and the Internet, which links together such products. Both of these innovations have the property that they rely heavily on standards and network externalities, and thus raise problems of 'natural monopoly' or near-monopoly. The problems raised by the nature of competition in such dynamic industries have been hotly debated by economists and others, most notably with respect to the various disputes in the USA and Europe involving the Microsoft Corporation, but also with respect to lesser-known disputes over the extension of market power via proprietary standards.[1]

A second cause of increased interest in policy-making in this area comes from the biotechnology revolution, which has brought into focus a series of issues: (i) the desirability or lack of desirability of patenting pure information or scientific discoveries when such discoveries lead directly to marketable products (such as genetic diagnostic tests); (ii) the problem of providing incentives for the development of research tools if all of their possible uses fall under a 'fair use' exemption, thereby making their invention unprofitable; (iii) the tensions induced when the world of scientific research, where rewards are determined by priority and information circulates freely, comes into contact with the world of private sector R&D, where strong intellectual property rights lead to secrecy and the restriction of information.

Thus, over the past couple of decades, our concerns have evolved away from a simple focus on how to induce spending on science, basic research, and other innovative activity. At this point, most developed countries have a menu of science and technology policies in place, and many of these policies are non-controversial. An issue that has grown in importance is the subject of at least two of the papers in this *Review* (those by David Encaoua and Abraham Hollander, and Neil Gandal): the interaction of competition policy and intellectual property systems in a world where markets and industries are characterized by a demand for standards and the existence of network externalities.

In this assessment, I first set the stage by describing the recent trends in innovative inputs and outputs in the G-7 economies. Then the rationale for having science and technology policies is outlined briefly. This is followed by a discussion of policy measures and evidence on their effectiveness. I conclude with a brief discussion of the unsolved and difficult problems in this area.

II. GROWTH OF INNOVATIVE ACTIVITY IN OECD ECONOMIES

Because of the increased interest of policy-makers in science and technology policy, national and international statistical agencies have undertaken a variety of initiatives to develop new and improved innovation indicators.[2] Such indicators include various R&D measures, patent counts, scientific publication counts, information and communication technology (ICT) expenditures, counts of technology alliances, disbursements of venture capital funds, and measures of education. It remains true that the single most important measure of a country's level of innovative performance is probably R&D spending, followed by patents granted to inventors resident in the country. I briefly consider the evidence for increased technological innovation during the past two decades that is contained in these two indicators.

Table 1 shows the changes in the 'R&D intensity' of eight major economies (the G-7 countries plus Sweden) during the past several decades. There is little evidence in this table of an increase in the intensity of innovative activity in these countries, except in Sweden and Japan. However, this masks a rather substantial change in the allocation of R&D effort in several of these countries. Table 2 shows the ratio of non-defence R&D to GDP for the same economies. Only the ratio for Germany has fallen significantly, and this is undoubtedly because the 1999 figure includes all of Germany rather than simply the western portion. Italy and the UK have maintained roughly the same level, while all of the other countries have increased their share of non-defence R&D, some substantially.

Turning to the patent indicators, Table 3 displays the well-known fact that patenting rates have increased substantially during the same period, by consider-

[1] See Evans *et al*. (2000) for a review of the two sides of the Microsoft case, and Shapiro (2000) for a discussion of intellectual property strategy in industries where standards are important.

[2] For example, see OECD (1999) and European Commission (1994).

Table 1
R&D as a Percentage of GDP, 1963–2000

Country	1963	1985	2000
Canada	n.a.	2.5	1.9
France	n.a.	2.3	2.2
Germany[a]	1.5	2.7	2.5
Italy	n.a.	1.1	1.0[b]
Japan	1.4	2.6	2.9[b]
Sweden	1.2	2.8	3.8[b]
UK	2.2	2.3	1.9[b]
USA	3.1	2.8	2.8

Notes: [a] West Germany in 1963 and 1985; reunified Germany in 2000. [b] Figures for 1999.
Source: OECD (2001, Table 2).

Table 2
Non-defence R&D as a Percentage of GDP

Country	1985	1999
Canada	1.40	1.80
France	1.87	2.01
Germany[a]	2.60	2.38
Italy	1.07	1.03
Japan	2.56	2.91
Sweden	2.55	3.73
UK	1.76	1.67
USA	1.89	2.25

Notes: [a] West Germany in 1985; reunified Germany in 1999.
Source: OECD (2001, Table 2).

Table 3
US Patent Grants

Country	1985	1998	Percentage change, 1985–98
Canada	1,342	2,974	121.6
France	2,400	3,674	53.1
Germany[a]	6,718	9,095	35.4
Italy	919	1,582	72.1
Japan	12,746	30,841	142.0
Sweden	857	1,225	42.9
UK	2,494	3,464	38.9
USA	39,556	80,294	103.0

Note: [a] West Germany in 1985; reunified Germany in 1998.
Source: National Science Foundation (2000, Tables 7–12).

