

Technology and the Wealth of Nations

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What Is “Commercial” and What Is “Public” About Technology, and What Should Be?

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The papers in this volume are concerned with: effective commercialization as a lure and reward for innovative effort, what leads to effective commercialization, and the implications of all this for technical advance and economic growth. This paper attempts to set commercialization of technology into a broader context that recognizes that technology has public aspects as well as private.¹

It is organized as follows. Section 1 lays out the private and public aspects of technology in modern capitalist economies, and their connections. In Section 2, I consider the means companies use to commercialize the technology they create, and the ways that initially proprietary technology goes public. Section 3 is concerned with the expressly public aspects of the capitalistic innovation system, particularly with the roles of universities. Section 4 addresses the question: what should be private and what should be public about technology?

1 The Private and the Public Aspects of Technologies in Capitalist Economies

Virtually all contemporary accounts of how technical change proceeds in capitalist economies are based on Joseph Schumpeter's in his *Capitalism, Socialism, and Democracy*. For-profit firms, in rivalrous competition,

¹Some of the material presented in this paper was published earlier in Dosi et al. 1988.

are the featured actors. The context within which they operate is set, on the one hand, by the laws and ethos of capitalism that enable firms to keep proprietary, at least for a while, the new technology they create, and on the other hand by public scientific and technological knowledge. The latter lends problem solving power to industrial R&D. The former enable firms to profit when their R&D creates something the market values. Indeed, given that its rivals are induced by this context to invest in R&D, a firm may have little choice but to do so also. The result is significant competition in innovation, generating a bountiful flow of new products and processes.

This volume is focused on the proprietary or commercial aspects of technology. If prospects for commercialization are inadequate, investments in industrial R&D will not be forthcoming. But technology has a public aspect as well as a private one.

Schumpeter recognized this clearly. While in his model of technical advance the lure and reward for private innovative efforts reside in a temporary monopoly over the new product or process, he stressed that in the general run of things that monopoly is temporary. Sooner or later the company's proprietary technology will be imitated or invented around. He did not see this as a problem, but rather as a principal mechanism through which the benefits of successful innovation are spread widely, and as a factor preventing firms from being able to rest on their laurels.

Schumpeter saw less well the consciously public parts of the capitalist innovation system, parts which were important even in his day, and which have become even more so since then. There were and are technical societies, industry associations, and other mechanisms through which new technical information is shared, and which can be used to pursue it cooperatively. Universities play a major role as repositories of public scientific and technological information, and as a prime locus of work aimed to enhance public knowledge. Public monies, as well as private, serve to fund the system.

Both the private and public, the commercial and collective, aspects of technology play an essential role in its advance. Together they set up technical advance as a cultural evolutionary process.

Again Schumpeter saw and stated the matter clearly: "The essential point to grasp is that in dealing with capitalism we are dealing with an evolutionary process." Empirical research on innovation amply supports Schumpeter's point. Technical advance inevitably proceeds through the generation of a variety of new departures in competition with each other and with prevailing practice. The winners and losers are determined in actual contest. Many contemporary modelers ignore this, treating tech-

nical advance as if it proceeded with much more accurate ex-ante calculation and before the contest agreement on winners than is the case. Sidney Winter and I (1982) have argued that such models not merely oversimplify, but fundamentally mis-specify, how technical advance proceeds under capitalism, which is through an evolutionary process in the sense above.

Of course the process through which technical advance proceeds in capitalist economies differs in various respects from evolutionary processes in biology, although on reflection, some of the apparent differences may not be real. Thus technology occasionally makes "big jumps." This is inconsistent with traditional concepts of evolution in biology, but not with more modern notions of punctuated equilibrium. Also, it is clear that innovation is far from a strictly random process; rather, efforts to advance technology are carefully pointed in directions that innovators believe to be feasible and potentially profitable. However, here again the difference with biological evolution may not be sharp if one recognizes the possibility that selection has operated on genes to make viable mutations more likely than would be the case were mutation strictly random.