Table 4
Strategic Technology Alliance Formation

	1980–9	1990–8
Intra-USA	908	2,150
Intra-Europe	670	521
Intra-Japan	233	77
USA–Europe	809	1,284
USA–Japan	550	437
USA–others	178	254
Europe–Japan	237	195
Europe–others	188	174
Japan–others	53	40
Information technology	1,396	2,267
Biotechnology	729	1,123
All other technologies	1,701	1,742
Total	3,826	5,132

Source: Hagedoorn (2000).

ably more than real R&D. The number of US patent grants for these eight economies doubled during the period, whereas real R&D rose by only 40 per cent. Kortum and Lerner (1998) discuss the reasons for this increase, reaching the conclusion that improvements in management of the R&D process are the most likely explanation, at least in the USA. Hall and Ziedonis (2001) qualify this conclusion by suggesting that the improvements are not so much in the management of R&D as in the management of patenting, as it has become an increasingly important strategic tool in the computing hardware and software industries, broadly defined. Important policy questions surround this phenomenon, as patent offices around the world find themselves dealing with ever-increasing numbers of patent applications.

It is often observed that research partnerships of various kinds have assumed increasing importance during the past two decades. Such partnerships include university–industry relationships (discussed in the contribution by Joanna Poyago-Theotoky, John Beath, and Donald Siegel to this issue), partnerships between government and industry, and partnerships between and among private firms. Systematic data on some of these relationships are hard to obtain, but we do have fairly good data on the growth in private strategic technology alliances from the 'Cooperative Agreements and Technology Indicators' (CATI) project at the University of Maastricht. Table 4 displays statistics on the formation of alliances intended to transfer technology or conduct joint research for two 10-year periods.

Two observations can be made on the data presented in Table 4: first, the number of alliances has clearly grown between the 1980s and the 1990s, with the majority of the growth in alliance formation coming from alliances within the USA, or between the USA and European or other countries. Second, about two-thirds of these alliances are in two relatively new technology areas—information technology and biotechnology—and this fraction has grown over time. As has frequently been argued, this kind of alliance is one way to deal with the complexity of new technology (Hagedoorn *et al*., 2000).

III. WHY HAVE SCIENCE AND TECHNOLOGY POLICY?

In their excellent assessment written for this journal in 1988, Stoneman and Vickers survey the various arguments in favour of policy in this area and I summarize them only briefly here. The primary reason is the mass of evidence, both theoretical and empirical, that firms and individuals left to their own devices will generally face insufficient incentives to invest in innovation from the point of view of society as a whole (Nelson, 1959; Arrow, 1962; Griliches, 1992). The source of the problem lies in the fact that once known, ideas and inventions can be reused at a lower cost than that incurred to discover them, leading to two separate but related problems: (i) the original inventor is unable fully to appropriate the returns to his or her invention; and (ii) the production of the invention is a fixed cost with respect to the final output, so that the production of any particular innovative product will have natural-monopoly characteristics. As Nelson (1959) argued, basic scientific research is likely to be particularly subject to the under-provision problem, owing to the broad and uncertain nature of its beneficiaries.

In addition to the basic argument for policy in this area, a variety of somewhat secondary considerations adds to the case. First, there is a set of reasons to believe that financing investments in innovation is subject to market failure owing to a combination of asymmetric information and moral hazard under uncertainty (see my other paper in this issue for a survey of this evidence and the policy solutions). Similar arguments may also apply to investments in human capital and can be used to make the case for subsidies to various forms of education and training.

Some have argued that certain industries are 'strategic', in the sense that they are either important for national security, or for advances in many other industries. This might imply targeting of research subsidies towards such industries. Finally, it is fairly clear that technological standards (even those as simple as weights and measures) are a public good, and will therefore often be subject to government policy. This fact has the obvious implication that investment in standards will face the same trade-offs as other innovation investments: either insufficient incentives or monopoly provision. Either outcome has welfare consequences.