I propose that the feature that most sharply distinguishes the evolutionary processes through which technology advances from biological evolution is that new findings, understandings, and generally useful ways of doing things do not adhere to their finder or creator and their well-defined descendants, but are shared among contemporaries, at least to some extent. In many cases the sharing is intentional, in others despite efforts to keep findings privy. But in any case that the new technology ultimately goes public means that technology advances through a "cultural" evolutionary process. The capabilities of all are advanced by the creation or discovery of one. This is fundamentally different than in biological evolution.

Some economists, recognizing this phenomenon, have attempted to analyze it in terms of a trade-off between incentives for innovation, which are seen as hinging on the ability of firms to make new technology proprietary, and the extent to which an innovation is used where it is efficient to use it, which may depend on the degree to which new technology is public.² While there is something to this point of view, it misses several important matters. First, the going public of new technology not only increases society's ability to use it in its present form, but also widens the range of parties who are in a position to further improve it, variegate it, more generally contribute to its advance. While analysts have

²Perhaps the best exposition of this point of view is contained in Nordhaus 1969.

argued the case both ways, I maintain that by and large the experience is that technical advance proceeds much more rapidly when a considerable number of parties are engaged in competitive efforts, than in a context where one or a few parties are in a position to control developments.

Second, for-profit firms on their own financial bottom are not the only actors in the innovation game. There are public institutions and public monies as well, and these can step in where profit incentives are weak.

Third, simple analyses of this genre do not recognize that technology and technical advance can be unpacked into different dimensions or aspects. It matters what aspects are kept proprietary or privy, and what aspects are left or made open to the public. The analytical problem here is reflected in the failure of many economists, and other scholars, to see into the complex relationships and overlays between technology and science which are characteristics of the modern system.

Technology at any time needs to be understood as consisting of both a set of specific practices, and a body of generic understanding that surrounds these and provides interpretations of why they work as they do.³ The distinction I am drawing here might seem to be between a science and its applications. However, it is a mistake to think of manufacturing technology as simply applied science. In many cases where it is known that a method works, it is not well understood how. The technique may have been discovered initially through trial and error learning, or even accident. And it may take a long time before a solidly grounded understanding of why and how it works is developed.

Further, in almost all technologies a considerable portion of generic understanding about how things work, key variables affecting performance, the currently binding constraints and promising approaches to pushing these back, stems from operating and design experience with products and machines and their components, and analytic generalizations reflecting on these. These understandings may have only limited grounding in any fundamental science, standing, as it were, largely on their own bottom. This is not quite what philosophers of science tend to mean when they talk of a "science."

However, the philosophers of science may be myopic about what a science is. A number of observers have noted that many modern fields of inquiry that call themselves sciences do not fit the classic mold. Thus fields like computer science, metallurgy, and pathology, are basically about this kind of understanding, and reflect attempts to make it "more

³Dosi (1982) refers to this body of understanding as a technological paradigm.

scientific." The various disciplines that call themselves "engineering" have a similar cast. These "applied sciences" tend to lie between the body of extant technique and simple experiential understanding, and the more fundamental sciences. They represent attempts to go deeper into the understanding of a technology than simple practitioner's knowledge, and often they reach down into fundamental physics, chemistry, and biology to provide a basis for such understanding. However, they by no means have been able to encompass and codify all of generic knowledge. And to a considerable extent they have an analytic structure of their own which is not completely reducible to the underlying fundamental sciences.

In much of economic theory it is presumed that technology is a latent public good, in the sense of having the capacity to benefit many parties, and inexpensive (if not literally costless) to teach and learn compared with the cost of invention or discovery in the first place. It is this view of technology and technical advance that lies behind the notion that intellectual property rights or secrecy are needed if there is to be private incentive for invention and innovation, but that when technology is proprietary there are major "dead weight" costs.

Now the notion that technology is a latent public good is a reasonable first approximation if the focus is on generic knowledge. Generic knowledge tends to be germane to a wide variety of uses and users. Such knowledge is the stock-in-trade of professionals in the fields, and there tends to grow up a systematic way of describing and communicating such knowledge, so that when new generic knowledge is created anywhere it is relatively costless to communicate to other professionals. Indeed, generic technology knowledge not only has strong latent public good properties; it may be difficult to prevent such knowledge from being manifestly a public good even if one tries to keep it privy. As I shall show in some detail shortly, rival firms have a variety of ways to ferret out the generic aspects of a competitor's technology, even if the specific details of particular products and process may remain beyond their ken.

On the other hand, the body of particular extant technique is more of a mixed bag. Some of practiced technique is widely applicable and easily learned by someone skilled in the art, if access were open. But scholars like Keith Pavitt (1987) and Nathan Rosenberg (1976, 1982) have argued persuasively that many prevailing industrial techniques that operate effectively in a given establishment can be transferred to another only with considerable cost, even if the original operator is open and helpful. Partly that is because of the complexities involved and the

high cost of teaching and learning.⁴ Partly it is because significant modifications may need to be made if the technology is to be effective in a somewhat different context. In these cases, technology, or at least a particular practice, is more like a private good than a latent public one.

So, in a sense the evolution of technology involves the co-evolution of a public good—generic knowledge—and a collection of private goods—specific practices. One might presume, therefore, that corporate R&D efforts would focus tightly on creating new techniques, with public institutions like universities doing most of the work advancing generic knowledge.

Note that this division of labor largely obviates the “trade-off” problem. However, while this is a tolerable first approximation, it misses three important points. First, a large part of generic knowledge is created as a by-product of creating new products and processes. Thus a portion of the trade-off problem remains. Second, in order to tap into an advancing field of generic knowledge one often needs to do work in it oneself. Third, in complex technologies which have strong underlying applied sciences, corporate and university scientists share a common training and belong to the same professional associations. They also share many interests. Because of these facts corporate R&D is an important source of public generic knowledge, in some fields professors invent, and in some technological areas the lines between what corporations do and what goes on in universities are blurry, not sharp.

2 How Firms Appropriate Returns to Their Innovative Efforts, and How They Ferret Out What Their Competitors Have Done

Schumpeter never was explicit about just how a firm that invested in R&D established and protected a proprietary edge. Economists and historians of technology writing since his time have recognized a variety of means, and their work suggests that different ones are operative in different technologies and industries. However, until my colleagues and I designed a survey, there was no systematic map of the terrain. The details of our questionnaire have been reported elsewhere (in particular, see Levin et al. 1987). Here I simply will briefly recount our findings.

To oversimplify somewhat, we distinguished three broad classes of means through which firms are able to appropriate returns to their innovations—through the patent system, through secrecy, and through

⁴For good studies of the cost of technology transfer, see Teece 1977 and Mansfield et al. 1981.

various advantages associated with exploiting a head start—and asked our respondents in different lines of business to score on a scale from one to seven the effectiveness of these for protecting product and process innovations. I will focus on product innovations.

There were significant cross-industry differences regarding the means rated most effective for appropriating returns to product innovation. However, in most industries, a head start and such associated advantages as ability to move down the learning curve ahead of one’s competitors, or getting ahead in sales and service, were rated as the most effective means. Included here were such industries as semiconductors, computers, telecommunications, and aircraft. In some of these industries patents also were rated as reasonably effective, in others not. But clearly in many industries where innovation is important, the gains to an innovator come largely from getting in early and exploiting that advantage.

An interesting feature of most of the above industries is that imitation of a new product is time consuming and costly even if it isn’t protected by patents. In some, the products take the form of complex systems. Our respondents from industries producing aircraft and guided missiles, canonical complex systems, reported that it would cost a competent imitator three-fourths or more of what the innovator invested to come up with something comparable, that considerable time would be involved as well, and that it did not matter much whether or not there were patents. Producing complex systems effectively requires that many components and details be got right, and this is difficult to learn to do even if one has a model to take apart, or a blueprint to follow. These industries, and others like semiconductors, also involve complex production processes with tooling and equipment often finely tuned to product design. Simply getting the production line in place and running right can yield the inventor a substantial lead over potential followers.

While only a few industries reported patents to be their most effective instrument for protecting product innovation, there are two groups that did.⁵ One consists of industries where chemical composition is a central aspect of design: pharmaceuticals, industrial organic chemicals, plastic materials, and synthetic fibers. The other consists of industries producing products that one might call devices: air and gas compressors, scientific instruments, power-driven hand tools, etc. In both of these cases the composition of the products is relatively easy to define

⁵Our finding that patents are important in only a few fields is consistent with the earlier findings of Scherer et al. (1959) and Mansfield et al. (1981).

and delimit. This means that they are relatively easy to reverse engineer and imitate; thus patent protection is essential if the innovator is to be able to reap profits. Happily, the same conditions seem to be conducive to ability to draw patents that can be enforced.