IV. WHAT POLICIES ARE APPROPRIATE?

The conventional menu of economic policy responses to the presence of market failure is the following: (i) internalize the externality; (ii) tax or subsidize the activity; or (iii) regulate the activity. In this arena, the last option is rarely used, perhaps because of the difficulty of regulating an activity that is still highly unpredictable and spread across a very large number of actors. It is difficult to argue that quotas (mandating technological performance) or price controls (on the wages of scientists and engineers) would be an effective way to deliver more innovation cheaply, although very occasionally the former is used, especially in the environmental area (e.g. experiments in the USA with mandated fuel economy standards or electric automobile sales). The only area where the regulatory approach is used in an affirmative way to encourage innovation is in the determination of technological standards. Of course, regulation of other kinds, especially antitrust or competition policy, but also environmental regulation, has a substantial impact on innovation, as discussed in this issue by Encaoua and Hollander. But, as Michael Grubb and David Ulph argue in this issue, it is not sufficient to rely on environmental objectives alone to promote the introduction of cleaner technologies. The achievement of environmental as well as innovation goals requires a carefully crafted combination of environmental and technology policies.

In the case of innovation, the externalities that result from market failure are usually positive and involve the spill-over of information and ideas from the entity that paid for them to other entities. Internalizing the externality implies designing a mechanism whereby the inventor receives the full social surplus from his or her invention in order to induce him or her to make it. This can be done either by allowing firms to form joint research ventures without the threat of antitrust enforcement (the USA, Europe, and Japan all have explicit policies to encourage such alliances), or by granting an individual or firm a limited right to exclude others from using its ideas, that is, by granting it intellectual property protection in the form of a patent on its invention. The latter method of encouraging innovation has had a long and somewhat uneven history, but is now accepted (with some reservations) throughout the world via the trade-related intellectual property (TRIPS) agreement signed as part of the Uruguay round of the General Agreement on Tariffs and Trade (GATT) negotiations in 1993.

Besides the well-known social cost of the system owing to the creation of temporary monopolies, recently researchers have identified a further problem that may be created by the existence of patents in technology fields where a single product can 'read on' hundreds of patents, or where technology is very cumulative (Scotchmer, 1991; Shapiro, 2000). In such areas, the fact that each patent-holder has the right to exclude another may lead to a failure to reach a mutually beneficial agreement to share their technologies if transactions costs are high enough. In fact, evidence for such a breakdown is somewhat limited, although desire to avoid breakdown does appear to lead to 'patent portfolio wars'. However, as Alfonso Gambardella argues in this issue, one advantage of creating a property right on information is that it facilitates trade in intellectual property, which can have the socially beneficial effect of spreading the cost of development of a general-purpose technology over many industries.

The policy of encouraging private R&D spending via tax credits and/or subsidizing R&D projects is widely used. This type of policy does not suffer from the problem of creating temporary monopolies (unless it is coupled, as it so often is, with the existence of a patent system), but does require taxation at some level to sustain it, which may have its own welfare costs. Although similar in their goals and effects, the two policies have rather different information requirements: typically an R&D tax credit is allowed without regard to the type of R&D being undertaken (other than requiring that it meet a conventional definition of expenditure on research). On the other hand, subsidies for R&D are frequently targeted towards special projects or areas of one sort or another. Thus the latter form of funding requires more information on the potential social and private benefits of the proposed expenditure, which may yield a better outcome than simply relying on firms to pick projects. The firms will rank projects by their private returns, whereas a benevolent government will rank them by the gap between private and social return, providing that it is fully informed.

One variation of the subsidy idea that deserves mention is the idea of awarding prizes for particularly desirable innovations, such as a cure for malaria. This idea has recently been revived by several researchers (Kremer, 1989; Shavell and van Ypersele, 2001). It has the advantage of inducing entry into particular areas of research, but requires considerable information on the part of the policy-maker or government to get both the choice of projects and the level of the prize set at the right level (Gallini and Scotchmer, 2001).

V. HOW WELL DO THESE POLICIES WORK?

Considerable effort has been devoted to the evaluation of science and technology policy by many governmental agencies, both national and international. Some of these efforts have resulted in more conclusive evidence than others. Beginning with the most straightforward, it does seem clear that the level of industrial R&D is influenced positively by the existence of R&D tax credits (Hall and van Reenen, 2000). Whether the tax credits reduce the gap between the social and private return to R&D is less clear.

The productivity of direct government R&D subsidy is more controversial, with large but very diffuse benefits seen in the hard-to-measure area of basic scientific research, and considerably more mixed evidence on the social benefits of funding research nearer to commercialization (David *et al.*, 2000; Klette *et al.*, 2000). For a survey of earlier evidence on this topic, see Hall (1996), and for a proposal to improve the evaluation of government R&D programmes, see Adam Jaffe in this issue.

A limited number of experiments with the use of prizes to encourage innovation exists in the historical record, such as the well-known prize for the nautical clock and the prize awarded in 1828 to Jean-Baptiste Guimet by the Société d'Encouragement pour l'Industrie Nationale for the invention of synthetic ultramarine blue dye (Ball, 2001). I am not aware of any systematic analysis of the success and cost of this type of programme, which seems to have fallen out of favour until recently.