Secrecy was rated an effective means of protecting product innovation in virtually no industries. On the other hand, secrecy was scored as quite effective in many industries in protecting process innovations.

Note that the results of our questionnaire provide a quite different picture of how firms gain returns from their product innovations than is often presumed by lay persons. Gaining returns from innovation in most cases is not so much a matter of establishing property rights or guarding secrets. Rather, profit comes from getting ahead of one's competitors, and exploiting that advantage. But with time competitors can catch on, if they make the required investments.

This picture is confirmed by the answers to the probes in our questionnaire about how firms acquire knowledge about new products developed by their competitors. The means included doing independent R&D or reverse engineering, trying to get information from employees of the innovating firms and perhaps hiring them away, patent disclosures and publications of various sorts, and open technical meetings.

The responses suggest that monitoring outside technological developments generally is an active and costly business. In most industries the means of monitoring judged most effective was either doing independent R&D (presumably while attending to clues about what one's competitors are doing) or reverse engineering. The industries that gave these means low scores almost invariably were those that do little R&D themselves, and hence don't have the capabilities to employ them. Conversely, virtually all R&D intensive industries rated one or both very effective as a means of learning about (and presumably mastering something comparable to) one's competitors' innovations. It is apparent that in these industries the fact that viable firms have active R&D efforts serves to bind them together technologically, as well as to advance the frontiers.

Those industries that reported reverse engineering to be effective also tended to report that they often learned a lot from conversations with scientists and engineers of the innovating firms. Some reported that they make a practice of trying to hire some away. It is apparent that in the United States in many industries communication between scientists and engineers and interfirm flow of R&D personnel both act to keep generic knowledge relatively public. Publications and open technical meetings also were rated effective sources of information in a wide range of industries.

It thus appears that, contrary to common beliefs, firms do not keep tight controls on all information about their new technology, and in some cases they seem actively to divulge information. How come? In the first place, the very staking of claims involves the release of information. That is one of the intents of the patent system, and where patents are effective, they also make knowledge public. Where patents are not effective, but aggressive use of a head start advantage is, firms have strong incentives to stake their claims through advertising, open meetings, and a wide variety of other ways, in addition to patenting. They need to attract customers, and this means they need to tell them about their new wares, but this means telling something to their competitors too. Also, as von Hippel (1988) has documented, engineers in different firms tend to help each other out by sharing and trading information.

Further, the divulging of certain kinds of information does not significantly undermine a company's real proprietary edge. Where new products are patentable and patents are effective, as in pharmaceuticals, it does not hurt a company to divulge generic information if it has the patent. Letting generic knowledge won in R&D go free does not handicap a firm from reaping handsomely from its product innovation, if it has a significant head start on production and marketing of the product in question, and the capacity to take advantage of that lead.

The way I have described the matter suggests that what firms have great difficulty in keeping privy is the generic aspects of the new technology that they have created, rather than the specific practical implementations. I think that is correct. Not just patents, but the location and organization-specific nature of the details of a firm's particular product and process technologies often make them difficult to directly imitate, even if another firm wanted to do just that. On the other hand, the general understanding behind those particular products and processes are very difficult to keep privy for very long, in an industry where most firms have sophisticated and alert engineers and scientists, and these tend to communicate with each other. Advances in generic understanding won through corporate R&D efforts thus go public quite quickly. As the data presented above indicate, this does not mean that rival firms get a free ride. They must do their own R&D in order to create their own specific ways of implementing this new knowledge.

3 The Expressly Cooperative and Public Components of Innovation Systems

Until recently most accounts by economists of how technical advance occurs in capitalist economies focused almost exclusively on the role of

for-profit firms (and sometimes private inventors), on rivalry, and on proprietary technology. The limits of proprietary grip were recognized and some of the significance of that understood, but voluntary sharing of technology was seldom mentioned. Above I have begun to develop the point that the public aspects of technology are there not simply because of unavoidable holes in proprietary shields, but because in many cases firms deliberately leak and share knowledge.

In contrast with the orientation of economists, virtually all sociologists and many historians writing about technical advance, while recognizing rivalry of business firms, have tended to stress the social and professional aspects of the process. The key actors in the stories they tell are engineers or applications oriented scientists with a wide shared base of technical and scientific knowledge. The competition is among ideas and approaches. Some approaches prove better than others, or their proponents more skilled in pushing them forward and getting them to work. When that happens, all have learned something, although disagreements are not necessarily put away. The process moves on.⁶

This point of view of course is not necessarily antithetical to the Schumpeterian one. Both capture part of what is going on. Advancing technology is a matter of both business and professional competition. And it is a matter of business and professional cooperation as well.

Recently writings by economists have begun to pick up on interfirm technology sharing and R&D cooperation. However, there still is inadequate attention to the roles of public finance, of professional associations, and of universities and other expressly public and cooperative components of the innovation systems. And where there is attention it often is rather simpleminded.

Here, I want to focus on the role of universities. Within the United States, university science and engineering, and our science-based industries, grew up together.⁷ Chemistry took hold as an academic field at about the same time that chemists began to play an important role in industry. The rise of university research and teaching in the field of electricity occurred as the electrical equipment industry began to grow up in the United States. In both cases the universities provided the industry with its technical people, and many of its ideas about product and process innovation.

The situation is dynamic not static. Academic research was very important to technological developments in the early days of the semi-

⁶For good examples of such studies see Constant 1980 and Hounshell 1984.

⁷See, e.g., Noble 1977, Thackray 1982, or Rosenberg 1985.

conductor industry, but as time went by, research and development in industry increasingly separated itself from what the academics were doing. As I will document in a moment, at the current time academic biology and computer science are very important sources of new ideas and techniques for industry. The latter is a new field, and the former is experiencing a renaissance. On the other hand, technologies associated with complex product systems or production processes, like aircraft and aircraft engines, telecommunications, and semiconductor production, involve much that the academics do not do, and mostly do not know about in any detail.

In our questionnaire, my colleagues and I asked our respondents to score on a scale from one to seven the relevance of various fields of basic and applied science to technical advance in their line of business. We also asked them to score, on the same scale, the relevance of university research in those fields. I propose that a high score for a science on the first question signals the importance of university training in that field, and a high score on the second indicates the relevance of what academic researchers are doing.

A large number of scientific fields received a relatively high score on the first of these questions. A much smaller number scored highly on the second. Recall my earlier remark that a number of fields of science are expressly concerned with the scientific underpinnings of various technologies. It is interesting that the fields of university research that were scored as highly relevant by a considerable number of industries tended to be of this sort. Computer science, material science, and metallurgy head the list. Academic research in chemistry, a more conventional science, also was scored as relevant by a number of industries, which is not surprising to anyone familiar with the long-standing close links between academic and industrial chemistry. University research in the engineering disciplines also received a high relevance score from a number of industries. Industries for which these fields are important look to universities for new knowledge and techniques as well as for training.

On the other hand, while physics as a field of science was scored as relevant by a large number of industries, academic research in physics was scored as relevant by only a few. This confirms the importance of training in physics to corporate research, and also signals that what the professors are doing in the way of research is at some distance from applications. Now the fact that academic research in a field like physics or mathematics was not scored by our respondents as relevant to technical advance by no means implies that literally. Historians of science and technology know better. Rather, the responses suggest that the

impact occurs over the long run, and is indirect, through influences on the applied sciences and engineering disciplines, which are the fields the industrialists are hooked into.

Industries where technological advance is being fed significantly by academic research naturally look for close links with university scientists and laboratories where that work is being done. In the application oriented sciences and engineering disciplines research is to a large extent motivated to facilitate technical advance. Many academics are strongly interested in industrial practices. Knowledge of prevailing technology, its strengths, and its weaknesses, helps them to define their own research agendas.