For evidence on the impact of increased strategic alliance formation on innovative activities, see the articles by Hagedoorn *et al.* (2000) and Poyago-Theotoky *et al.* in this issue.

(i) The Patent System and Innovation

The question of whether the patent system has the desired effect on innovation has proved exceedingly difficult to answer, owing to the lack of real experiments. Most researchers who investigate this topic have looked at historical eras when there were changes to the system and examined the consequences for subsequent innovative activity. Recently, there have emerged a couple of studies that use mainly nineteenth-century data, because there was substantial variation across countries in patent systems during that era. Moser (2001) finds that inventors in countries without a patent system do not innovate more than inventors in countries with patent systems. However, inventors in countries without patent systems do tend to innovate in areas that are more easily protected with trade secrecy. Lerner (2002) finds that when a country strengthens its patent system, inventors from other countries patent more in that country. However, inventors in that country do not seem to invent more—they neither patent more in their own country, nor in Great Britain (an important market and one with a well-functioning patent system).

Results using data from the twentieth century are harder to find, but we do have some survey evidence. The Yale and Carnegie–Mellon surveys have demonstrated fairly clearly that patents are *not* among the important means to appropriate returns to innovation in the USA, except perhaps in pharmaceuticals (Levin *et al*., 1987; Cohen *et al*., 2000). More important means of appropriation are usually superior sales and service, lead-time, and secrecy. Patents are usually rated by managers as important for blocking and defensive purposes. Similar results have been obtained by other researchers for other countries. For example, Baldwin *et al.* (2000) used firm-level survey evidence from Canada and found that the relationship between innovation and patent use is much stronger going from innovation to patent use than from patent use to innovation. Firms that innovate take out patents; but firms and industries that make more intensive use of patents do not tend to produce more innovations.

The most positive results are those from Park and Ginarte. In a 1997 paper using aggregate data across 60 countries for the 1960–90 period, they find that the strength of the intellectual-property system (an index based on coverage, especially whether pharmaceuticals are covered; membership in international agreements; lack of compulsory licensing and working requirements; strength of enforcement; and duration) is positively associated with R&D investment in the 30 countries with the highest median incomes (that is, G-7 and others). In the other countries, the relationship is positive but not significant.

Sakakibara and Branstetter (2001) studied the effects of expanding patent scope in Japan in 1988 (allowing multiple claims per patent as in the USA had the effect of increasing scope, according to the managers they interviewed). This change to the patent system had a very small effect on R&D activity in Japanese firms. Hall and Ziedonis (2001) looked at a single industry (semiconductors) that doubled its patenting-R&D rate after the creation of the Court of Appeals for the Federal Circuit and other changes to patent legislation in 1982. Interview evidence suggested that the increase was due to the fact that inventions in this industry use technology that is covered by hundreds of patents held by a number of firms, and that firms increasingly feared litigation and preliminary injunctions if they failed to have cross-licensing agreements in place. Negotiating such agreements was greatly facilitated by having a large patent portfolio; so several firms, large and small, were engaged in defensive drives to increase their patenting rate. This had little to do with encouraging innovation, and in fact looked like a tax on innovative activity.

The conclusion from this brief survey of the relationship between the patent system and innovative activity is that introducing or strengthening a patent system (lengthening the term, broadening subject matter coverage, increasing patent scope) unambiguously results in an increase in patenting and in the strategic uses of patents. However, it is much less clear that these changes result in an increase in innovative activity, although they may redirect such activity toward things that are patentable and/or are not subject to being kept secret within the firm. If there is an increase in innovation owing to patents, it is likely to be centred in the pharmaceutical and biotechnology areas, and possibly speciality chemicals. Finally, the existence and strength of the patent system *does* affect the organization of industry, by allowing trade in knowledge, which facilitates the vertical disintegration of knowledge-based industries and the entry of new specialized firms.

VI. CONCLUSIONS

Current problems in science and technology policy centre on these areas: the design and administration of the intellectual property system; whether the encouragement of the privatization of university research via patenting and entrepreneurship is a good thing in general; the problem of standard setting when elements of the standard are owned by individual firms; and the interaction between the patent system and competition policy in innovative industries and industries characterized by network externalities.

Several of these topics are addressed directly by the papers in this issue and it is probably safe to say that no firm conclusions have been reached. All of these policy problems involve trading off the private property rights that create incentives *ex ante* versus the welfare cost of restricting an output which could be provided *ex post* at a relatively low cost, which means that a single solution that will apply at all times and in all cases cannot be given. Nevertheless, it is our hope that the papers here help to illumine the decision-making process, which necessarily rests on the particular features of a specific case.

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