In fields like electrical engineering and biochemistry, the lines between what academics do and what at least some corporate scientists and engineers do may be blurred, not sharp. Thus, some research scientists and engineers in companies like IBM, AT&T, and DuPont, engage in research that is virtually indistinguishable from what their academic counterparts are doing. While in some cases this research is motivated by beliefs that a particular new product or process innovation will come of it, in many instances the reason is that this research is needed if the company is to stay abreast of developments in the relevant scientific fields, from wherever these developments may come (see, e.g., Rosenberg 1988). On the other hand, in fields like biochemistry and electrical engineering, academics often come up with patentable inventions.

4 What Should Be Public and What Should Be Private?

The lines between what is private and what is public about technology are blurred and shifting. A good portion of the debate about technology policy is about where these lines are drawn, or about redrawing them. I wish to conclude this essay by considering some of the current issues under debate.

At the present time in the United States there are many voices raised pressing the case for better enforcement of intellectual property rights. The complaint, of course, is that foreign firms are stealing American-created technology, but the argument is not simply about American interests. It also is that, if innovators cannot reap returns, innovative R&D will disappear. I think there is something to that position. But the problem is the broad one of enabling an innovator somehow to reap returns, not the narrower one of the adequacy of intellectual property rights. Patents are the principal means of appropriating returns in only a few industries, and many of the loudest complaints are not coming from these. What has been happening, I believe, is that generic public

knowledge has grown in power in many fields, and this has enabled sophisticated companies quickly to find the generic technological basis of a competitor's innovation, and to come up with an equivalent. In many of these industries, patents never were important. A head start was, and now the advantage a head start gives is diminished. There is a problem here, but it is not necessarily a problem of intellectual property rights.

Another current issue is where to encourage firms to cooperate in generic research, and what greater cooperation would buy them. If I am right about the enhanced power of generic knowledge, it is of increased importance that firms tap into its source, which I have suggested requires that they themselves work at that endeavor. And cooperative generic research programs seem to some an attractive vehicle for doing this. However, it is important to recognize that the advantage that can be gained by participating firms will not be gained unless they individually build something proprietary from what they have learned cooperatively. Cooperative generic research may (or may not) be a superior substitute for individual uncoordinated basic research effects, but is a complement not a substitute for private efforts at product development.

While a moment ago I characterized much of the current argument about intellectual property rights as superficial, there are some quite deep questions about what should be patentable and what should not, about the scope of allowable patent claims, criteria for judging whether a patent has been infringed, etc. Yet there is very little careful analysis behind the key decisions affecting these variables. Thus as a result of a series of court decisions and congressional votes, in the United States substances found in nature in dilute or non-pure form now are patentable in pure form. Not simply the process which creates these pure forms but the natural substance itself has been ruled patentable. More generally, there has been a tendency to allow quite broad patent claims. At the present time the scope of several basic patents in biotechnology is under contest. At stake is whether the further development of this technology is to be the province (subject to licensed extension) of a single or small number of parties, or if it is to be open to a large number. While one can argue what ought to be both ways, it is clear that society can influence which way it is by decisions about the scope of proprietary patent rights.

A number of years back there was a change of policy regarding who owned patents emanating from university research financed by the National Institutes of Health and the National Science Foundation. The old rule had been that rights rested with the government, and the general policy was open licensing of these patents. Under the new policy, patents

are owned by the researcher. While these rights tend to be given over to the university, the researcher now can profit handsomely. A number of observers have argued that a consequence has been less open communication among academics in fields of commercial relevance.

I am concerned that successful university entrepreneuring in biotechnology and computer science has caused a swing in beliefs about the appropriate roles of universities, so as to diminish emphasis on their mission as guardians of public knowledge. I believe that such a swing would be both ineffective and harmful. If I am right, in most fields of technology what gives advantage to a company is a particular manifestation of a generic technology that is tailored to its own particular circumstance, products and processes. In most fields university scientists are not very good sources of proprietary capabilities. Computer programs and products of biotechnology currently are exceptions. But it may be a mistake to glorify this and try to make the exception the rule. To try to make universities more like industrial labs will tend to take attention away from their most important functions, which are as a major source of new public technological knowledge, and as society's most effective vehicle for making technological knowledge public.

Technology is a public good as well as a private one. It is important to preserve both aspects.

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